THESIS ON MECHANICAL ENGINEERING E77

Company's Strategy Based Formation of e-Workplace Performance in the Engineering Industry

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TUT
PRESS

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Declaration:
Declaration: I hereby 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 doctoral or equivalent academic degree.

/Kaia Lõun/

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E-töökoha võimekuse kujundamine lähtuvalt masinatööstusettevõtte tegevusstrateegiast

KAIA LÕUN

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LIST OF PUBLICATIONS

The dissertation is based on the following papers (sequenced in chronological order and referred in the text as “Paper I”, “Paper II” etc):

1. Riives, J., Otto, T., Lõun, K. (2007). Methods for enhancing productivity and work efficiency in the workshop. – *Journal of Machine Engineering*, 7, 2, 86–95.
2. Lõun, K., Riives, J., Otto, T. (2008). Necessity for E-manufacturing model in tooling cluster and its essence. – *Proceedings of 6th International Conference of DAAAM Baltic Industrial Engineering*. Ed. R.Küttner. Tallinn: TUT Press, 345–350.
3. Lõun, K., Otto, T., Riives, J. (2009). E-manufacturing concept solution for tooling sector. – *Estonian Journal of Engineering*, 15, 1, 24–33.
4. Lõun, K., Riives, J., Otto, T. (2011). Evaluation of the operation expedience of technological resources in a manufacturing network. – *Estonian Journal of Engineering*, 17, 1, 51–65.
5. Lõun, K., Riives, J., Otto, T. (2012). Workplace performance and capability optimisation in the integrated manufacturing. – *Proceedings of 8th International Conference of DAAAM Baltic Industrial Engineering*. Ed. T.Otto. Tallinn: TUT Press, 518–523.
6. Lõun, K., Lavin, J., Riives, J., Otto, T. (2013). High performance workplace design model. – *Estonian Journal of Engineering*, 19, 1, 47–61.

ABBREVIATIONS

B2B – Business to Business
BIAJS – Brief Index to Affective Job Satisfaction
CAD – Computer-Aided Design
CAM – Computer-Aided Manufacturing
CAPP – Computer-Aided Process Planning
CNC – Computer Numerical Control
CRM – Customer Relationship Management
CSF – Critical Success Factors
CSM – Competitive Sustainable Manufacturing
EFQM – European Foundation for Quality Management Excellence Model
ERP – Enterprise Resource Planning
FMEA – Failure Mode and Effect Analysis
JDI – Job Descriptive Index
JSS – Job Satisfaction Survey
JIT – Just-in-Time
GT – Group Technology
HAV – High Added Value
HPWO – High-Performance Work Organization
Kaizen – Methodology for continual improvement
KPI – Key Performance Indicators
MES – Manufacturing Execution System
MPM – Manufacturing Process Management
MRP – Materials Requirement Planning
MSQ – Minnesota Satisfaction Questionnaire
OEE – Overall Equipment Effectiveness
PDCA – Plan-Do-Check-Act model
PLM – Product Lifecycle Management
Poka-yoke– mechanism in Lean manufacturing that helps to avoid mistakes
SCM – Supply Chain Management
SME – Small and Medium-Sized Enterprises
TEEP – Total Effective Equipment Performance
TQM – Total Quality Management
TUT – Tallinn University of Technology
5S – Workplace standardization methodology: Sorting, Set in order, Systematic cleaning, Standardizing, Sustaining
7 wastes – seven forms of “Muda” or waste in Lean philosophy that does not add value: transportation, inventory, motion, waiting, over-processing, over-production, defects
8D – Eight Disciplines Problem Solving
20 keys– 20 focus areas that will help the organization to build a sustainable continuous improvement culture

INTRODUCTION

Background

Engineering industry is one of the leading branches of Estonian industry that provides approximately one third of the state's export turnover of products and where about 7.4% of the personnel are employed (Statistics Estonia, 2010). According to Statistics Estonia, the number of mechanical engineering companies forms about one fourth of the number of all companies in manufacturing industry and this percentage has remained stable during the years 2005–2011. The percentage of net value added created in engineering industry has risen from 6.5% in 2005 up to 10.7% in 2011 of the net value added of the Estonian economy and from 26.3% in 2005 up to 37.3% in 2011 of the net value added created in Estonian manufacturing industry. In engineering industry, about 71% of companies are micro companies with up to 9 employees, about 21.5% are small companies with the number of employees between 10 and 49 and about 7.5% are companies that have 50 or more employees (Statistics Estonia, 2011). Various problems may occur due to large percentage of micro and small companies, for example for achieving export capacity and competitiveness in international markets, usually certain minimum scale of activities is necessary; in addition micro and small companies usually lack personnel and other resources needed for research and development activities.

In 2008–2010 companies faced economic crisis that has enforced them to consider possibilities to improve their performance.

In 2010–2011, the sector survey about Estonian engineering industry was conducted by U. Varblane of University of Tartu, in which the author of this thesis also participated. The report of the research (Varblane et al, 2011) outlined the main problems of Estonian engineering industry:

- Long-term strategic planning of company development is slightly used, ad hoc activities based on customers' wishes and current orders are prevailing;
- Few proactive planning in the field of product development, most companies base on customers' orders in their product development;
- Low level use of management techniques;
- Strong orientation to subcontracting, which is characterized by cost effectiveness;
- Lack of research and development activities;
- Lack of cooperation between companies and with research institutions;
- Lack of qualified personnel.

One of the challenges would be moving closer towards research intensive subcontracting and own products to help to increase value added. The size of companies refers to the need for cooperation between companies. The keywords are also adaptive manufacturing and mass customization that require ability to react quickly to market changes, to produce small batches whilst making the best use of mass production possibilities (module based production etc). This requires also flexible production management processes. Closer cooperation between companies and between companies and research institutions with networking would be of additional help.

In 2011, the survey about production management on operational level was carried out by Tallinn University of Technology (TUT) (Gans and Kokla, 2011). In this survey, 184 manufacturing companies from all over Estonia were questioned and analysed. 20% of them were machine-building and metalworking companies. The survey (Gans and Kokla, 2011) demonstrated the following:

- Many manufacturing companies do not connect production management methods with objectives related to production (e.g. quality, price, delivery accuracy, delivery time, flexibility etc.);
- Company managers are not aware of the necessity of the production system;
- Although production equipment is maintained, however, machining tools are not as effectively used as they could be and effectiveness of the use is not monitored;
- There are problems with involvement and motivation of personnel and no activities are applied to improve that;
- Measurement and monitoring of the performance results are not widespread actions (e.g. over 50% of the respondents do not monitor reliability of the equipment and do not have record about failure causes of the equipment);
- Inventory management and inbound logistics are not efficient. This sets limits to achievement of high productivity.

According to the report of the survey about production management on operational level (Gans and Kokla, 2011), general estimation about the technological possibilities is average (47%); 29% of the respondents estimated its technological possibilities as good; 13% as weak; 9% as excellent and 2% as inadequate (see Figure 1). Based on the survey, it can be concluded that lack or insufficiency of machine tools is currently not the main limiting development factor for manufacturing companies.

This survey showed that there is a gap between actual and required level of integrated production and personnel management in the companies, especially in SMEs. The need for improving personnel management issues (especially involvement, motivation and discipline), production process monitoring and more effective use of machine tools appeared from the survey.

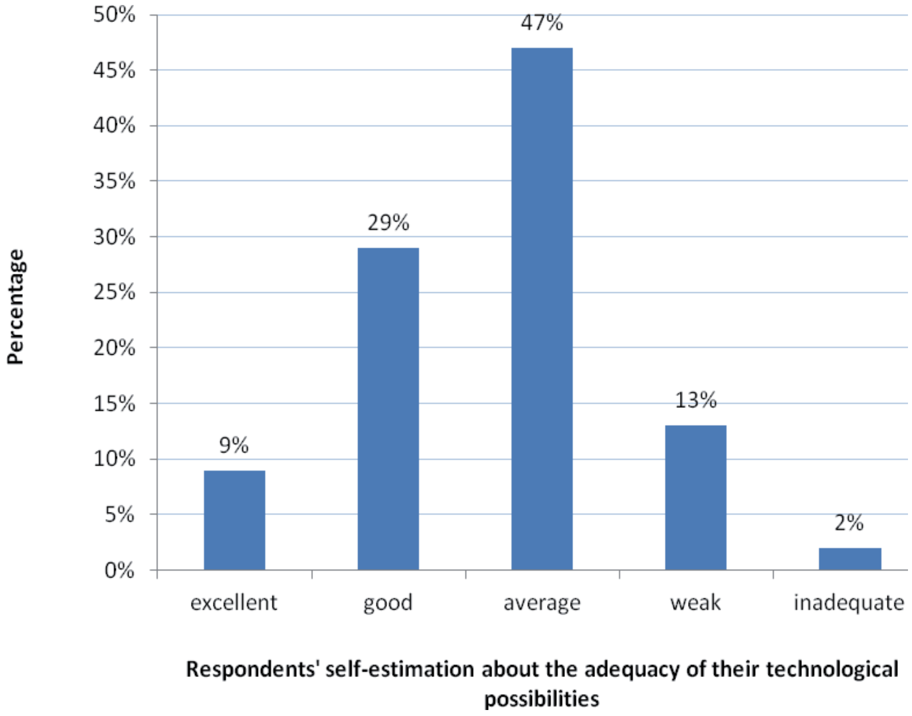


Figure 1. Estimation about technological possibilities of manufacturing companies (Gans and Kokla, 2011)

Problem setting

Company's assets, competent employees, production system, business processes and appropriate strategy form basis for a company's business success.

Engineering industry is strongly influenced by changes in technology, demand and required competences. Future industry provides higher demands on skills and qualification, human resources will be the most important production input (Association of Swedish Engineering Industries, 2009). Without know-how and technological knowledge it is not possible to develop new products and production technologies (Varblane et al, 2011). According to ManuFuture High Level Group reports (ManuFuture, 2004, 2005, 2006), the keyword of further development is innovation (both process and product innovation). Fundamental concept of European technology platform ManuFuture is innovative production that covers new business models, new technologies and ability to benefit from new scientific results. Mass customization in combination with short production and delivery times are the key words (ManuFuture, 2004, 2005, 2006).

The recent surveys about Estonian engineering industry (Varblane et al, 2011; Gans and Kokla, 2011) have indicated that Estonian engineering companies have procured new modern machine tools, but the use of new equipment and technology is not as efficient as it could be (e.g. it is not economically reasonable to purchase very expensive and very modern machine tools to produce a very simple product) or personnel's competences are not appropriate to work with new technologies and machine tools. Therefore, purchase of new equipment does not automatically assure effectiveness and competitiveness of the company. As rising level of competences of personnel and acquisition of modern technology is expensive, the decisions for personnel training or purchasing new equipment should be considered carefully and be based on company's strategy and be compatible with the company's development policy. Making decisions based on clear future vision helps to avoid over-dimensioning and unnecessary costs that do not help the company to achieve competitiveness.

Main objectives

The primary objective of the current work is **the development of a general concept and models for estimating and improving workplace's performance** that will respond to the company's development strategy and would support the company to achieve competitiveness and sustainability in network manufacturing. The concept and models are developed based on engineering industry and mainly directed to SMEs, but the proposed methodology and elaborated models can be extended to other manufacturing industries, too.

To obtain the goal the following tasks have to be solved:

- Determination of factors influencing company's sustainability and competitiveness, connections between company's strategy and use of new business models in manufacturing industry and development of organization performance model according to a company's strategy;
- Determination of essence of a manufacturing system, workplace, technological resources, technological and workplace capability in e-manufacturing environment;
- Development of methods and techniques for effective collaborative use of technological resources in network of cooperating manufacturing companies and development of the concept of suitable information system for SMEs;
- Development of the model for optimization of a workplace performance as basis for company's capability.

Research and methodology

The research was conducted in close cooperation with industry, TUT and Innovative Manufacturing Engineering Systems Competence Centre IMECC Ltd. through various projects during several years (Table 1, Figure 2) with participation of the author of this thesis.

Table 1. Main projects supporting the research

Project name	Programme	Duration
Development of Innovative Business Models for Ensuring Competitiveness ("INNOREG")	Central-Baltic Interreg IVA	01.06.2010 – 31.05.2013
Research Based Competence Brokering ("REBASING")	Leonardo da Vinci programme	01.10.2010 – 30.09.2012
Methods and tools for event oriented web-based manufacturing planning and supply chain management systems development ("e-manufacturing") (IMECC (EU30006) project 1.1)	Regional Development Fund, Enterprise Estonia (EAS), competence centres' programme	01.06.2009 – 30.06.2013
e-manufacturing concept for SMEs ("e-manufacturing, ETF7852")	Estonian Science Foundation	01.01.2009 – 31.12.2012
Inter-countries research for manufacturing advancement ("IRMA")	International agreement	01.01.2008 – 31.12.2009
Proactivity and behavioural models of mechatronics and production systems (SF0140113Bs08)	Estonian Science Foundation	01.01.2008 – 31.12.2013
Promotion of entrepreneurship and innovation ("PREMIO")	ERASMUS	01.01.2008 – 31.12.2009
Preliminary research about e-manufacturing concept and realization possibilities for tooling sector ("Preliminary e-manufacturing analysis")	EAS	15.10.2007 – 01.03.2008
Enlargement of human resources development system in Estonia (INNOMET-EST)	European Social Fund (ESF)	01.01.2007 – 30.06.2008

In Figure 2 timeline overview of the main projects and topics of the research conducted in the framework of the projects in which the author of the current thesis participated as one of the main researchers and that support the research is presented.

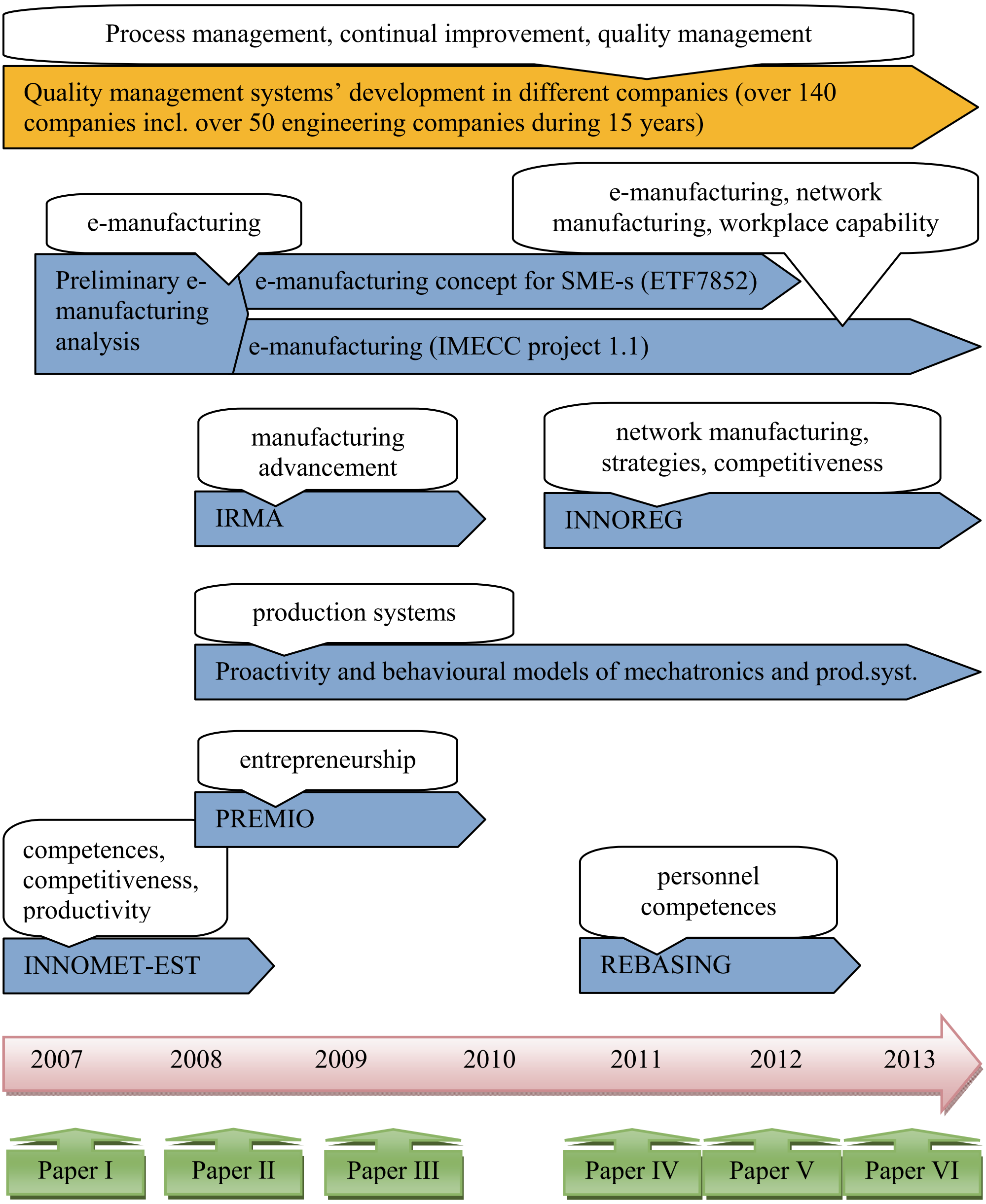


Figure 2. Overview of the research and main supporting projects

The results of the research are experimentally implemented in companies for testing the concepts.

Novelty of the research and experimental verification

Principles for improving workplace and production system performance are related to the company's competitiveness development strategy. Workplace and its optimization are considered as basis (basic level) for company's performance improvement. Factors influencing the workplace's performance are presented in the current thesis, demonstrating that the impact of workplace's performance to the whole company exists through the processes and systems which the workplace is related to. In the thesis, mutual connections between workplace, production system, processes, company strategy and networking issues are analysed, as well as relations and comparisons between planned and achieved results with an aim to detect reasons of nonconformities and through implementation of improvement actions quickly eliminate negative impact factors.

When positioning a company, data was collected and analysed on the basis of INNOMET-EST and INNOREG projects. In INNOMET-EST project, a unique model for positioning a company was created and used for the first time in Estonia. Model for technological resources and technological capability was developed and tested in the framework of e-manufacturing project 1.1 of IMECC. Workplace capability model was escalated from workplace to production system and its capability on the basis of preliminary analysis of e-manufacturing in tooling sector (supported by EAS) and IMECC's project 1.1 (e-manufacturing) was determined. Principles and concept of network manufacturing and reallocation of technological resources are developed and tested mainly in the framework of IMECC's project 1.1 (e-manufacturing) and project INNOREG. The model for workplace performance optimization has been developed based on the importance of the workplace in manufacturing system and company, methodology to evaluate the workplace's performance and networking issues.

The proposed approach enables matching manufacturing tasks and manufacturing system resources based on their required and provided capabilities and supports rapid allocation of resources and effective use of the systems.

The previously described projects and complex analysis have not been conducted in Estonia before, but are important, due to considering the peculiarity and capacity of Estonian engineering industry and companies.

The main results of the research have been published in 11 pre-revised international journals and conference proceedings (incl. 6 international journals) and presented at 5 international conferences.

1. FACTORS INFLUENCING PERFORMANCE AND OUTCOME OF A COMPANY

1.1. Factors influencing sustainability and competitiveness of a company

The overall aim of every company is to be competitive and sustainable. According to the Brundtland Report, that gives the most common definition of sustainable development in general, sustainable development is considered as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987). Sustainable development embraces economic, social and environmental side and their interactions (see Figure 1.1). Important is that the world is regarded as a system.

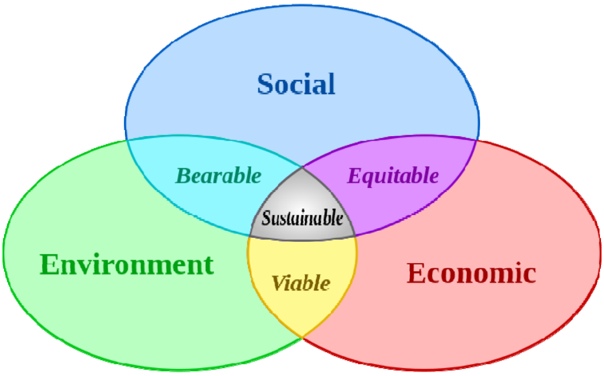


Figure 1.1. Sustainable development (Dréo, 2006)

The nowadays manufacturing mission is to pursue High Added Value (HAV), knowledge-based Competitive Sustainable Manufacturing (CSM) (Jovane et al, 2010).

In terms of company, we could consider sustainable and competitive development of a company as a process of continual changes where optimization of using the resources, determination of the need and essence of investments, planning of technological development and changes in the company are based on current needs, but aimed at assuring development and effectiveness in the future. Basis for competitive sustainable manufacturing are suitably planned and formed processes and products of the company and lifetime of the products with flexible reaction to economic, social and technological development of external environment.

Every manufacturing company has key components that form basis for the company's success. The key components are: business models, competences and production system. The company acts to integrate these three key components: the production system which makes the physical product, the business model that matches the product with the market and determines how the company generates revenue, and the competences and capabilities within the business, necessary for success (Jovane et al, 2010). The essence and performance of these key components are influenced by the company's structure, business strategy, business processes, implementation of PDCA cycle (Deming, 1994), employees and work teams with their competences. These three key components influence the level of quality, productivity and reputation of the company (see Paper I), which form basis for the company's sustainability and competitiveness (see Figure 1.2).

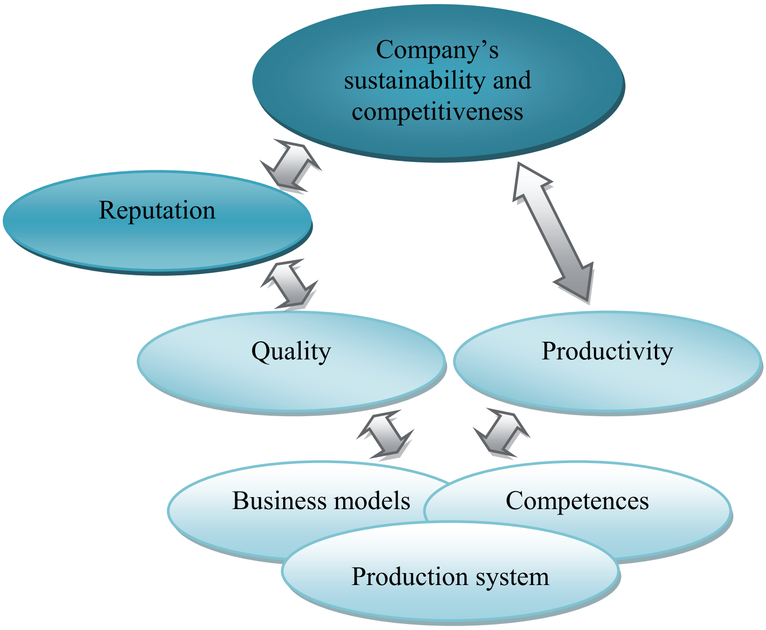


Figure 1.2. Main components of business performance

A business model describes the rationale of how an organization creates, delivers and captures value (Osterwalder et al, 2010). The process of business model development is part of a business strategy. The business model is at the core of competitive response of the company to the market. A business model outlines how a company generates revenues with reference to the structure of its value chain and its interaction with the industry value system (Afuah, 2007; Bell, 2006). Business models are used to describe and classify businesses, but they are also applied to help planning and realization of business processes and to explore possibilities for future development by managers in the companies.

Competence is the ability to do a job properly. Competencies are combinations of knowledge, skills, experiences and behaviour (Kutseseadus; Riives et al, 2007). Competencies of employees influence productivity and quality of the work (Lõun, 2010). Management of competencies is one part of personnel development process that forms important part of personnel management (Lõun, 2011). Determination of needed competences for each job and evaluating personnel's actual competences and comparing them to the needed level of competences is one possibility for personnel development and was developed in the framework of INNOMET-EST project and implemented in web-based information system INNOMET (INNOMET, 2008; Riives et al, 2007; Otto et al, 2008).

Production system is a core of every manufacturing company that transforms inputs (energy, materials, knowledge etc.) to outputs (products). Structure of production systems (equipment, automation level, flexibility level etc.) is extremely varied and depends on the company's possibilities, capabilities and specific needs. General essence of production systems is described by Groover (Groover 2008 and 2010), and Rembold and Nnaji (Rembold et al, 1993), production system's development techniques are described by D.T.Semere in the doctoral thesis (Semere, 2005). Production systems have to be in continual development in order to respond to the changes in external environment, customers' needs etc. The following factors have direct influence on production systems: considerable shortening of order fulfilment time, increase in product nomenclature with products' life-cycle shortening and customers' requirement towards manufacturing high-quality products in time. Manufacturers have to be able to react quickly, responsively and effectively to the market which is becoming more international, dynamic and customer-driven. Therefore production systems have become increasingly complex and even more e-manufacturing techniques are applied (Greeff and Ghoshal, 2004; Cheng, 2005; Timings and Wilkinson, 2003).

1.2. Company's strategy, new business models in manufacturing industry and their connection with resources' development policy of the company

1.2.1. Comparative analysis and corporate positioning

Efficient resource selection models, which provide the needed information for equipment, technology and personnel selection, are critical factors for production system design and planning.

To determine and compare the company's position with others and detect emerging trends, comparative analysis and corporate positioning can be used. Research conducted by the author of the current thesis in the framework of INNOMET-EST project (Eesti ettevõtete suunalise uuringu raport, 2008) indicated clear differences between competitiveness, productivity and sustainability of Estonian companies (see Figures 1.3–1.5). In Figures 1.3–1.5 indices *IM, LM, TM*, and *TMT* with a number signify different engineering companies. The objective of the research was to get adequate comparative estimation of Estonian companies based on statistical and comparative analysis. For that a methodology was elaborated to compare companies by different criteria (e.g. competitiveness, sustainability, productivity, innovativeness, competences and motivation, innovation, flexibility etc.). Six different sectors were analysed (engineering industry, electronics, furniture and wood industry, information technology, construction and manufacturing of construction materials, and car servicing). A questionnaire was composed by expert group and in total, 190 companies were questioned over Estonia. The questioning occurred in 2007-2008. For comparative analysis, the key criteria were competitiveness, sustainability and productivity. The results and report of the research enable to get an overview about the situation of companies belonging to different sectors and to notice possible threats in their sustainability and competitiveness (Eesti ettevõtete suunalise uuringu raport, 2008).

In addition to the analysis of machine-building and metalworking sector, another analysis was conducted on tool-makers subsector, and development potential of tool-makers was analysed. The results reflected the situation tool-makers faced in 2009. According to the results, despite of good technological level problems lied in rational use of resources, organization of work, and employed management methods. Systematic approach to productivity management, and more efficient integration of the systems inside the organization and in the level of cooperation network would have been useful.

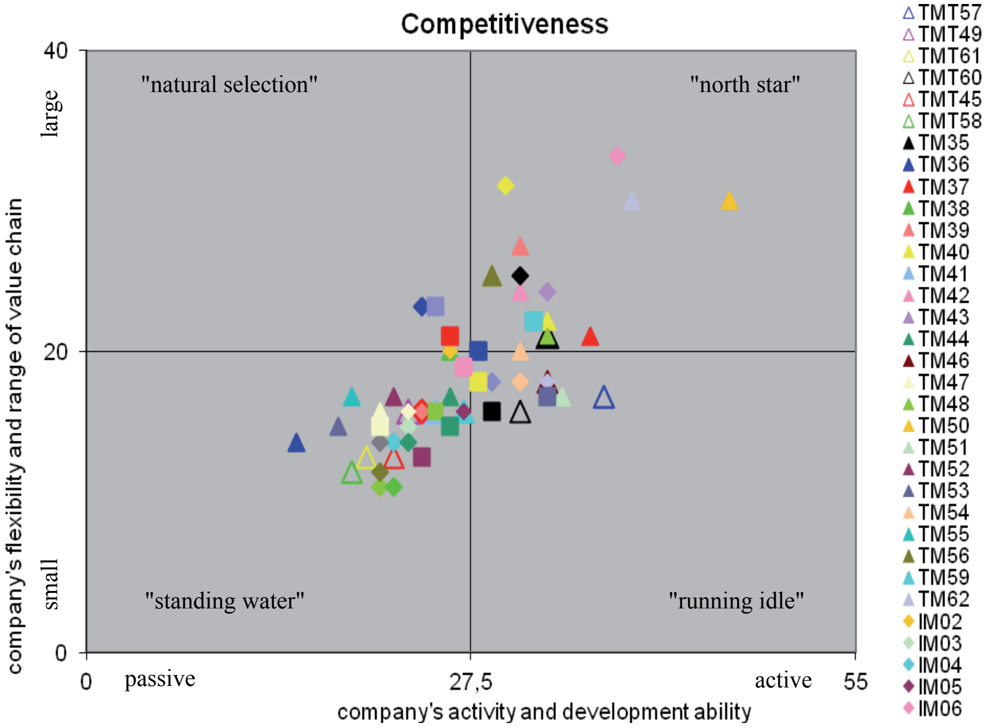


Figure 1.3. Results of comparative analysis of machine-building and metalworking sector: competitiveness (INNOMET, 2008)

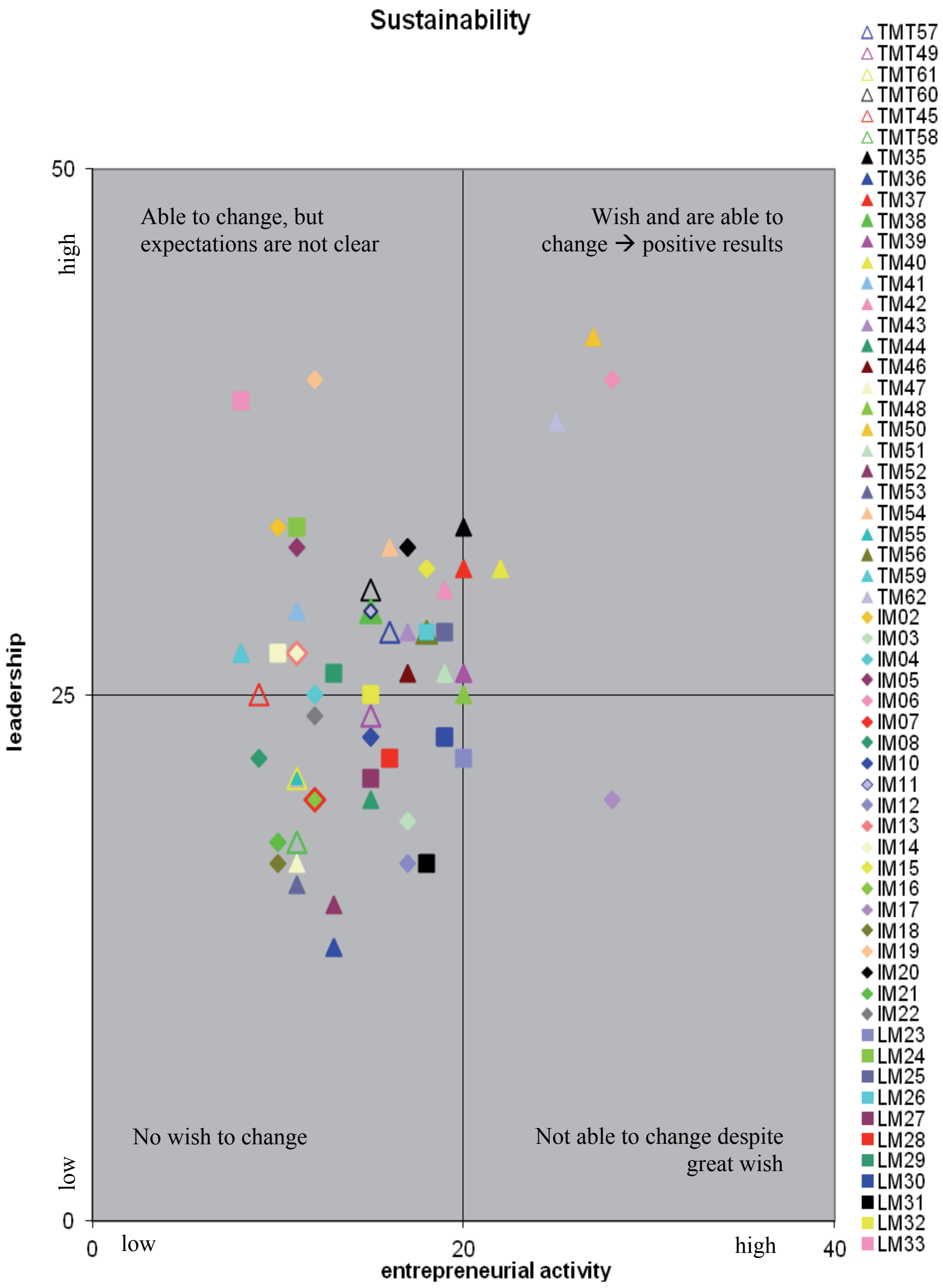


Figure 1.4. Results of comparative analysis of machine-building and metalworking sector: sustainability (INNOMET, 2008)

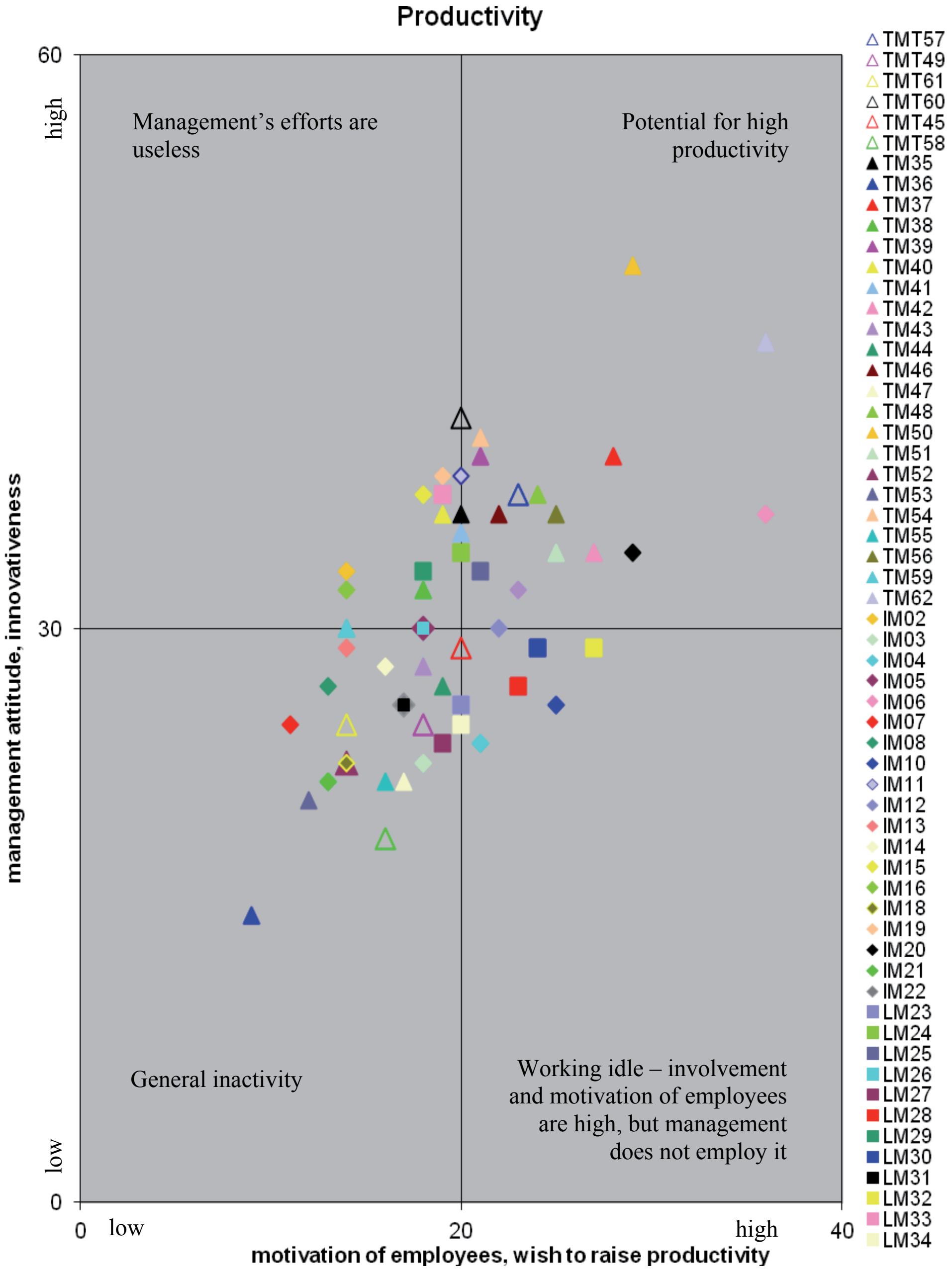


Figure 1.5. Results of comparative analysis of machine-building and metalworking sector: productivity (INNOMET, 2008)

In 2011 in the framework of INNOREG project (SFE23) the survey about capability and competitiveness of the mechatronics field in North-Estonia and South-Finland region was carried out with the author's participation. The results were divided into general data about the companies and the following seven fields of activity: business environment and management; technological capability; development of products and technology; personnel; ICT solutions; quality assurance and control; cooperation. The objective of the study was to map and analyse the following aspects of companies:

- main competences, markets and products;
- market geography;
- technological capability of equipment;
- research and development capability;
- personnel competence;
- experience related to participation in cluster-based cooperation.

The basis for executing the study was the completed survey questionnaires. The companies were queried by recognised Estonian and Finnish experts in the mechatronics field. The analysis (HeiVäl Consulting and the INNOREG project expert group, 2011) indicated that in comparison between Estonian and Finnish mechatronics companies Estonian companies are mainly SMEs and serve mostly small and mid-sized companies, while Finnish companies serve mostly large companies. Thus, Estonian companies should consider closer cooperation, and cluster and network activities to be competitive. The survey also indicated that in both countries there is room for development in the implementation of productivity programmes on company level, as well as documented systems for making suggestions related to motivation system. According to the survey, Estonian companies cooperate significantly less than Finnish companies and have practically no experience with cluster-based and quality-related cooperation. The primary objective of participating in cooperation is the development of supply chains, but Finnish companies also place great importance on the development of joint competences and network manufacturing.

1.2.2. Company strategy

Management of any system begins with the fundamental objective. The decision maker sets policies in an attempt to achieve this objective and evaluates performance in terms of measures (Hopp and Spearman, 2008).

To identify the most important leverage points in a manufacturing system, it is not enough to lay out a list of subordinate objectives that support the fundamental objectives. Not all of these are of equal importance and some objectives conflict with each other. So, framework is needed for prioritizing subordinate objectives and for making appropriate trade-offs. Such framework must incorporate both strategy and operations. Operations determine the capabilities of the manufacturing system. All manufacturing firms make a value proposition to their customers, made up of price, time, quality and variety (Hopp and Spearman, 2008).

Strategy is the determination of the basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals (Chandler, 1962). According to Costas Markides (Markides, 2008), strategy is the art of making choices. The three main strategic choices are: WHO is your customer? WHAT are you offering to them? And HOW? Answers to these questions determine what resources, competences, technologies etc. are needed to be able to achieve competitiveness.

Globalization, changes in external environment, increasing competition and continual raise in prices of resources create a need for more flexible business strategy and new business models to be able to adapt the changes in the turbulent economy.

1.2.3. New business models and techniques

New business models require turning more attention to development of competences and rational use of them, but also to production system essence and its suitability to the company's strategy, dimensioning and purposeful use of technological possibilities and evaluation of performance. Cluster activities, network manufacturing and e-manufacturing can be employed.

The term "cluster" was introduced in Michael Porter's book The Competitive Advantage of Nations (Porter, 1990). Porter refined the idea of economic clusters in his article on Clusters and New Economics of Competition (Porter, 1998) and since then cluster development has become a focus for many government programmes and industry as well as company development efforts. Through organization in clusters, SMEs are expected to overcome problems associated with small size as well as lack of capacities and knowledge, and jointly be able to access foreign markets (UNIDO, 2009). A cluster may be defined as a group of companies – including competing and non-competing firms, lead customers, researchers and service providers – working within a geographical location to develop products and services for an identified market. Cluster initiatives facilitate acceleration of innovation and then bring them to maturity, thus ensuring the long-term economic success of companies involved. They present an efficient instrument for the concentration of resources and funding (see Paper II and Paper III). Cluster activities would enable to benefit from:

- more efficient exchange of information and knowledge;
- increased productivity;
- human resources development;
- coordination of development projects;
- network manufacturing (e.g. reallocation of resources, share orders etc.).

E-manufacturing can be determined as "IT-based manufacturing model, optimizing resource handling over entire enterprise and extended supply chain" (Lee, 2003). E-manufacturing is a systematic methodology that enables to successfully integrate manufacturing operations with functional objectives of the company through the use of Internet and predictive technologies. E-manufacturing is a concept to integrate all business elements (supplies, manufacturing units, service networks, etc.). Using the Internet and the myriad tools that support commerce functions, new customers can be found, costs of managing orders can be reduced and interaction with a wide range of suppliers and trading partners can be done. Additionally, new types of information-based products can be developed, such as remote monitoring and control software and other online services (Worthington and Boyes, 2002). E-manufacturing is not an event; it is the result of an evolving process that manufacturing business will continue to refine as technology capabilities expand and business conditions change. Internet based e-manufacturing covers the range of online manufacturing activities for products and services, including product design, production control and conditions monitoring, supply chain management, maintenance and sale services, etc., through the internet (Cheng, 2005). E-manufacturing is the vertical (business) and horizontal (supply chain) integration of systems to ensure the correct dissemination of information throughout the value chain of a business, making use of appropriate technology like the internet to ensure that real-time accurate information is available, at all decision points throughout an organization and supply chain (Greeff and Ghoshal, 2004). The characteristics of e-manufacturing emphasises the new philosophy through which manufacturing will be operated in integration with internet technology. E-manufacturing philosophy is based on the way people work and how it is altered by the internet. The main key-words here are: digitalization, globalization, mobility, collaborative work, immediacy (Zachary and Richman, 1993).

The value creation process covers the complete supply chain until the customer. B2B framework covers relations between customers and suppliers. With emerging applications of internet and communication technologies (Tapscott, 2009; Meister and Willyerd, 2010) the impact of e-intelligence is forcing companies to shift their manufacturing operations from the traditional factory integration philosophy to an e-factory and networking philosophy.

According to Koc et al (2005) and Unifi Technology Group (2000), there is a tight integration of e-Business (SCM, technology infrastructure, CRM, dynamic decision making), e-manufacturing (outsourcing, collaborative planning, technology structures, real-time information) and e-maintenance (production technologies, information pipeline, real time data processing).

Simplified e-manufacturing infrastructure (Unifi Technology Group, 2000) is presented in Figure 1.6. The levels of the infrastructure are tightly connected. Marketing, order compatibility determination and creating basis for effective manufacturing takes place on the first level. Supply chain management (SCM) and customer relationship management (CRM) are typical first level tasks (Hopp and Spearman, 2008; Sousa et al, 2008). Order management, resource allocation and production management tasks are solved on the second level. Lean management principles can be basis for performance improvement (King, 2009). From the realization level, feedback about real performance is received, being basis for analysis. MES enables scheduling based upon available production resources and model workflows.

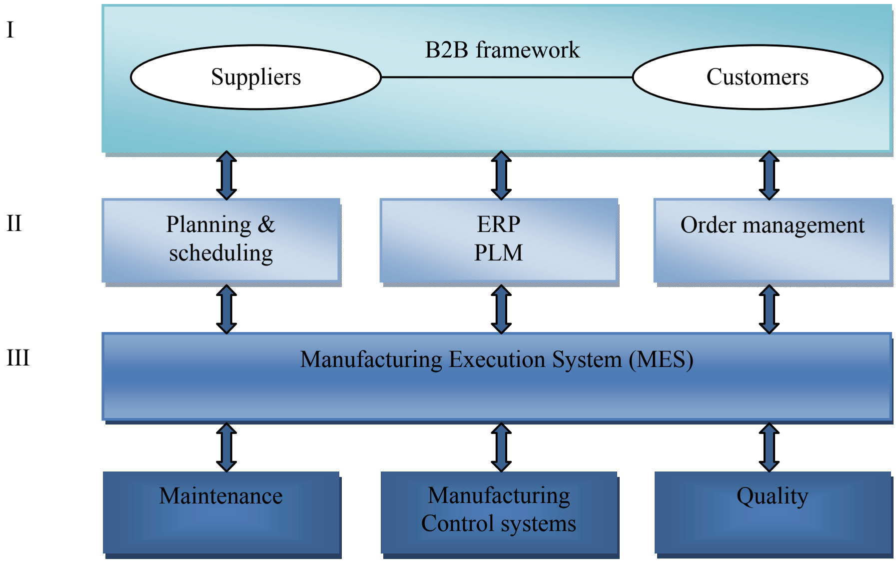


Figure 1.6. Simplified e-manufacturing infrastructure (Unifi Technology Group, 2000)

Using e-manufacturing models enables web-based reallocation of resources and coordination of order handling process inside the company as well as in the network of companies (see Paper II and Paper III). E-manufacturing gives advantages in shorter production times, more effective order handling and faster product development. E-manufacturing enables cut down costs in different supply chain segments due to shorter cycle time, minimization of unplanned works, precise planning, optimal use of resources, faster data delivery, faster product development, elimination of management mistakes etc. (Lõun et al, 2007).

1.3. Organizational performance model

Competitiveness pertains to the ability and performance of a company (or sector or country) to sell and supply goods and services in a given market, in relation to the ability and performance of other companies (or sectors or countries) in the same market. Competitiveness characterizes the company's position among other companies in the same market (Stajano, 2009). When the company's performance level is high, the company's competitiveness is also high. Performance of a company (or whatever system) is determined with the ability and rate to fulfil its objectives.

According to Tiia Tammaru, successful organizations are characterized by the ability to be aware of their state (condition) and possibilities. Balanced, value based approach to performance estimation covers the following fields (Tammaru, 2012):

- Organization’s financial sustainability;
- Organization’s “fitness” (effectiveness and efficiency);
- Cooperation with partners and customers;
- Continual training and development;
- Organizational coherence and satisfaction of employees;
- Organization’s relations and contribution to local community and society.

External environment includes micro and macro environment. Macro environment includes economic, social, legal, political, technological environments and has wider impact; it covers factors that influence all organizations. Micro environment is narrower and close to the organization; it covers organization’s competitors, customers, suppliers and other related parties. Strategy has to establish communication between organization and external environment. Changes in external environment have to reflect in changes of the strategy and this causes the need to make changes in the organization. The connection between external environment and organization has to be dynamical and flexible to be able to react to the changes in turbulent environment (Markides, 2000). Acting in turbulent environment requires more resources because an organization has to be prepared for unexpectedness, take into account more factors and foresee more activities.

Strategy determines the development of competences and technological resources, the appropriate level of automation, employment of new technologies and business models and the usage of cooperation or network activities. When changes in external environment occur, the need to make changes in the strategy arises. How appropriate is the strategy for external environment and which decisions are taken according to the strategy, determines the performance level of the organization. Endeavour of every organization is to increase effectiveness, productivity, to achieve excellence and to be competitive and sustainable. Thus, performance measurement and evaluation have to be employed at different levels (management, process / department, workplace) in the organization (see Figure 1.7).

Critical success factors (CSF) are elements necessary for an organization (or other system) to achieve its mission (Rockart, 1979). A critical success factor drives the strategy forward; it makes or breaks the success off the strategy. The answer to the question: “Why would customers choose us?” is typically a critical success factor.

As important as determining CSFs derived from the strategy is to determine key performance indicators (KPI). KPIs are the measures that quantify objectives and reflect strategic performance and success of an organization. The application of KPIs provides executives from a high-level to a real-time view of the progress of a project or company (Parmenter, 2010). Without right KPIs a company has no way to measure its performance in relation to its strategic goals (McNeeney, 2005).

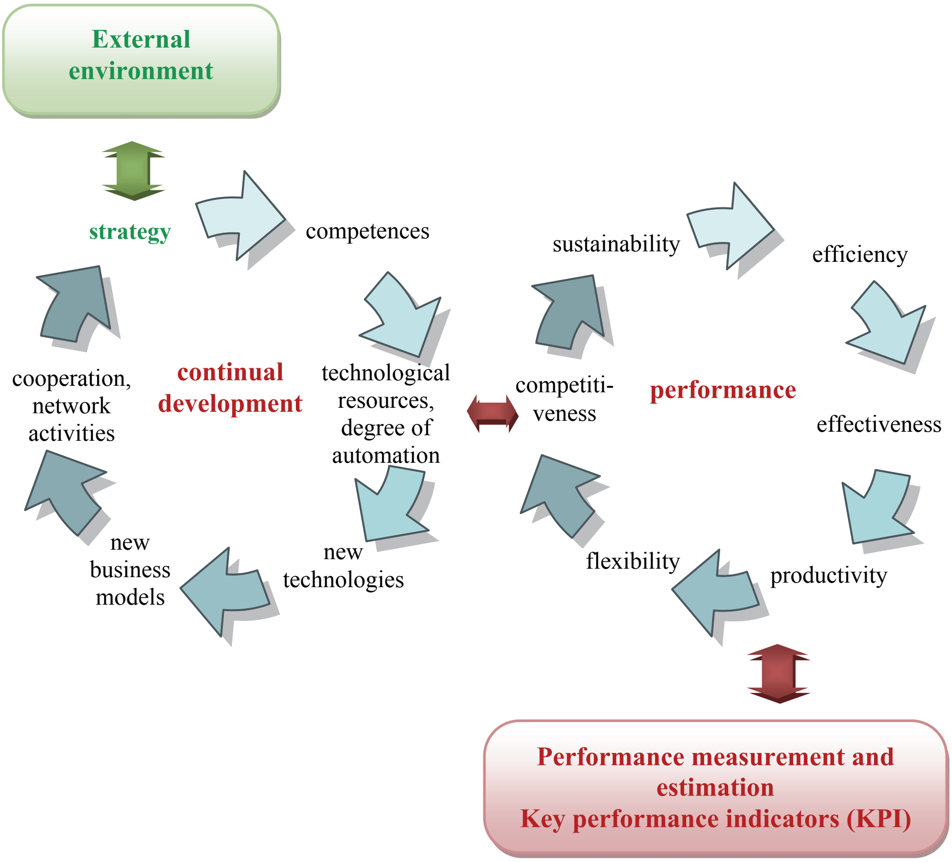


Figure 1.7. Organization's performance development model

1.4. Conclusions

1. Organization is an entire system the performance of which depends on the strategy, and different factors determined by the strategy, especially competences, production system and business models. Competences, production system and business models influence the level of quality, productivity and reputation of the company that in turn influence the company's sustainability and competitiveness.
2. Depending on the strategy, new business models and techniques as cluster activities, network manufacturing and e-manufacturing can be employed.
3. Strategy is the basis for determining competences and technological resources to be developed. Strategy enables to choose the appropriate level

of automation, new technologies and business models, as well as cooperation or network activities. When there are changes in external environment, the need to make changes in the strategy arises. How appropriate is the strategy for external environment and which decisions are taken according to the strategy, determines the performance level of the organization.

4. Endeavour of every organization is to increase effectiveness, productivity, to achieve excellence and to be competitive and sustainable. Methodology for comparative analysis regarding competitiveness, sustainability and productivity can be used to position a company. To manage and monitor performance of the company, critical success factors derived from the strategy should be determined as well as key performance indicators. Performance has to be measured and estimated on different levels, the results have to be analysed and decisions for continual development have to be made.

2. INTEGRATION OF A WORKPLACE TO THE PRODUCTION SYSTEM IN TERMS OF NETWORK MANUFACTURING

2.1. Essence and ontology of a production system

While often used interchangeably, there is a slight difference between the terms "production" and "manufacturing". According to the Merriam-Webster Dictionary (2013), production is used to describe a "total output" as well as the "act or process of producing" a commodity. Manufacturing, as described by the Merriam-Webster Dictionary, is "to make into a product suitable for use". For a product to be considered manufactured it has to be produced "according to an organized plan and with division of labour". Manufacturing specifically means the use of raw materials in the process of creating a product by using various processes, machines and energy. The definition of production is broader; it is a process of converting inputs to outputs. All manufacturing can be categorized as a form of production.

System is a set of elements that has certain connections and interactions, form an integrated whole and obey certain rules and management principles (Hitomi, 1996). Features of the elements of the system can be characterized by different parameters and their values. Common characteristics of the systems are:

- Structure – system contains parts (or components) that are directly or indirectly related to each other;
- Behavior – system contains processes that transform inputs into outputs (material, energy, data etc.);
- Interconnectivity – the parts and processes are connected by structural and/or behavioural relationships;
- A system's structure and behaviour may be decomposed via subsystems and sub-processes to elementary parts and process steps.

Elements of the system may form groups (e.g. sub-systems, modules, units etc.) that have common or similar technological and functional task. Basis for forming the groups are for example common location, common or similar function, similar components or elements. Essence and structure of production systems has been analysed by Groover (2008 and 2010).

Production system is a structural complex of manufacturing equipment and auxiliaries, personnel, technologies, information etc. that have mutual informative and logistical connections inside the system as well as with external environment. Production system has certain resources, processes and strategies. Production system is characterized by physical environment (number, type, model of machine tools, their layout and location) and functional environment expressed by technological possibilities (and utilization) of machine tools. Machine tools have mutual logistical relations inside the system as well as with external environment (Lõun et al, 2010). Hierarchical diagram describing the production system in engineering industry is presented in Figure 2.1. Indices used in Figure 2.1 are as follows: *k* is number of sub-systems; *m* is number of cell/modules in mechanical machining sub-system; *p* is number of machine tools in cell/module 1 in mechanical machining sub-system; *r* is number of operators in cell/module 1 in mechanical machining sub-system *q* is number of machine tool elements in machine tool 1 belonging to mechanical machining sub-system.

Production system is a collection of arranged elements into a purposeful sequential or spatial (or both) order or structure and forming a unified whole. The core of the developed methodology lies in the capability-based matching of manufacturing task (product) requirements and system capabilities.

Matching available resources requires formalized and structured representations of the functional capabilities, properties and constraints of the production system resources. In the proposed approach capabilities are functionalities of resources. Capabilities have parameters, which present the technical properties and constraints of resources.

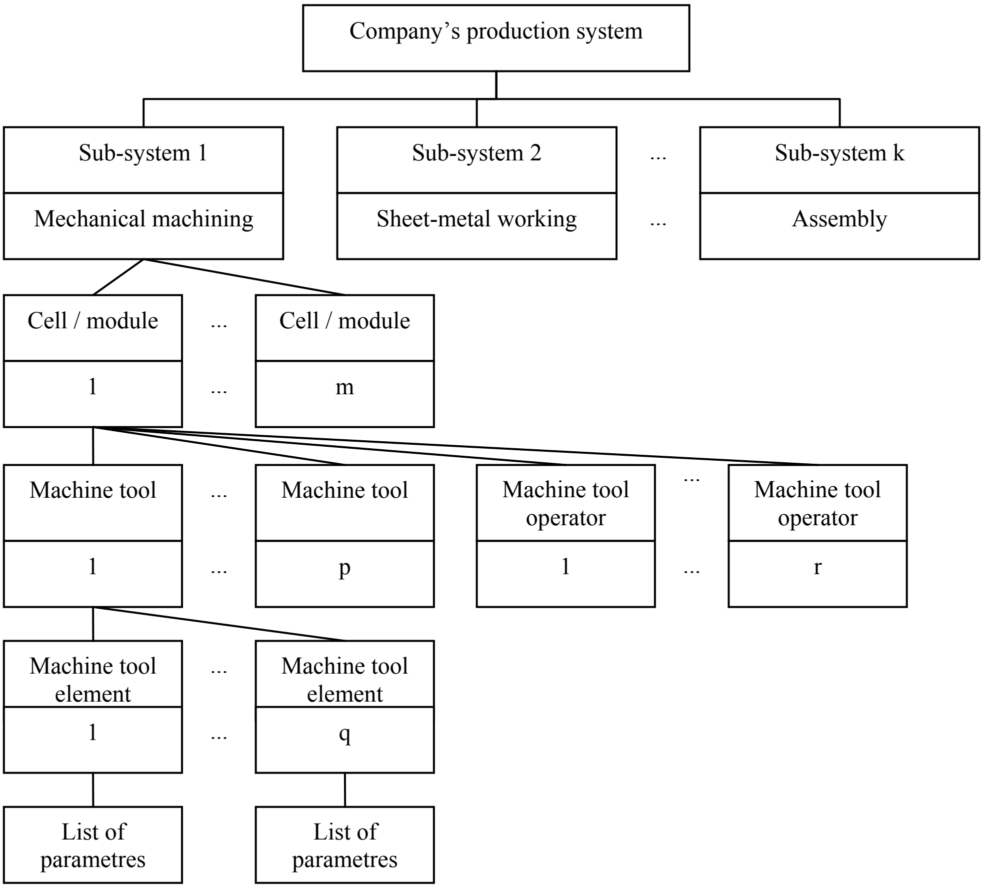


Figure 2.1. Hierarchical diagram describing the production system

Abstract description of a production system is formulated as presented in Eq. (2.1).

$$T = \{N, A, S, F, P), \tag{2.1}$$

where T is production system, N is components of the system (e.g. 5-axes milling-turning centre etc.), A is parameters describing the components of the system (technological parameters of the machining tools), S is structure of the system (locations of machining tools and connections between them) and F is number of functional connections between the elements of the system (depends on the ontology of the system and defines essence of single events). Number and essence of events depends on technology, rate of automation and organization of production. P is number of manufacturing operations taking place in the system, p_1 ... p_k (e.g. p_1 is milling; p_2 is turning; p_3 is boring etc.), depends on technological possibilities of the system.

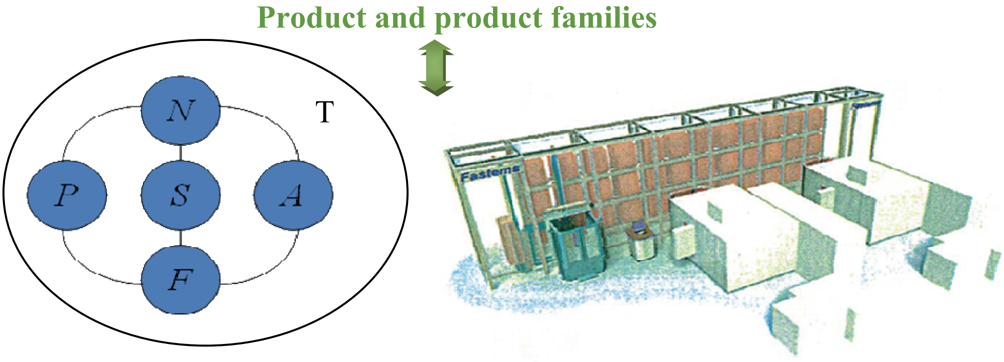


Figure 2.2. From abstract description of a production system to realization

Structure of a production system with other attributes $\{N, A, P, F\}$ determines technological possibilities of the production system and also preconditions for fulfilling certain type of orders (the volume of orders, delivery time, special type of produced goods etc.) and manufacturing certain type of products (product size, geometric complexity of surfaces, position accuracy, surface quality parameters etc.). The structure of a production system can be linear (sequential arrangement of machine tools and operations) or matrix-shaped (automatized storage and transportation system can service machine tools in random order and operations can take place one by one or simultaneously).

Today's production systems are characterized by constantly changing requirements caused by short lifecycle of products, small batch sizes, increasing number of product modifications and fast emergence of new technical solutions.

Manufacturing system converts raw material into a completed product, and comprises of equipment, products, people, information, planning and control, and support functions. Value is directly added to the product in manufacturing system.

A manufacturing system consists of a multitude of functions, interconnected usually by a complex computer-controlled communication system. It supports strategic and technological planning, organizational planning and scheduling, manufacturing control and monitoring and accounting functions. In this system, the flows of information, funds and material have to be controlled in a precise manner to service the customer market with high quality product and assure the financial soundness of the company (Rembold et al, 1993).

Manufacturing process management (MPM) is a collection of technology and methods used in the manufacturing to define how products are to be manufactured. MPM differs from ERP/MRP which is used to plan the ordering of materials and other resources, set manufacturing schedules, and compile cost data (Machover, 1996). Most popular tools for supporting the manufacturing are CAD, CAM, CAPP, PLM, ERP, also GT. The main objective of the use of these tools is to minimize the time for process planning, preparing the CNC programs for machine tools and also minimizing the throughput time.

In manufacturing process, also network manufacturing can be used. The aim of the use of network manufacturing is to use resources efficiently and fulfil the company's objectives. Internet gives a lot of good possibilities for sharing the resources for effective cooperation in an order fulfilment process. Example for tooling sector is presented in Paper III. Generalized concept of an internet-based e-manufacturing system is presented in Figure 2.3. Abbreviation used in the Figure 2.3: *E* is company (1, 2 ... *n*). Figure 2.3 demonstrates that some activities have to be performed inside the company while others can be decentralized (mainly B2B contacts and order handling) (see more in Paper III).

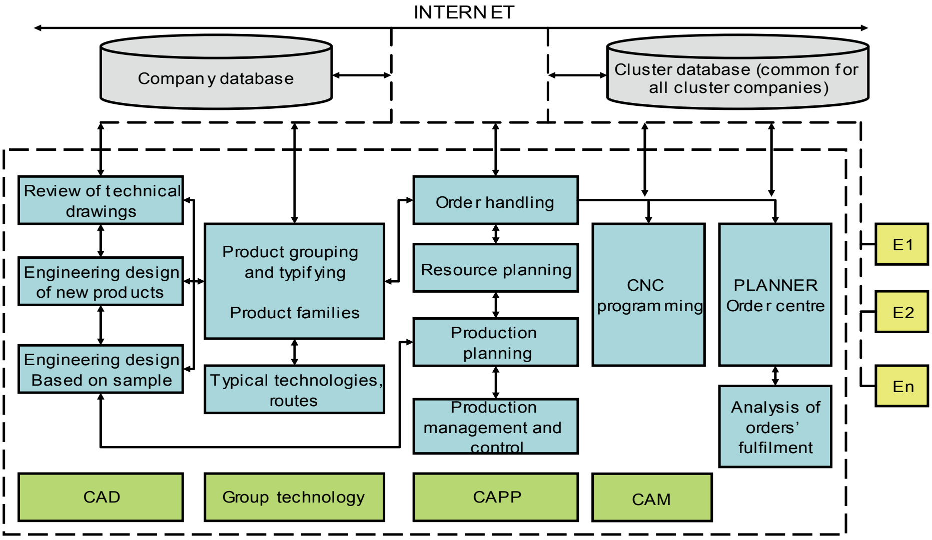


Figure 2.3. General concept of Internet-based e-manufacturing system

Production system ontology is described in Paper IV. Production system ontology presents production system and its components and their mutual relationships. As presented in Paper IV, the production system has central part in a company's order handling process with its resources and technological possibilities.

Determination and essence of technological possibilities is dealt with in Paper III and Paper IV. Technological possibilities of a manufacturing enterprise evolve on the basis of technological possibilities of machinery (machine tools, presses, welding equipment etc.). Technological possibilities can be defined as a set of characteristics or parameters of the current device, robot, production module or system for performing some technological task. Technological possibilities constitute one part of the formation of technological capabilities which is described in chapter 2.2.

The range of products to be manufactured is a general characteristic of technological possibilities of a machine tool. On the basis of technological possibilities of separate machines belonging into a system, the possibilities of the whole system are formed (Riives et al, 2004). Technological possibilities of machine tools belonging to the production system and technological possibilities of the production system as a whole determine functionalities of the production system. Technological possibilities of machine tools and competences of the machine tool operators belonging to the production system determine the spectrum of workpieces which can be manufactured in the system (Eq. (2.2) and (2.3), see also Paper IV). As indicated in Eq. (2.2) and Eq. (2.3), required needs are based upon the number of necessary parameters $\bigcup P_w$ (product dimensions, manufacturing accuracy, surface finishing, surface roughness, etc.) compared with the number of production system parameters $\bigcup P_s$ and needed competences $\bigcup S_w$ to existing competences $\bigcup S_s$

$$\bigcup_{i=1}^{p} P_{Wi} \leq \bigcup_{i=1}^{p} P_{Si} , \tag{2.2}$$

where p is the number of technological parameters,

$$\bigcup_{i=1}^{q} S_{Wi} \leq \bigcup_{i=1}^{q} S_{Si} , \tag{2.3}$$

where q is the number of competences.

Utilisation expedience expert estimation can be given regarding the following aspects:

- s_1 is estimation of technological resources (manufacturing methods, technological possibilities), $s_1 = \{0,1\}$;
- s_2 is estimation of manufacturing competence (necessary and existing skills and knowledge), $s_2 = \{0,1\}$;
- s_3 is estimation of manufacturing organisation structure (workshop layout, level of automation, complexity of manufacturing path), $s_3 = \{0,1\}$.
- Complex estimation: utilisation expedience $S = s_1 \, x \, s_2 \, x \, s_3$.

It is the decision of the management, based upon experience and behaviour loop results the index of which defines utilisation as ineffective.

The process planning (see Paper IV) depends on the technological possibilities of the machine tools belonging to the production system. Categorized by machine tools, there are two basic variants:

a) one level production;
b) multi-level production.

In the first case there are machining centres or machine tools with a wide range of technological possibilities. The second case covers typically monofunctional (drilling, boring, milling, etc.) machine tools. The machine tools of the first group are usually more expensive. Minimizing the costs and number of machine tools in use is a task that is described in Paper IV. The model for determining numerically technological resources is presented in Eq. (2.4). Parameters: X_j, Y_{ikj}. Function:

$$\min \sum_{j=1}^{J}(X_j P_j + C_j \sum_{i=1}^{I}\sum_{k=1}^{k_i} Y_i k_j t_{ikj}) \tag{2.4}$$

Subject to constraints:

$$\sum_{i=1}^{I}\sum_{k=1}^{k_i} Y_{ikj} t_{ikj} \leq X_j F_j \eta_j \text{ , } j = 1, 2, \dots J$$

$$\sum_{j=1}^{J} Y_{ikj} = N_i \text{ , } k = 1, 2, \dots K, \; i = 1, 2, \dots I$$

$X \geq 0$, $X_i = int$

$Y_{ikj} \geq 0$, $Y_{ikj} = int$,

where i is type of processed workpieces (from the product mix), N_i is production amount of workpieces per certain time, j is model of a machine tool among these types of machine tools, I is number of types of possible workpieces for processing using machine tool j, k is number of processing types, J is number of types of machine tools which enable to perform processing type k, t_{ikj} is time of realisation of process ik using machine tool j, F_j is effective work time front of machine tool j, η_j is planned loading coefficient of machine tool j, P_j is price of machine tool j used for processing certain workpieces type i (from the product mix), C_j is cost of working hour of machine tool j, X_j is number of machine tools type j used for processing certain workpieces type i (from the product mix) and Y_{ikj} is number of workpieces of type i used for processing operation k using machine tool type j.

In the same time there is also a need for shortening the production throughput time (see also Paper VI). T_{TS} is manufacturing throughput time (also known as throughput time) – the period required for a material, part or subassembly to pass through the manufacturing process. Throughput time can be expressed as a sum of cycle time, transportation time, final control time and idle time, see Eq. (2.5):

$$T_{TS} = T_{SM} + \sum_{i=1}^{r} T_{R_i} + \sum_{i=1}^{c} T_{C_i} + \sum_{i=1}^{x} T_{X_i}, \tag{2.5}$$

where T_{SM} is the cycle time, T_{Ri} is the summarized transportation time in manufacturing process, r is the number of transportation operations, T_{Ci} is the summarized final control time, c is the number of final control actions, T_{Xi} is the summarized idle time and x is the number of different types of the idle time.

T_{SM}, the cycle time, is the period required to complete an operation or a job from start to finish. Cycle time consists of different times as presented in Eq. (2.6):

$$T_{SM} = \sum_{i=1}^{n} (T_{m_i} + T_{p_i} + T_{s_i} + T_{k_i}), \tag{2.6}$$

where n is number of machine tools used to manufacture a product, T_m is the machining time, T_p is the workpiece loading and unloading time in machine tool, T_s is the machine tool setup time (a period required to prepare a machine tool to be ready to fulfil an operation), T_k is the measurement and control time in machine tool during fulfilling an operation. Indicators for analysis of effectiveness of a workplace are described in more detail in Paper VI.

The objective is to maximise the importance of cycle time in throughput time and the importance of machining time in cycle time as presented respectively in Eq. (2.7) and (2.8):

$$\frac{T_{SM}}{T_{TS}} [0,1] \rightarrow \max \tag{2.7}$$

$$\frac{T_{m}}{T_{SM}} [0,1] \rightarrow \max \tag{2.8}$$

For achieving this there are two important tasks that also arise from the ontology of the production system and are tightly connected to the strategy of the company (see Figure 2.4):

a) Production system configuration design;
b) Production system utilisation design.

Both tasks are tightly related to the problem of design of a workplace. Production system configuration design is based on the strategy of the company.

Manufacturing system design is a process that contains a number of related or interdependent tasks. Generally, it is a complex process the degree of which largely depends on the underlying set of requirements to be fulfilled (Semere, 2005). An Integrated Manufacturing System Design is defined broadly to include the interface and coordination of functions, linkages of physical components, and information flow and processing that occur both vertically and horizontally, throughout the entire organization (Academy of Engineering Staff, 1988). According to Semere (Semere, 2005), manufacturing system configuration design is strategic, i.e., the effects are long term and determine the competitiveness of manufacturing. Manufacturing system configuration design tasks are described by Semere (Semere, 2005). A manufacturing system configuration can be understood as a design task in which system components are selected and arranged to form a system (Dixon and Poli, 1995). If the requirements are specified, the configuration design (selection of the attributes) takes place.

Production system configuration design (task A) in its whole complexity is quite a rare task. Redesign occurs more often, for example, when characteristics of orders or company strategy changes. Effective use of a production system (task B) is a task that every manufacturing company faces daily. Effective use of the production system is in tight correspondence with the processes of the company and creates preconditions for achieving effectiveness of the company. Production system and business / production processes are in interaction (see Figure 2.4). Effective utilization of a production system can be understood as a design task where components of the system (with their technological possibilities) are selected with the aim to optimize the production process of certain product (product families), according to the orders. Both tasks (A, B) differ from each other significantly, but are also quite tightly connected (Figure 2.4). Task B is under investigation in the current thesis. Design of the production system creates basis for the system's effectiveness, although achieving the effectiveness is possible only through effective utilization of the system. The author's experiences in quality management systems' development and implementation in different companies have demonstrated that the structure of processes is quite different in different companies, depending on the size of the company; nomenclature, functionality and complexity of products; type of production etc., but the objectives and tasks of the processes are quite similar. Models of some essential processes (e.g. order handling) of tooling companies in the context of e-manufacturing were described in Paper II and Paper III.

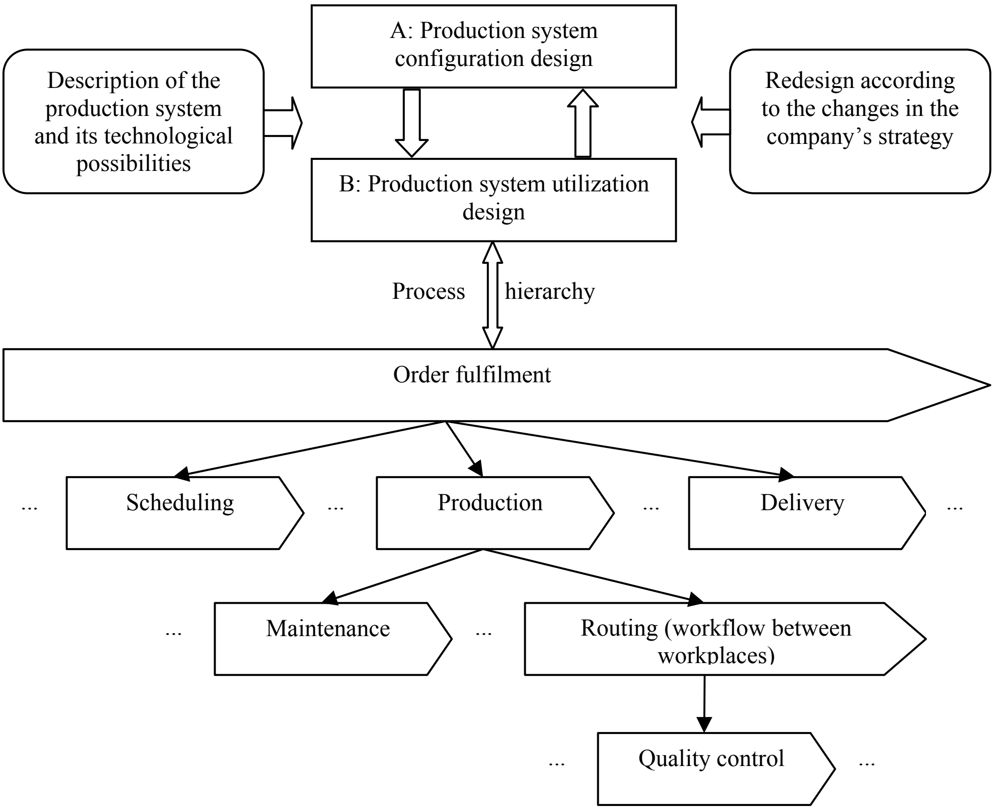


Figure 2.4. Example of process hierarchy in the production system utilization

Effective utilization of the system is based on determining the essence and connections and elaborating effective interaction between different attributes of the system – strategy, resources, processes, workplaces, orders, production routes etc. An approach to defining manufacturing taxonomy and axioms, based on production systems' engineering ontology, is presented in Paper IV. According to the ontology, the system, process, resources, manufacturing route, order etc. are connected to the workplace. Workplace is the direct unit creating value to the product. The performance of a process, system and/or company starts from the workplace.

The research about description of technological resources and their technological possibilities is used by competence centre IMECC for developing web-based module for sharing information about technological resources, their availability and use in network manufacturing.

Some KPIs that characterize performance of a production system are presented in Figure 2.5. The strategy and CSFs of the company determine which KPIs to measure, therefore the list presented in Figure 2.5 is not final.

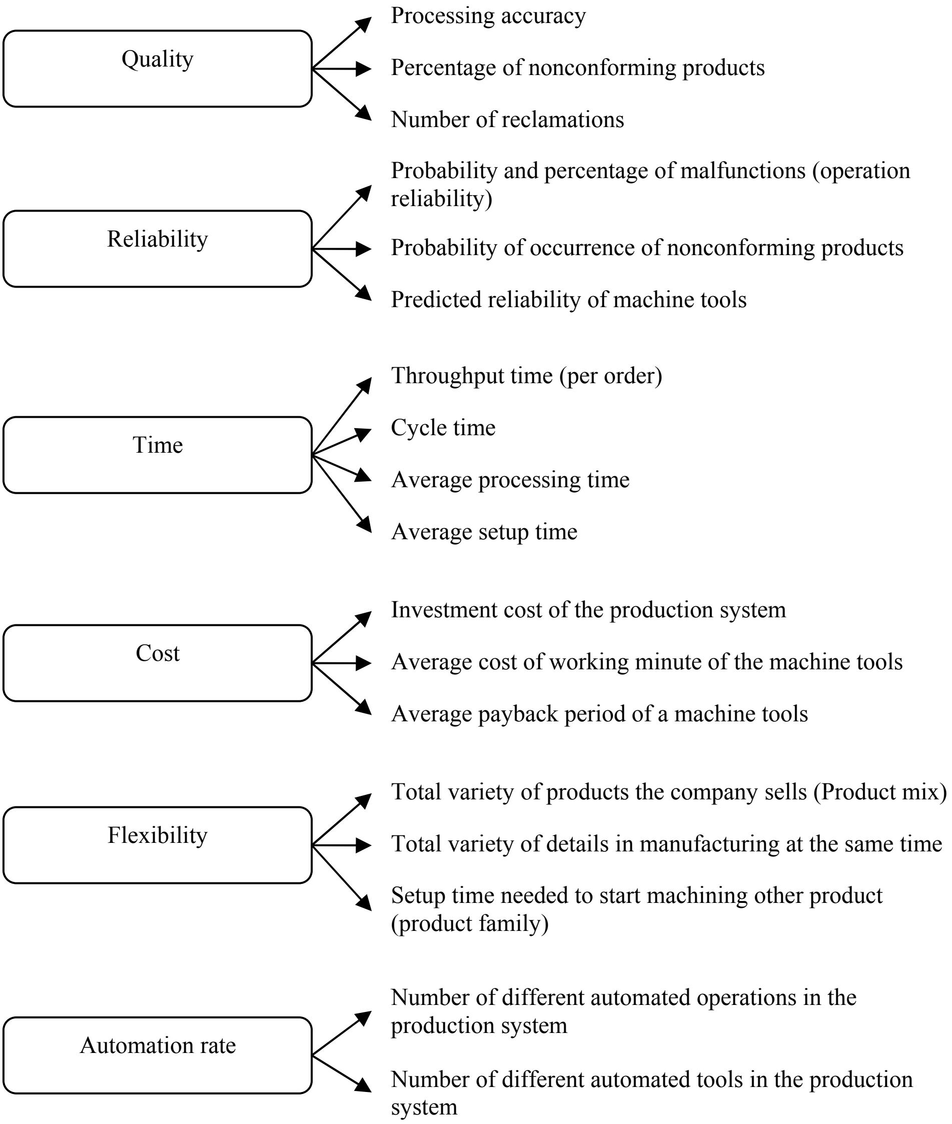


Figure 2.5. KPIs characterizing a production system performance

2.2. Factors influencing capability of a production system

2.2.1. Definition of a workplace

Production system consists of workplaces that perform technological tasks (single or recurrent) in order fulfilment process. In this paper, a workplace is defined as a combination of machine tool and machine tool operator that form together the simplest man-machine system (see Figure 2.6).

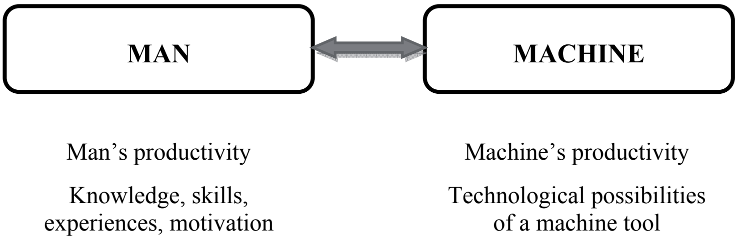


Figure 2.6. Conceptual scheme of a workplace: man-machine system

Workplace is a single unit of a production system that is organized on the basis of machine tool (or group of machine tools) serviced by an operator and additional servicing equipment if needed.

Competences are human capabilities. In production systems a human can act as one of the most flexible and intelligent system resources, he or she can perform a large variety of tasks ranging from simple material handling to complex tasks such as inspection or monitoring and control of the system. From this argument, rational integration of the human resources into the system operation is a critical aspect in the design of production systems.

The man's (machine tool operator's) skills, knowledge, experiences and motivation influence productivity – how many pieces it is possible to produce during a certain period using a certain machine with certain technological possibilities. Essence and management of the productivity are described by the author (Lõun, 2010), tools for the production systems to raise efficiency and productivity and human resources management in the workshop with an aim to raise productivity are described in Paper I.

Another factor influencing the workplace's capability in addition to the machine tool operator is the technological possibilities of the machine tool. The machine tool operator's productivity and machine tool's productivity together determine the workplace's productivity. Raising the productivity of the workplace is based on two levels:

1) Management level: machine tools with wider technological possibilities, higher automation level, more trained personnel and broader spectrum of competences, motivation systems;
2) Work-shop level: better planned and organized work, implementation of Lean principles (e.g. 5S, 7waste, 8D, poka-yoke, visual control etc.) that form basis for cost-effective manufacturing.

Actions on these levels create preconditions, performing tasks on the workplace gives measurable results.

2.2.2. Essence of technological resources and technological capability

As it was demonstrated previously, technological resources form an important part of a production system. Machine tool with its technological possibilities and machine tool operator with its competences and motivation influence technological capability of the workplace (see Figure 2.7). Capability is an ability to perform actions. Technological capability of a production system is formed by technological capabilities of different workplaces belonging to the production system. Through its technological capabilities, technological resources influence nomenclature and complexity of products that can be produced with a certain production system (Lõun et al, 2010).

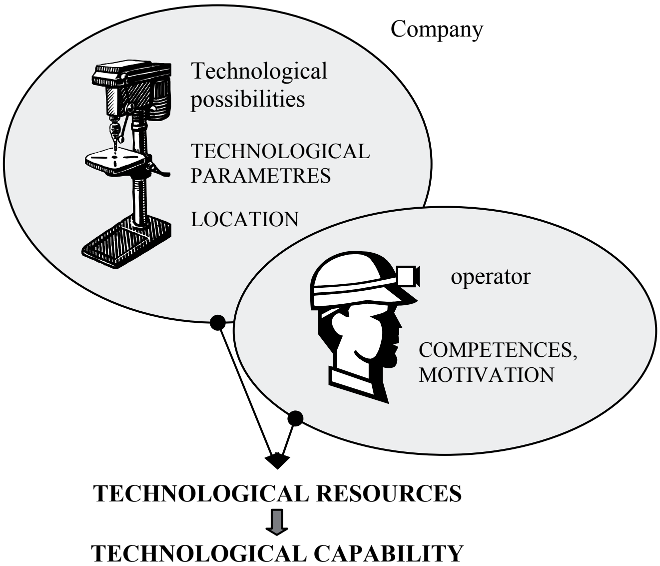


Figure 2.7. Essence of technological possibilities, resources and capability

Using nowadays complex machine tools and production technologies, competences of employees are extremely important. Full exploitation of technological possibilities is not possible without appropriate competences (Lõun, 2011). Competences needed for different jobs were analysed, mapped and tested on the basis of different companies and methodology of competence charts that was elaborated in the framework of INNOMET-EST project. Competence charts are composed on the basis of professional standards and can vary according to the company’s activity field, structure, jobs, and tasks. Competence evaluation process has two levels:

1) Evaluation of required level of competences on the basis of certain job (e.g. welder);
2) Evaluation of actual level of competences of a person performing this job.

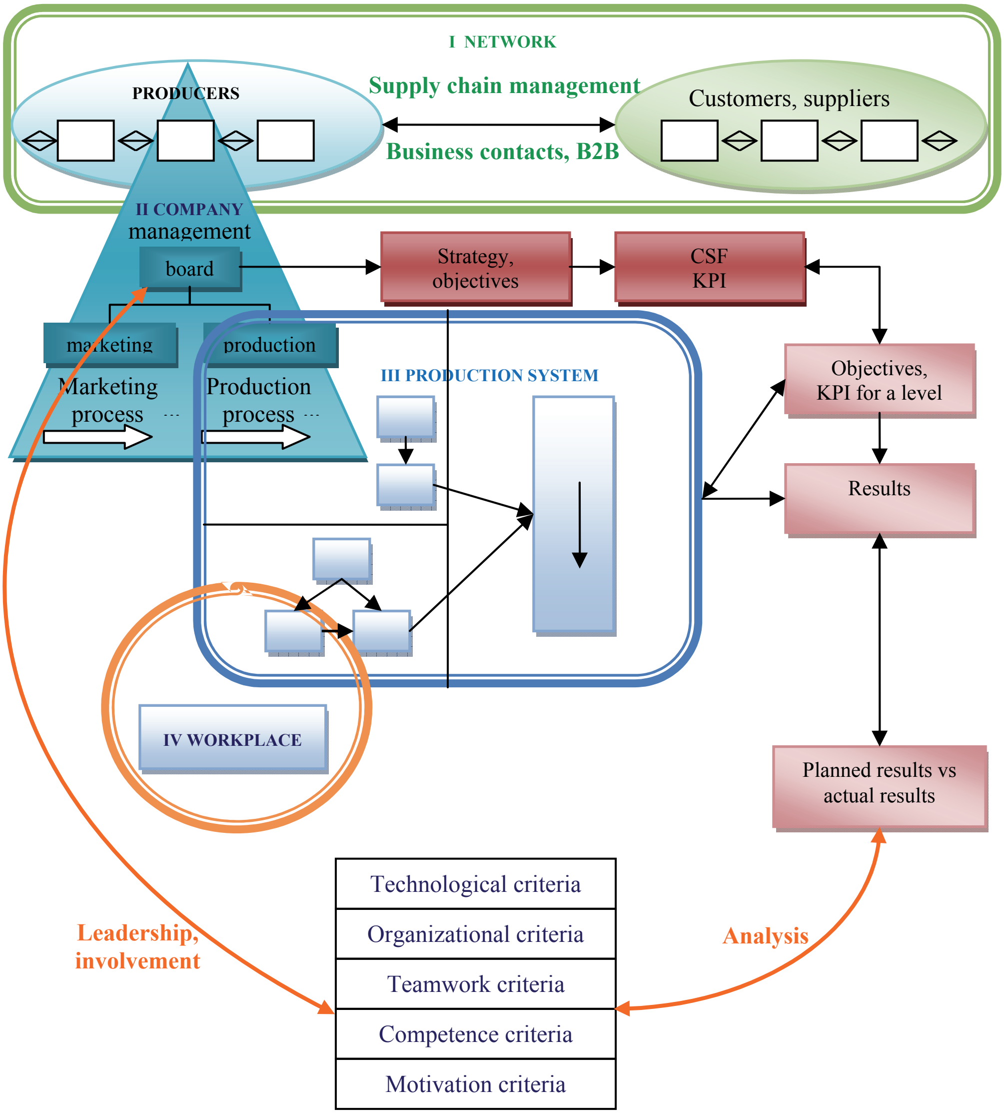
Comparing required and actual levels of competences estimation about an employee's training needs are presented and an overview about the company's, department's or unit's existing and lacking competences has been received. Ideally, required level and actual level of the competences should match. If the employee has more competences than necessary for the job he/she performs, it is waste of resources. If the employee has less competence than necessary, work results (e.g. quality, productivity etc.) could be affected (Riives et al 2007; Otto et al, 2008). The methodology of estimation of actual and required competence level on the basis of competence charts was tested with the participation of the author of this thesis in different Estonian companies. The analysis of testing results showed that the lack of key competences could cause considerable decline in productivity at workplaces.

If the complexity of processed detail is under technological capability of the workplace or production system, we face waste of resources that influences the product's cost. When the product's complexity responds to the technological capabilities of the workplace, we use resources at optimal level and this is reflected also in productivity and product cost. Therefore, optimization task to find appropriate balance between machine tool's complexity and automation rate and machine tool operator's competences should be solved based on the company's nomenclature of products and business strategy.

The role of workplace in formation of the production system's efficiency is presented in Paper V.

2.3. Hierarchy of systems in e-manufacturing and optimal management of orders' allocation process

Workplaces are integrated into the production system, production system belongs to the company and a company can be part of a network, which in turn is a part of an industry. As seen in Figure 2.8, the workplace is directly connected to the system (e.g. production system) and also to the process. The process organization in a company is the central part of a process-oriented corporate design (Becker et al, 2011). While the organizational structure divides the company into sub-systems (departments, workshops, units etc.) with their determined capabilities, the process orientation deals with the execution of orders (in company and department level) and tasks (in the workplace level) in time-bound sequence of simple events. The more complex the orders are, the more flexibility is required from the system and the more complex is the fulfilment of work orders in workplaces. In case of problems, the location of problem should be determined and according to that, optimal solutions found (see Figure 2.8). Thereby, As-Is To-Be modelling can be used.



Vertical integration levels: I – Network; II – Company; III – Production system; IV – Workplace

Figure 2.8. Integration of the systems and position of the workplace

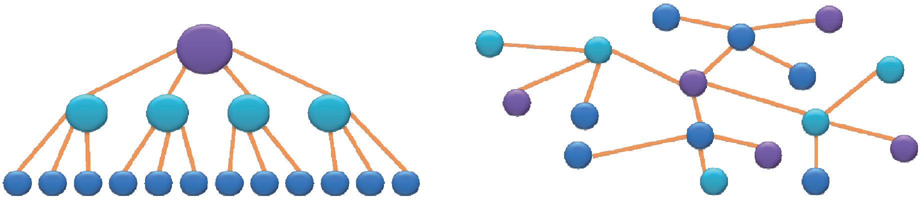
Customers' requirements towards quality, delivery speed and accuracy have increased. Nowadays it is not economically feasible to produce a whole final product (or fulfil the whole order) without subcontracting because the order fulfilment time would be too long and it would require too many workplaces with different functionalities that have to be effective at the same time.

Therefore, nowadays there is a trend towards optimisation of the entire network or supply chain, focusing on the performance and competitive situation for a supply chain rather than a single company. The supply chain perspective implies an increased need for orchestrating a broad set of activities, resources and companies, often with decentralised geographical structure and high complexity. Capturing market trends and satisfying customer demand by supplying high quality products is the dominant challenge in manufacturing. Tomorrow's successful companies must meet this challenge by adopting the concepts of modern manufacturing with a true supply chain perspective. Key concepts in this respect are lean thinking, automation, modularisation, integration and collaboration, process focus, information sharing and transparency (Bjartnes et al, 2008.).

Manufacturing and industrial activities take place in networks and supply chains environments where the total responsibility for finalizing products is divided between a set of companies, each with specific roles in the value creating activity (Chopra and Meindl, 2007; Simchi-Levi et al, 2005). The supply chain structure can be viewed as a network of suppliers, manufacturing plants, transporters and customers, organized to acquire raw materials, to convert these raw materials to finished products and to distribute these products to customers (Küttner, 2009). In operations of manufacturing and supply chains systems the planning and control process is vital. Planning and control secures an efficient utilization of resources when fulfilling demand from customers (Vollmann et al, 2005). The complexity of the planning and control process is closely connected to the number of different products, the variation of demand and the number of companies in the supply chain (Bjartnes et al, 2008). Küttner (2009) determined the generic framework that was created for describing the strategic planning process for a supply chain and a corresponding model for modelling the demand, product or process time variability in case of low-volume production in make-to-order environment.

For all these problems, workplace's capability plays an important role. More capable workplace enables to produce wider nomenclature of products, achieve higher flexibility and shorter delivery times. In case of network manufacturing, it is possible to develop workplaces in network of companies to achieve higher efficiency and effectiveness and better results integrated in the network.

In the new global market, competitiveness and growth of industry highly rely on the move toward innovative high performance industrial systems and agile networked enterprises through the creation and consolidation of non-hierarchical manufacturing networks of multi-national SMEs in front of networks based on powerful large-scale companies. The traditional hierarchical manufacturing networks are based on centralised models, where some of the involved actors must adapt themselves to the constraints defined by the dominant ones. For current highly dynamic markets, this generates major inefficiencies in the operation of the whole supply chain. Centralized networks performance can be significantly improved through more harmonious and equitable peer-to-peer inter-enterprise relationships, conforming a decentralised and collaborative decision making model (Poler, 2009). A conceptual scheme of hierarchical manufacturing network and non-hierarchical manufacturing network is presented in Figure 2.9.



Hierarchical manufacturing network

Non-hierarchical manufacturing network

Figure 2.9. Hierarchical manufacturing network and non-hierarchical manufacturing network (Poler, 2009)

Benefits of non-hierarchical manufacturing networks (Canetta, 2010):

- Enhanced overall competitiveness, innovation and adaptability in today and tomorrow's enterprise partnership scenario;
- Cross-country and inter-enterprise interchanges, building networked enterprises that are supported by stable relationship schemas and modern co-operation & co-ordination business paradigms;
- Cost reduction, through overall optimisation and elimination of inefficiencies of processes, stocks, flows, plans, etc.;
- Companies' human resources improved quality of work and skills, through improved knowledge management and dissemination, better understanding of dynamics and flows, and clearer definition of roles and responsibilities;
- End consumers' advantages, mainly in terms of diminishment of products time-to-market and costs;
- SMEs empowerment and enhanced accessibility to networked enterprises;
- Optimisation of materials, wastes and energy consumption based on more rational and homogeneous production and supply plans, stocks and workforce balance.

2.4. Risks in network manufacturing

Globalisation of manufacturing has caused an increase of locations with common markets and customers resulting in a harder competition for each of the involved players. Combining this observation with the trends toward more complex products, decreasing product life cycle times, higher customisation of products and higher demand of knowledge, leads to the necessity for companies to produce products in co-operation with other enterprises. In the same time each company has to operate in an increasingly dynamic market and sourcing situation (Hauge and Duin, 2008).

The ability of serving markets in time is one of the most important indicators for staying competitive. The harder the competition is, the higher the efficiency must be. This leads to cost reduction strategies like out-sourcing, etc. (Jüttner, 2005; Pfohl, 2002). The main result of this development is the emergence of complex and widespread manufacturing networks, which are more vulnerable and more sensitive to external and internal changes (Pfohl, 2002; Peck, 2005; Freidank, 1999).

Figure 2.8 presented a conceptual scheme for optimization order fulfilment time based on the vertical integration of levels (network, company, production system, and workplace) and workplace's role in it. Monitoring and analysis of the performance of a workplace is important in bottom-up analysis. For achieving company's competitiveness and sustainability, optimal use of resources (incl. competences of the employees, technological possibilities of machine tools) is essential. It results in the increasing use of network manufacturing models.

Using network manufacturing, customer needs must always be kept in mind. Networks not configured with the customer in mind will invariably lead to low customer satisfaction and lost revenue, and will eventually drive the company out of business. Target customers may value short lead times, whole-order delivery, reliability, responsiveness, low cost, value-added services or some combination of these variables, and what is valued may vary by subsegment. Each of these customer differentiators, however, may have a different implication for network design (Shorten et al, 2004). In case of network manufacturing, several risks arise that have to be estimated before making strategic decision for or against network manufacturing.

Organizations of all types and sizes face internal and external factors and influences that make it uncertain whether and when they will achieve their objectives. The effect this uncertainty has on an organization's objectives is risk. Many definitions of risk exist in common usage. Usually risk is understood as the potential that a chosen action or inactivity (including the choice of inaction) will lead to a loss (an undesirable outcome). The ISO 31000:2009 (Risk management – principles and guidelines, 2010) definition of risk is the "effect of uncertainty on objects".

All activities of an organization involve risk. Organizations manage risk by identifying and analysing it, thereafter evaluating whether the risk should be modified by risk treatment in order to satisfy risk criteria. Systematic and effective risk management enables an organization above all:

- Increase the likelihood of achieving objectives;
- Establish a reliable basis for decision making and planning;
- Improve controls;
- Effectively allocate and use resources for risk treatment;
- Improve operational effectiveness and efficiency;
- Minimize losses.

Risk management helps to maximise opportunities whilst minimizing the threats. According to ISO 31000:2009 (Risk management – principles and guidelines, 2010), risk management includes the following steps:

- Risk assessment:
    - Risk identification;

    - Risk analysis;
    - Risk evaluation;
- Risk treatment.

Risk assessment is usually based on estimation about the risk probability and impact. Risk probability and impact are the two primary dimensions of risk:

1) Probability – a risk is an event that "may" occur. The probability of it occurrence can range anywhere from just above 0 percent to just below 100 percent (Note: it cannot be exactly 100 percent, because then it would be a certainty, not a risk; and it cannot be exactly 0 percent, or it would not be a risk);
2) Impact – a risk, by its very nature, always has a negative impact. However, the size of the impact varies in terms of cost and impact on health, human life, or some other critical factor (MindTools, 2013).

Mathematically, risk could be calculated as presented in Eq. (2.9):

$$R = P \times L\,, \tag{2.9}$$

where R is risk, P is probability of a (negative) event occurring and L is expected loss in case of an event.

In a situation with several possible negative events, total risk is the sum of the risks for each different event, provided that the outcomes are comparable, Eq. (2.10):

$$R = \sum_{i=1}^{I} (P_i \times L_i)\,, \tag{2.10}$$

where i is the type of risk and I is the number of risks.

Manufacturing network design can improve a company's cost structure even more than the best manufacturing practices, but there are associated risks. One of the most common mistakes is to ignore broader strategic context. Supply networks have a lot of moving parts; labour rates, productivity, product design, process technology, and raw material costs are only a few of them. Companies with cost-reduction tunnel vision have put intellectual property and proprietary information worth many times the savings gained from reduction of production costs at risk. Any network redesign must consider the stability of demand and the speed of technological change. Developing a manufacturing organization with a network in an emerging country is a challenge. Risks include local currency exposure, political issues, and variations in local taxes and penalties. Other risks include the possibility of quality problems with new suppliers, the loss of intellectual property, and the change management challenges (Bliss et al, 2007).

Some of the main risks that may exist in network manufacturing are presented in Table 2.1. The risks in Table 2.1 and estimations about their probability are presented in generalized form, considering an average Estonian engineering company. Some risks exist mainly when collaborating with partners abroad; others may occur in domestic or international collaboration.

Table 2.1. Main risks in network manufacturing and possible control measures

Potential risks	**Estimation about risk probability**	**Possible control measures**
Organization lacks strategy and therefore over-/ underdimensions its technological resources and competences	High	Development of clear vision and strategy, taking into account the nomenclature of products, characteristics of customers' orders, etc. and periodical review of them
Lack of information about new technologies and/or availability and prices of resources outside the company	Medium	Use of resource management databases (e.g. IMECC's resource management module, www.imecc.ee), clusters
Issues regarding competition, intellectual property risks	Medium	Obtain competent legal advice; protection of intellectual property
Unreliability of partners (e.g. orders are not fulfilled in time, work does not respond to customer's requirements)	Medium	Evaluation of partners before cooperation relationship, communication, regular exchange of information
Lack of cooperative behaviour in the organization and/or in the network and/or teamwork and collaboration skills and competencies	High	Lifelong learning, training of engineers regarding collaboration and teamwork competencies
Transportation delays	Low	Evaluation of partners before cooperation relationship
Additional risks in case of international cooperation		
Political risks	Medium	Evaluation of target countries and economic situation
Currency movements	Medium	Evaluation of target countries
Variations in local taxes and penalties	Low	Evaluation of target countries

Risks in network manufacturing are dealt with in Paper IV.

2.5. Conclusions

1. Production system supported by tools as CAD, CAM, CAPP, ERP, PLM etc. is the main part of every manufacturing company which may stand alone or be a part of some manufacturing network (e.g. set of companies, cluster). Production system ontology helps to understand connections in the production system and thus improve the performance.
2. The structure of a production system and its attributes determine technological possibilities of the production system and also preconditions for fulfilling certain type of orders. Technological possibilities of a production system and a manufacturing enterprise evolve on the basis of technological possibilities of machinery. Technological possibilities can be defined as a set of characteristics of the current device, robot, production module or system for performing some technological task. The research about description of technological resources and their technological possibilities is used by competence centre IMECC for developing web-based module for sharing information about technological resources, their availability and use in network manufacturing.
3. Workplace is an important part of the production system. In this paper, a workplace is defined as a combination of machine tool and machine tool operator that together form the simplest man-machine system. Workplace's capability is influenced by: 1) the machine tool operator's skills, knowledge, experiences and motivation influence productivity – how many pieces it is possible to produce during a certain time period using a certain machine with certain technological possibilities and 2) technological possibilities of the machine tool. The machine tool operator's competences and productivity and machine tool's technological possibilities and productivity together determine the workplace's capability and productivity.
4. The technological capability of a production system is formed by technological capabilities of different workplaces belonging to the production system. Through its technological capabilities, technological resources influence nomenclature and complexity of products that can be produced with a certain production system.
5. No company has all resources needed to be successful in today's global market in terms of strong competition. The challenges to achieve competitiveness lie in successful management of the network of cooperating enterprises (supply chain). Through cooperation it is possible to share technological resources and achieve optimal resource allocation for the whole supply chain. The model of integration of the systems demonstrates workplace's place and role in the production system and its importance in network manufacturing. However, network manufacturing brings along certain risks. Common risks in network manufacturing are overdimensioning of resources, lack of cooperative behaviour and teamwork skills, decisions based on insufficient information, competition and intellectual property issues.

3. INFLUENCING THE COMPANY'S PERFORMANCE THROUGH OPTIMIZATION OF THE WORKPLACES' CAPABILITY

3.1. General concept of workplace development

To be competitive, the company's strategy has to be adapted to the changing economic environment. In case of "make to order" production, the company daily faces a high rate of variability (complexity, volume, delivery dates of different orders, customers' wishes to make changes in orders, turbulences due to market situations, unexpected problems with supply chains, lack of competences etc.). All these circumstances and their changes are different to manage and predict. The variability influences the company and shop floor activities every day and therefore there is a need to improve continuously order fulfilment and production system to have adequate feedback for eliminating the bottlenecks and maximising profit. Nowadays manufacturing companies must place their faith in fluid and organic systems, adaptability and continual improvement. The focus has to be concentrated to the workplace which is one organic part of the company and is integrated to the whole through the information and material flows. The emphasis of Lean philosophy is that every team member would take personal responsibility in the continual improvement process. Contrasting attributes of Lean and traditional thinking are presented in Table 3.1 (Bell, 2006).

Table 3.1. Contrasting attributes of Lean and traditional thinking (Bell, 2006)

Attribute	Lean	Traditional
Change management	Organic, incremental and continuous	Engineered and planned by events
Organization	Cross-functional teams	Central command and control
Measures	Top-down and bottom-up performance measures linking improvement initiatives to strategic goals	Cost containment and uptime
Knowledge management	Generalization	Specialization
Education	Process focus	Task focus
Definition of success	Speed and agility	Stability

General concept of the development of workplace and production system in accordance with the organization's development policy is presented in Figure 3.1. Use of Lean philosophy and IT-technologies contribute to the realization of this concept in companies.

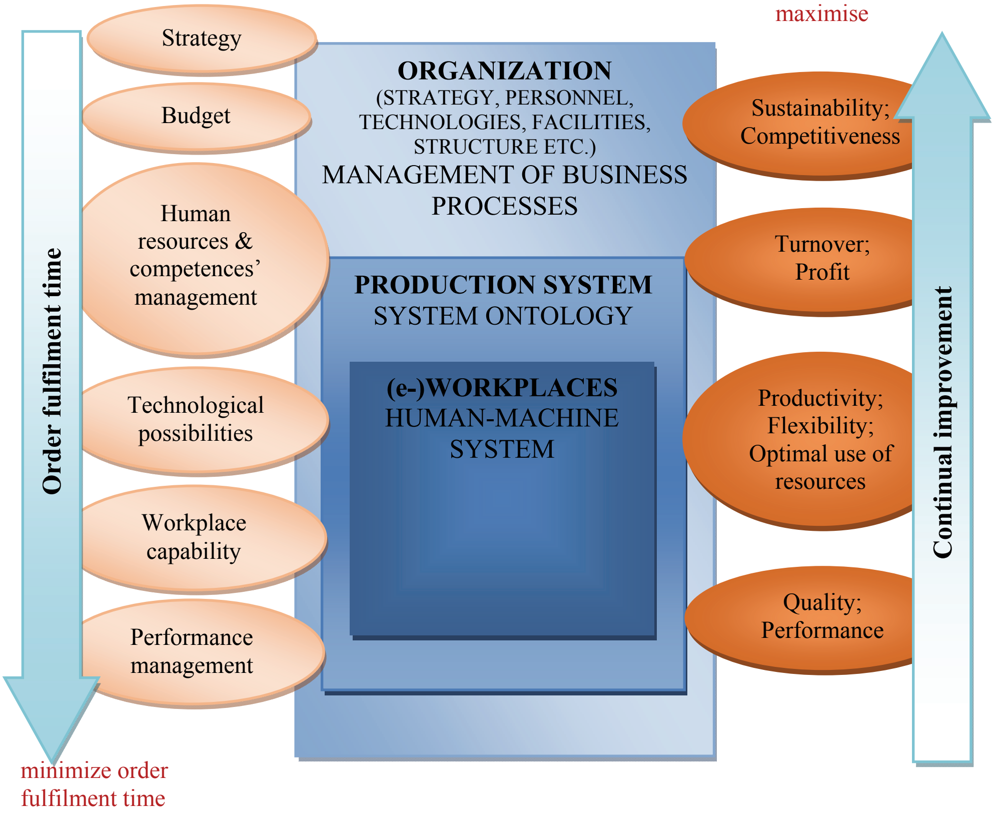


Figure 3.1. General concept of development of a competitive company

Workplace is part of a system (e.g. production system) and implementer of a process (e.g. production process). From the organizational viewpoint, for achieving the competitiveness of a company, it is essential for workplace to perform its tasks as effectively as possible. Thus, all non-productive times during which value is not created (e.g. setup time, transport time, control time, idle time in production process) should be minimised (Lõun, 2010). Technological role of a workplace means exact fulfilment of product's functional and quality requirements with maximum productivity. Technological process and production documentation (work instructions, manufacturing drawing) are basis for successful accomplishment of this task at the workplace. Appropriate strategy, employment of suitable management techniques and workplace capability influence order fulfilment time and possibilities to minimize it (see Figure 3.1).

The most important characteristics of a workplace in a production system are its location, place in the production system, functionality and technological capabilities. Technological possibilities of a machine tool and competences of its operator determine the workplace capability (Riives et al 2004; Uuenduslik tootmine: käsiraamat, 2011). Workplace capability forms the basis for determining which details can be processed at the certain workplace, and creates preconditions for efficient performance (productivity, product's quality, expedient use of work time, accuracy of fulfilment of work tasks etc.). Management theories (Scholtes, 1998) refer to the effectiveness of teamwork; quality management is based on the Deming's Plan (*P*) – Do (*D*) – Check (*C*) – Act (*A*) circle and process management principles (Deming, 1994; Quality Management Systems – Requirements, 2008). According to these theories and the author's practical experiences with implementing quality management systems in different companies, it is clear that the role and importance of every workplace performance plays more and more important role in the effectiveness of a manufacturing company. Main steps in workplace development are presented in Figure 3.2. Workplace development is further described in Paper VI.

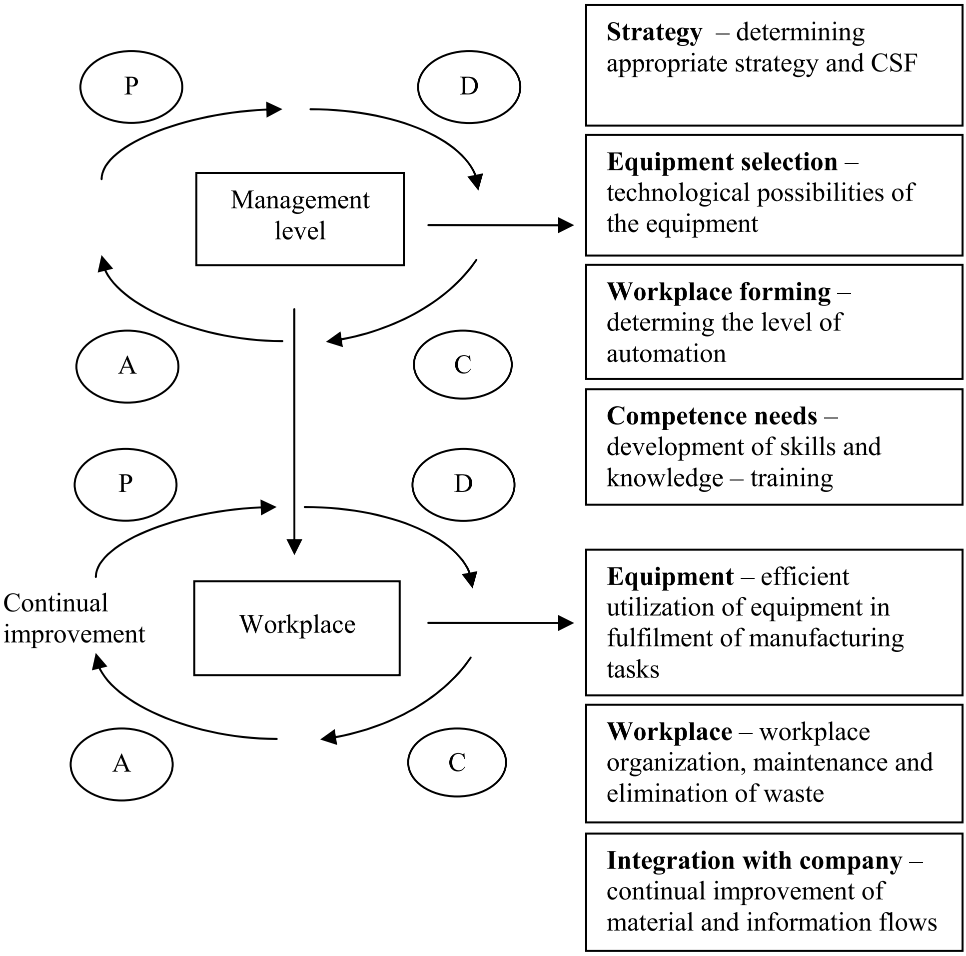


Figure 3.2. Steps in workplace development

3.2. Factors influencing performance of the workplace

Many organizations wonder why they do not perform as effectively as they would like, with assets, employees, and products at hand. Whilst there could be many causes of sub-optimal performance, one is a misalignment between the organization's strategic objectives and its culture and working practices. To deliver an organization's performance potential, it needs the right working practices to be identified and implemented and the right formal organizational structures to exist to reinforce these practices (Austin et al, 2003).

The performance description model on the company level is described in Paper VI. The model consists of three parts:

- Phase of forming company's objectives and tasks;
- Phase of planning activities (for subunits, processes, workplaces etc);
- Phase of estimating results (results of simple events and actions as well as processes, projects or company as a whole).

The aim of the model is to consider a company as a system that is a part of the economic environment and to connect clearly different levels of company activities and theories used for estimating their performance.

There are several possibilities to estimate the level of performance of a workplace and determine the problems. Having identified the problem, it is possible to solve it. Workplace productivity is usually used for estimating workplace success (Lõun, 2010). Although productivity measurement is important, it does not allow estimating adequately the capability of the workplace. The complexity of relations, related to the fulfilment of work tasks and groups of factors having influence to workplace performance are described in Paper VI. Main factors that influence the workplace performance and techniques that could be used for analysing the actual performance of the workplace, find problems and help to solve them, are introduced below (see Figure 3.3).

- ➢ **Organization of the workplace**. Without proper order in the workplace time losses may occur, also variability enabling nonconformities increases. Most known methodologies for workplace improvement are 5S, 20 keys and visual control.
  - 5S is a workplace organization method that helps to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order. 5S phases are (Hirano, 1995; Rubin et al, 1996):
    - Sorting – eliminate all unnecessary items. Keep only essential items and eliminate what is not required. Keep necessary items in easily-accessible places.
    - Setting in order – arrange all items so that they are quick and easy to locate, find, and use. Each thing in its place. This helps to eliminate wasting time for searching or obtaining necessary item.
    - Sweeping or shine – clean the workspace and equipment and keep it clean and organized.

    - Standardizing or systemizing – make it easy to maintain. Create the rules and work standards. All employees doing the same job should be able to work in any station with the same tools. Everyone should know his/her responsibilities.
    - Sustaining the practice – maintain and review standards, use the new practice.
  - 20 keys are 20 focus areas that will help the organization to build a sustainable continuous improvement culture, introduced by I.Kobayashi. The keys cover 5S, quick changeover, scheduling, reducing inventory, maintenance, skill building activities, eliminating waste, value analysis, empowering workers, quality, developing supplier etc. The balance should be kept between the developments of the keys – we should not develop one key without keeping track of the others (Makigami Info, 2013).
  - Visual control is a technique of using visual signals, sometimes combining them with audible sounds to attract attention. The objective of the signals is to allow quick recognition of the information being communicated, in order to increase efficiency and clarity. The signals can be of many forms, e.g. labelled storage board, stop signs etc. (Ortiz and Park, 2010; Shimbun, 1995; Greif, 1991).
- ➢ **Accuracy**. The right materials are available at the right place at the right time at the right amount, work tasks are fulfilled correctly and in time, rules and standards are obeyed and there exist no nonconformities. Just-in-Time (JIT) methodology could be helpful. JIT philosophy has in focus inbound and outbound logistics and inventories. JIT states that storage of unused inventory is waste of resource, but it also defines how inventory is viewed and how it relates to management and relies on other elements in the inventory chain as well (Akkermann, 2004).
- ➢ **Reasons of the problems**. When the system (organization, department, workplace etc.) does not work as it should, the root causes of problems should be clarified to find optimal solutions. Following techniques could be used:
  - 5 Why’s is a question asking technique that helps to identify cause-and-effect relationships in case of a particular problem. The idea is to determine the root cause of a problem by asking why at least five iterations (Serrat, 2009; Bulsuk, 2009).
  - Eight Disciplines Problem Solving (8D) is a problem solving method that follows the logic of Plan-Do-Check-Act (PDCA) cycle and enables to identify the problem, determine its root cause, correct the problem and take preventive actions to avoid similar problems in the future. The eight stages or disciplines used are (Rambaud, 2011):
    D1 – Use a team;
    D2 – Define and describe the problem;
    D3 – Develop a plan;
    D4 – Determine, identify and verify the root cause of the problem;

D5 – Determine corrective actions;
D6 – Implement corrective actions;
D7 – Take preventive measures to avoid the problem in the future;
D8 – Congratulate the team.

- Failure mode and effect analysis (FMEA) – one of the first systematic techniques for failure analysis. FMEA is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service (Rausand and Hoyland, 2004; Quality-One International, 2011; MindTools, 2013).

➢ **Job satisfaction**. Occupational psychologists have long been aware of the link between job satisfaction and job performance. High job satisfaction is associated with greater job performance and hence improving job satisfaction is important. There are several methodologies to measure job satisfaction, e.g. BIAJS, JDI, MSQ, JSS etc. (Thompson and Phua, 2012; Smith et al, 1969; Weiss et al, 1967; Spector, 1994).

➢ **Continual improvement**. Continual improvement is an on-going effort to improve products, services or processes. Some of the most common approaches of continual improvement are Deming's PDCA cycle, Kaizen and EFQM.

- PDCA cycle is also known as Deming's circle/cycle/wheel. Main steps in PDCA cycle are (Bell, 2006; Moen and Norman, 2009; Quality Management Systems – Requirements, 2008):
    - Plan – establish the objectives and processes necessary to deliver results in accordance with the expected output (the target);
    - Do – implement the plan;
    - Check – study the actual results and compare them against the expected results;
    - Act – perform corrective actions, analyse the differences between actual and planned results, and determine where to apply changes that will include improvement of the process of product.

  The PDCA cycle should be repeated continuously for continual improvement.
- Kaizen is a methodology for continual improvement characterised by following aspects (Imai, 1986 and 1997):
    - Improvements are usually based on many small changes;
    - Ideas come from workers, which helps to reinforce teamworking and take responsibility for the work;
    - Implementation of improvement actions usually does not cost very much.
- EFQM excellence model – according to the EFQM Foundation (www.efqm.org), EFQM is the most popular quality tool in Europe, used by over 30000 organizations to improve performance. EFQM model is used for (self) assessment against a set of 9 criteria (leadership; strategy; people; partnerships and resources; processes, products and services; customer results; people results; society results; business results).

Since there are many different techniques, the list above is not final.

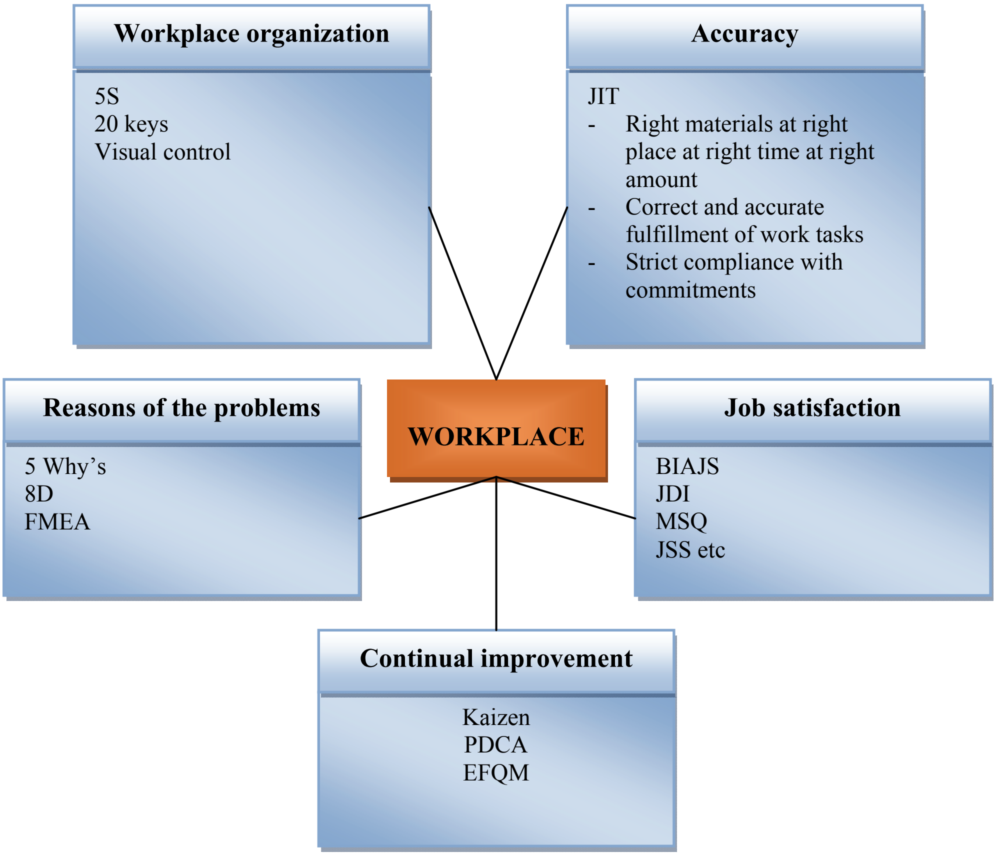


Figure 3.3. Techniques for analysing performance of a workplace

3.3. Optimization of workplace capability in e-manufacturing, high performance workplace design model

Modern manufacturing systems are increasingly required to be adaptable to changing market demands, which adds structural and operational complexity and requires both – a high efficiency and an enhanced adaptability to changing requirements of external environment.

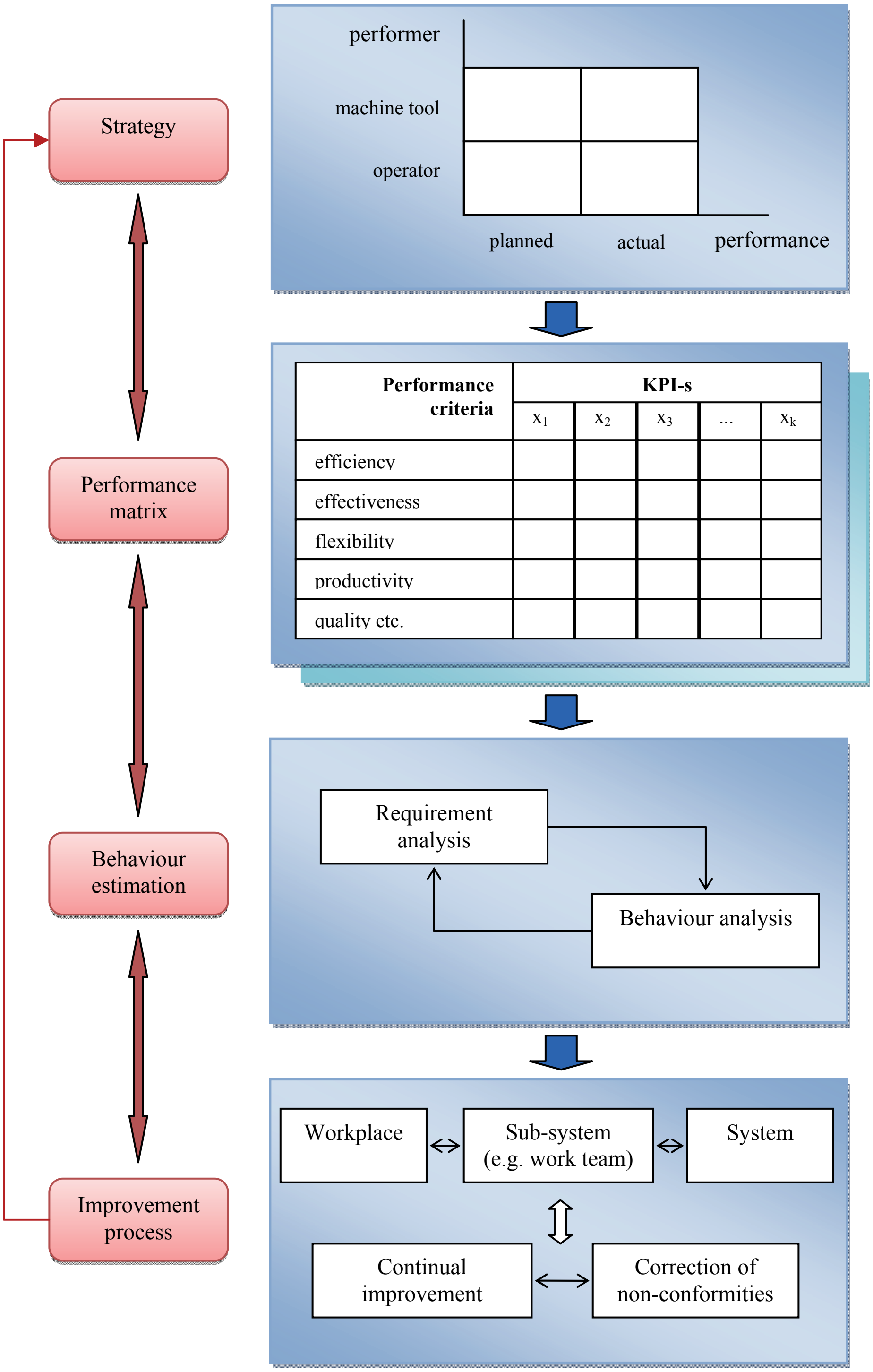
The concept of High-Performance Work Organization (HPWO) has evolved from research into the link between human resource management and organizational performance (Becker and Gerhart, 1996). In such conditions, people in an organization have to change, learn and continuously develop themselves in the quest for high performance and promising future. The high-performance workplace integrates a broad range of technologies, including business intelligence, collaboration support, business process management, content and knowledge management, communications, e-learning, productivity tools, and the physical workplace and related infrastructure (Introducing the High-Performance Workplace, 2005). Gartner, the world's leading information technology research and advisory company, defines a high performance workplace as a physical or virtual environment designed to make workers as effective as possible in supporting business goals and providing value. A high-performance workplace results from continually balancing investment in people, process, physical environment and technology, to measurably enhance the ability of workers to learn, discover, innovate, team and lead, and to achieve efficiency and financial benefit (Gartner, 2013). The conditions that give rise to a HPWO are numerous and inter-dependent. The greater the number of these elements that are developed within an organization, the greater the performance payoffs. Among key elements the following items are mentioned (Baugh, 1994):

- use of all organizational resources to achieve *continuous improvement*;
- acute concern for the *quality* of products and services to satisfy the needs of a consumer-driven marketplace;
- participative, non-authoritarian *management style*, in which workers are empowered to make decisions both at the point of production and at the point of customer contact;
- internal and external *flexibility* to rapidly adjust work processes;
- *positive incentives* including policies which promote an appreciation of how the organization functions as an integrated whole;
- *leading-edge technology* deployed in a manner that extends human capabilities;
- *well-trained, well-educated* employees engaged in continuous learning.

Workplace is connected to a certain system in the company and is a bearer of certain process. The performance of a workplace is a basis for a performance of the system and this in turn influences the performance of the whole company. To achieve an effective and flexible connection between management and workplaces, a model for estimating and improving performance of workplaces has been developed. The model enables to get an overview about the workplace's performance and factors influencing it, but also about the level of realization of the objectives and tasks of the workplace. The model is based on the following conceptual principles which are covered in Paper IV and V:

- Production system ontology;
- Essence of a workplace;
- Workplace capability (technological possibilities and competences);
- Performance interpretation and factors influencing the workplace's performance (productivity, flexibility, effectiveness, efficiency etc.);
- Requirement and behaviour analysis.

Conceptual model of workplace performance improvement is presented in Figure 3.4.



Performance criteria	**KPI-s**				
	x_1	x_2	x_3	...	x_k
efficiency					
effectiveness					
flexibility					
productivity					
quality etc.					

Figure 3.4. Conceptual model of workplace performance improvement

The techniques described in the previous section (see Figure 3.3) help to determine the situation regarding the factors influencing the performance of the workplace. Once the situation is ascertained, it is possible to improve it. Measurable indicators can be categorized as follows (Parmenter, 2010):

- Quantitative indicators, which can be presented as a number;
- Practical indicators that interface with the existing company processes;
- Directional indicators, specifying whether an organization is getting better or not;
- Actionable indicators, which are sufficiently in organization's control to effect the change;
- Financial indicators, used in performance measurement and for checking an operating index.

In the shop floor, planning meets processes. In addition to qualitative measures (see Figure 3.3) also quantitative indicators can be used. Productivity is the ratio between the system's (e.g. workplace) outputs (e.g. product, details) and inputs used to obtain these outputs. The productivity of the workplace indicates the number of outputs obtained using a certain amount of inputs. Although productivity measurement is important, it alone does not enable an adequate estimation of workplace capability. Technological capability of a workplace determines framework what nomenclature of products and how efficiently it is possible to manufacture there. Key performance indicators (KPIs) represent a set of measures focusing on the aspects of organizational and individual performance that are critical for the success of the organization (Ran and Wang, 2008; Ran et al, 2008). KPIs can be used to assess almost any aspect of work performance, depending on an individual organization's design. KPIs are typically tied to an organization's overall strategy and they differ according to the nature of the organization and its strategy (Wang et al, 2010). Derived from the organizational KPIs, the KPIs for each business unit (e.g. production system) are specified. Based on the unit KPIs, the KPIs for each workplace within the unit are then defined (Parmenter, 2010). KPIs characterizing a production system performance were presented in Figure 2.5. Additional KPIs can be used to measure the workplace performance. As the KPIs used must be in accordance with the company's strategy and CSFs, every company's KPIs are different, but as the main objective in all companies is to eliminate waste and improve performance that usually results in lower net cost and higher competitiveness, the most common indicators suitable for every engineering company are presented in Table 3.1. As there are hundreds of KPIs, the list is not final, but the author's subjective opinion about KPIs most suitable and common for every manufacturing company.

Table 3.1. Critical success factors and respective KPIs for a workplace

Critical success factor	Key performance indicators
Safety and reliability	• Number of accidents and complaints per unit of time (e.g. in a year) • Lost days due to illness or work accident per unit of time • Lost hours when no processing takes place due to equipment malfunction per unit of time
Quality	• Number of scrap details in the whole number of processed details at the workplace per unit of time • Percentage of total product produced at the workplace, sold and shipped subject to recalls and reclamations due to quality problems • Number of products related complaints received per unit of time • Number of nonconforming units discovered in-house per unit of time
Training and development	• Average training hours per employee (operator) per unit of time • Number of trainings where worker participated per unit of time • Training expenditure spend on the worker per unit of time
Productivity	• Number of details processed per unit of time
Effectiveness	• Overall equipment effectiveness (OEE) • Total effective equipment performance (TEEP) • Percentage of manufacturing time in production time at the workplace • Percentage of idle time in production time at the workplace • Percentage of machining time of total production time • Percentage of operations fulfilled on time of total number of operations in workplace per unit of time
Efficiency	• Rate of damaged material by the error of worker to total material processed, measured by the number and/or value of money • Sales turnover per worker
Flexibility	• Percentage of setup time in production time • Nomenclature of product that can be produced at the workplace

Monitoring of KPIs has to be a repetitive action and trends have to be monitored and estimated continually. Target values have to be set for the indicators and it has to be estimated, whether the expected results have been achieved. After having estimated KPIs for a certain period, tolerances can be set between acceptable results. KPIs and their achievement or non-achievement should be communicated clearly to staff. Additionally, KPIs should be connected with motivation system.

The main operations of a production process where value is created are manufacturing and assembly (Lõun, 2010). Non-productive operations occur with manufacturing process (see Figure 3.5) and are unavoidable, but nevertheless, every company's aim is to minimize time during which value is not created. Indicators and formulas used for analysis of effectiveness of a workplace, manufacturing system and process are described in greater detail in Paper VI.

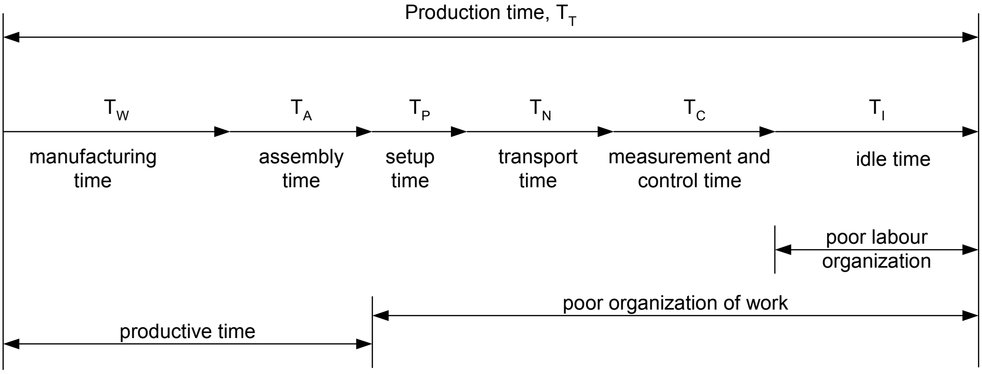


Figure 3.5. Components of production time (Lõun, 2010)

Requirement loop (Figure 3.4) has to assure that in the planning phase workplace is provided with products that are appropriate for processing at this workplace both technologically (product dimensions, complexity, precision, batch size etc. i.e. product processing needs are in correlation with the technological possibilities of the machine tool) and by competences (operator's competences, experiences, personal qualities etc. i.e. ability to use the technological possibilities of the machine tool in accordance with requirements described in the product's technical documentation). Behaviour loop has to assure fulfilment of planned tasks and expected outcome. Tasks are usually described in production documentation (procedures, instructions, work orders, drawings etc.). Performance indicators result from company's strategy and tasks set.

The performance improvement process formation is based on As-Is and To-Be modelling. As-Is modelling is used for process analysis. The determination of the current situation is the basis for identifying weaknesses and for determining potential improvements. Existing processes and systems have to be identified prior to modelling in order to obtain an overview of the domain under consideration. To-Be modelling is the basic for process optimization. To-Be modelling is carried out on the basis of As-Is models. The results of To-Be modelling and the evaluated To-Be processes are linked with inwardly aligned expectations from both management and employees. To-Be modelling is strictly connected to the continual improvement process (Becker et al, 2011). In To-Be modelling both applications top-down and bottom-up approach are used. In a top-down approach, core processes are identified starting from the services consolidated through the strategic business fields (Sommerlatte and Wedekind, 1991). The bottom-up approach is based on the entirety of all activities in the company planned in the To-Be stage. Important part in modelling process is distinction between substantial and insubstantial factors and taking into account different factors and their effects (Rosemann and Green, 2000). Determining problems is the task of As-Is modelling while To-Be modelling is directly connected with performance optimization.

3.4. Conclusions

1. Workplace is a part of a system (e.g. production system) and implementor of a process (e.g. production process). From the organizational viewpoint, for achieving the competitiveness of a company, it is essential that every workplace performs its tasks as effectively as possible. Thus, all non-productive times during which value is not created (e.g. setup time, transport time, control time, idle time in production process) should be minimised. Appropriate strategy, employment of suitable management techniques and workplace capability influences order fulfilment time and possibilities to minimize it. General concept of development of a competitive company and workplace's role in it was presented as well as steps in the workplace development.
2. The main factors which influence the performance of the workplace are organization of the workplace, accuracy, awareness of the problems and their reasons, job satisfaction and continual improvement. Techniques that can be used for determining and solving problems in the workplace were grouped according to these factors and described. However, as there is a large number of different techniques covering a wide area, the appliance of a certain technique depends on the particular case and the character of the problem. In the current thesis only a brief overview of the main techniques was introduced.
3. Common KPIs to assess workplace performance were presented. As there are hundreds of KPIs and set up of KPIs for every workplace must depend on the KPIs of production system, KPIs of the company and considering the company's strategy, the KPIs presented represent the author's subjective opinion about the most common and widely usable KPIs

suitable for every manufacturing company. Monitoring of KPIs has to be a repetitive action and trends have to be monitored and estimated continually.

4. Structure and essence of the production system depend on the strategy, including the choice of machine tools, automation rate etc. As it was shown in the conceptual model, the improvement of the workplace performance must take into account the company's strategy, performance monitoring and measurement using KPIs and appropriate techniques to determine the performance of the workplace, behaviour estimation using requirement analysis and behaviour analysis and improvement process based on Deming's PDCA circle and As-Is and To-Be modelling. Workplace performance improvement model is universal. The interpretation of results and the choice of improvement techniques depend on the strategy of the company.

GENERAL CONCLUSIONS

As the researches (Gans and Kokla, 2011; Varblane et al, 2011; Eesti ettevõtete suunalise uuringu raport, 2008; HeiVäl Consulting and the project expert group, 2011) demonstrated, in case of Estonian companies the problem does not primarily lie in lack of modern equipment or novel technologies but in the lack of competences of workers and engineers and labour productivity, as well as insufficient cooperation between companies. The main objective of the thesis was the development of a concept and models for improving performance of the workplace to raise competitiveness and sustainability of the company.

Main results of the research and thesis:

- New business models for SMEs of engineering industries were proposed, proceeding from company's strategy and its connections to the company's innovation and development policy. Positioning the company's performance and benchmarking is the basis for a business model.
- A model of technological resources and technological capability was created to help to determine workplace's capability in (e-)manufacturing environment.
- Model of workplace capability is escalated from workplace to the whole manufacturing system capability.
- A concept of effective use of technological resources in network manufacturing SMEs and basis for developing respective (e-manufacturing) information system was developed.

The generalised conclusions of this thesis are the following:

1. Organization is an entire system the performance of which depends on the appropriate strategy corresponding to the changes in external environment and economic situation, and different factors determined by the strategy, especially competences, production system and business models.
    - Competences, production system and business models influence the level of quality, productivity and reputation of the company that in turn influence the company's sustainability and competitiveness.
    - Strategy determines the development of competences and technological resources, appropriate level of automation, employment of new technologies and business models, and usage of cooperation or network activities.
2. Production system supported by different tools is the main part of every manufacturing company which may be independent or be a part of some manufacturing network. Production system ontology helps to understand connections in the production system and thus improve performance. The structure of a production system and its attributes determine technological possibilities of the production system and also preconditions for fulfilling certain type of orders. Technological possibilities of a production system and a manufacturing enterprise evolve on the basis of technological possibilities

of machinery. Technological possibilities can be defined as a set of characteristics of a device, robot, production module or system for performing a technological task.

3. In this paper, a workplace is defined as a combination of machine tool and machine tool operator that form together the simplest man-machine system. Technological possibilities of a machine tool and competences, experiences and motivation of the operator together form technological capability of the workplace. Technological capability of a production system is formed by technological capabilities of different workplaces belonging to the production system. Through its technological capabilities, technological resources influence nomenclature and complexity of products that can be produced with a certain production system.
4. No company has all resources needed to be successful in today's global market in terms of strong competition. The challenges to achieve competitiveness lie in successful management of the network of cooperating enterprises (supply chain). Through cooperation it is possible to share technological resources and achieve optimal resource allocation for the whole supply chain. Model of integration of the systems (Figure 2.8) demonstrates workplace's place and role in production system and its importance in network manufacturing. The most common risks in network manufacturing are overdimensioning of resources, lack of cooperative behaviour and teamwork skills, decisions based on insufficient information, competition and intellectual property issues (Table 2.1).
5. As presented in the model of general development of a competitive company (Figure 3.1), workplace is a part of a system (e.g. production system) and implementer of a process (e.g. production process). In the organizational viewpoint, for achieving the competitiveness of a company, it is essential that every workplace performs its tasks as effectively as possible. Thus, all non-productive times during which value is not created in production process have to be minimised. Appropriate strategy, employment of suitable management techniques and workplace capability influences order fulfilment time and possibilities to minimize it.
6. Conceptual model of workplace performance improvement (Figure 3.4) takes into account the company's strategy, performance monitoring and measurement using KPIs and appropriate techniques to determine the performance of the workplace, behaviour estimation using requirement analysis and behaviour analysis and improvement process based on Deming's PDCA circle and As-Is and To-Be modelling. Workplace performance improvement model is universal.
   - The main factors influencing the performance of the workplace are organization of the workplace, accuracy, awareness of problems and their reasons, job satisfaction and continual improvement. The main techniques that can be used for determining and solving problems in the workplace were grouped and described according to these factors (Figure 3.3). However, as there is a large number of different techniques covering

wide area, their usage has to be determined in every particular case and depends on the character of the problem. In the current thesis only a brief overview of the main techniques was presented.

- To monitor and measure the performance of the company, production (or some other sub-system) and/or workplace, CSFs derived from the strategy has to be determined as well as KPIs for every level. Set up of KPIs for every workplace must depend on the KPIs of production system, KPIs of the company and consider the company's strategy. Common KPIs to assess performance of the production system were presented in Figure 2.5 and KPIs for workplace performance were presented in Table 3.1. Monitoring of KPIs has to be a repetitive, continual action.
- The interpretation of results and usage of improvement techniques depend on the strategy.

Significance of the research and its importance to the companies and industry

1. Results of the research about human resources competences and their influence on the productivity were used in INNOMET-EST project for creating a database for measuring needed and actual level of competences of the workforce available for companies. Results of the research about productivity, sustainability and competitiveness were used in INNOMET-EST project for creating a methodology for comparative analysis of companies regarding their productivity, sustainability and competitiveness. The methodology can also be used by each individual company for self-assessment and positioning.
2. Results of the research about description of technological resources are used by competence centre IMECC for creating a web-based test-version of technological resources data-base. This database can be further developed as web-based exchange market of currently available technological resources and be used in network manufacturing.
3. Large number of projects regarding the research topic demonstrates the necessity of the research. The main results of the projects are introduced to representatives of Federation of Estonian Engineering Industry, Association of Mechatronics and IMECC to contribute to the development of engineering industry.
4. The developed models and concepts apply both to individual companies as well as network manufacturing. The current solution is focused on the sector of metalworking, machinery and apparatus engineering. The proposed model can be transferred also to other industrial sectors (wood processing, chemical industry, construction materials industry, etc.).

Further research

Some concepts and results of the research are in testing phase and further development in competence centre IMECC and its partner companies will be conducted.

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Kaia Lõun

Tallinn, 2013

ABSTRACT

Engineering industry is one of the leading branches of Estonian industry. The economic crisis in 2008–2010, ever-increasing competition, globalization and need to react quickly to changing needs of customers have enforced companies to consider possibilities of improving their performance. One of the challenges for Estonian companies would be applying research intensive subcontracting and manufacturing own products that would help to increase value added. As most Estonian engineering companies are micro, small and average sized companies (SMEs), there exists a strong need for cooperation and networking between companies.

This PhD thesis "Company's Strategy based Formation of e-Workplace Performance in the Engineering Industry" is based on published articles included also in the current thesis. The research was carried out in tight cooperation with industry, Tallinn University of Technology, competence centre IMECC and other institutions through various projects with involvement of the author of this PhD thesis during several years. Obtaining knowledge about process management, quality issues, continual improvement and every single employee's role in the company's performance can be traced back to the year 1999 when the author started with elaboration and implementation of quality management projects in various different companies. The majority of the research was carried out during years 2007–2013 in the framework of various projects (e.g. INNOMET-EST, INNOREG, e-manufacturing projects etc.).

Novelty of the research:

- **Principles for improving workplace and production system performance** are connected with the company's competitiveness development strategy. Workplace and its optimization are considered as a basis (basic level) for company's performance improvement.
- **Factors that influence the workplace's performance** are presented and they demonstrate that the impact of the workplace's performance to the whole company exists through the processes and systems which the workplace is related to. **Mutual connections** between workplace, production system, processes, company strategy and networking issues are analysed, as well as relations and comparisons between planned and achieved results with an aim to detect reasons of nonconformities and through implementation of the improvement actions eliminate quickly negative impact factors.
- **The model for workplace performance optimization** has been developed based on the importance of the workplace in the manufacturing system and company, methodology to evaluate the workplace's performance and networking issues.
- **The proposed approach** enables matching of manufacturing tasks and manufacturing system resources based on their required and provided

capabilities and supports rapid allocation of resources and effective use of the systems.

The main objective of this research was the development of concept and models for improving performance of the workplace to raise competitiveness and sustainability of the company.

The thesis consists of three chapters. In the first chapter factors influencing performance and outcome of a company were described, as well as methodologies developed in the framework of INNOMET-EST project for comparative analysis and company positioning. Importance of the company's strategy in formation of the company's competitiveness and sustainability was demonstrated and new business models and e-manufacturing described. Organizational performance model was developed and described. Organization's performance depends on the strategy appropriate to economic situation and environment. Strategy determines which competences should be developed, which business models and techniques employed and how the production system should be developed. Business models, production system and competences form basis for productivity and quality which in turn determine the competitiveness and sustainability of the company.

The second chapter describes integration of a workplace to the production system in terms of network manufacturing. Essence and ontology of a production system were presented. Production system ontology presents production system and its components and their mutual relationships and helps to understand connections in the production system, thus improving the performance. Workplace which is a direct unit where value is created to the product is regarded in the current thesis as a man-machine system. Technological possibilities of a manufacturing enterprise evolve on the basis of technological possibilities of machinery. Technological possibilities of a machine tool and competences, experiences and motivation of an operator together form technological capabilities of a workplace and determine which details can be processed and which orders fulfilled at that workplace. Technological capabilities of all workplaces belonging to the production system determine the system's technological capabilities. Mathematical model for determining numerically technological resources was presented. The research about description of technological resources and their technological possibilities is used by competence centre IMECC for developing web-based module for sharing information about technological resources, their availability and use in network manufacturing. Model of workplace and its integration to the production system and network was developed and determined its importance in company performance. Workplace with higher capability enables to produce wider nomenclature of products, achieve higher flexibility and shorter delivery times. In case of network manufacturing, it is possible to develop workplaces in network of companies to achieve higher efficiency and effectiveness and better results integrated in the network.

The third chapter describes influencing the company's performance through optimization of the capability of single workplaces. For achieving the competitiveness of a company, every workplace has to perform its tasks as effectively as possible. Concepts for development of a workplace and a competitive company were presented. The main factors which have influence on the performance of the workplace are organization of the workplace, accuracy, awareness of problems and their reasons, job satisfaction and continual improvement. Techniques that can be used for determining and solving problems in the workplace were grouped according to these factors and described. KPIs for every workplace in production unit must depend on the KPIs of the production system which in turn have to consider KPIs of the company. KPIs of the company should take into account the strategy of the company. The commonest KPIs for producing workplaces were presented. Monitoring of KPIs must be a repetitive action and trends have to be monitored and estimated continually. Conceptual model of workplace performance improvement was developed and presented. The model takes into account the company's strategy, performance monitoring and measurement using KPIs and appropriate techniques to determine the performance of the workplace, behaviour estimation using requirement analysis and behaviour analysis and improvement process based on Deming's PDCA cycle and As-Is and To-Be modelling.

As a **result** of this thesis:

- New business models for SMEs of engineering industries were proposed, proceeding from company's strategy and its connections to the company's innovation and development policy. Positioning the company's performance and benchmarking are the basis for the business model.
- A model of technological resources and technological capability was created to help to determine workplace capability in (e-)manufacturing environment.
- Model of workplace capability is escalated from workplace to the whole manufacturing system capability.
- A concept of effective use of technological resources in network manufacturing SMEs and basis for developing respective (e-manufacturing) information system was developed.

The developed models and concepts were developed for engineering industry, but they can be transferred also to other industrial sectors.

Keywords: workplace, performance, company, strategy, competitiveness, sustainability, e-manufacturing, production system, ontology, resource allocation.

KOKKUVÕTE

Masinatööstus on üks Eesti juhtivaid tööstusharusid. Majanduskriis aastatel 2008–2010, üha suurenev konkurents, globaliseerumine ja vajadus reageerida kiiresti klientide muutuvatele nõudmistele on sundinud ettevõtteid üha enam mõtlema võimalustele parandada oma tulemuslikkust. Üks võimalusi Eesti ettevõtetele oleks liikuda teadmusmahuka allhanke ja oma toodete suunas, mis aitaks kaasa lisandväärtuse kasvule. Kuna enamik Eesti masinatööstuse ettevõtteid on mikro-, väikese ja keskmise suurusega ettevõtted, siis see tingib tugeva vajaduse ettevõtetevahelise koostöö järele.

Käesolev doktoritöö "E-töökoha võimekuse kujundamine lähtuvalt masinatööstusettevõtte tegevusstrateegiast" baseerub avaldatud artiklitel, mis on lisatud tööle. Uurimistöö viidi läbi mitmete aastate vältel tihedas koostöös tööstuse, Tallinna Tehnikaülikooli, tehnoloogiaarenduskeskusega IMECC ja teiste asutustega mitmete projektide raames, milles töö autor osales ühe vastutava teostajana. Teadmiste kogumine protsesside juhtimise, kvaliteedi teemade, pideva parendamise ja töötaja rolli kohta ettevõtte tulemuste saavutamisel algas juba 1999. aastal kvaliteedijuhtimissüsteemide väljatöötamise ja juurutamisega erinevates ettevõtetes. Suurem osa uurimistööst viidi läbi aastatel 2007–2013 erinevate projektide raames (nt. INNOMET-EST, INNOREG, e-tootmise projektid jm.).

Uurimistöö uudsus seisneb eeskätt järgnevas:

- **Põhimõtted töökoha ja tootmissüsteemi tulemuslikkuse parendamiseks** on seotud ettevõtte konkurentsivõime arendamise strateegiaga. Töökoht ja selle optimeerimine on aluseks ettevõtte tulemuslikkuse parandamiseks.
- On esitatud **tegurid, mis mõjutavad töökoha tulemuslikkust,** ja näidatud, et töökoha tulemuslikkusel on mõju kogu ettevõttele läbi protsesside ja süsteemide, milles antud töökoht osaleb või millega ta seotud on. Eksisteerivad vastastikused seosed töökoha, tootmissüsteemi, protsesside, ettevõtte strateegia ja koostöö vormide vahel. Planeeritud ja saavutatud tulemusi tuleb hinnata ning läbi parendustegevuste elimineerida negatiivsed mõjufaktorid.
- **Mudel töökoha tulemuslikkuse optimeerimiseks** lähtub töökoha tähtsusest tootmissüsteemis ning töökoha tulemuslikkuse hindamise metodoloogiast ja koostöövormidest.
- **Esitatud lähenemine** võimaldab tootmisülesannete ja tootmissüsteemi ressursside omavahelist sobitamist lähtuvalt nende võimekusest ning toetab kiiret ressursside jagamist ja süsteemide efektiivset kasutamist.

Käesoleva töö **põhieesmärk**: välja töötatud kontseptsioon ja mudelid töökoha tulemuste parendamiseks, mis vastavad ettevõtte arengustrateegiale ja toetavad ettevõtte konkurentsivõime ja jätkusuutlikkuse saavutamist võrgustikus tootmise tingimustes.

Käesolev doktoritöö koosneb kolmest peatükist. Esimeses peatükis on kirjeldatud ettevõtte tulemuslikkust mõjutavaid faktoreid ning metoodikat võrdlevaks analüüsiks ja ettevõtte positsioneerimiseks, mis töötati välja INNOMET-EST projekti raamistikus. Samuti kirjeldati väliskeskkonna ja selle muutustele vastava ettevõtte strateegia tähtsust ettevõtte konkurentsivõime ja jätkusuutlikkuse saavutamisel ning kirjeldati uudseid ärimudeleid ja e-tootmist, mida tänapäevases kiirelt muutuvas keskkonnas on võimalik kasutada. Esitatud on ettevõtte tulemuslikkuse mudel. Ettevõtte tulemuslikkus sõltub majandusoludele ja väliskeskkonnale vastavast strateegiast. Strateegia peab määratlema, milliseid kompetentse tuleks arendada, milliseid ärimudeleid ja tehnikaid kasutada ning millises suunas ja kuidas arendada tootmissüsteemi. Ärimudelid, tootmissüsteem ja kompetentsid moodustavad baasi tootlikkuse ja kõrge kvaliteedi saavutamiseks, mis omakorda on aluseks ettevõtte konkurentsivõime ja jätkusuutlikkuse saavutamisele.

Teises peatükis on kirjeldatud töökoha integratsiooni tootmissüsteemi võrgustikus tootmise tingimustes. Esitatud on tootmissüsteemi olemus ja ontoloogia. Tootmissüsteemi ontoloogia kirjeldab tootmissüsteemi ja selle komponente ning nende omavahelisi vastastikuseid seoseid ning aitab mõista seoseid tootmissüsteemis ning seeläbi parendada tootmissüsteemi tulemuslikkust. Töökohta, mis on vahetu tootele väärtuse loomise üksus, käsitletakse käesolevas töös kui inimene-masin süsteemi. Tootmisettevõtte tehnoloogilised võimalused baseeruvad tööpinkide tehnoloogilistel võimalustel. Seadmete tehnoloogilised võimalused ning tööpingi operaatori kompetentsid, kogemused ja motivatsioon koos moodustavad töökoha tehnoloogilise võimekuse ning määratlevad, milliseid detaile on võimalik töödelda ja milliseid tellimusi täita antud töökohal. Tootmissüsteemi kuuluvate töökohtade tehnoloogiline võimekus määratleb tootmissüsteemi tehnoloogilise võimekuse. Töötati välja matemaatiline mudel tehnoloogiliste ressursside optimaalse arvu määratlemiseks. Tehnoloogiliste ressursside kirjeldamise mudelit on kasutatud IMECCis veebipõhise võrgustikus tehnoloogiliste ressursside jagamise mooduli arendamiseks. Välja on arendatud töökoha tootmissüsteemiga integreerimise alane mudel ja määratletud töökoha roll ettevõtte tulemuslikkuse saavutamisel. Suurema tehnoloogilise võimekusega töökohad võimaldavad toota laiemat toodete nomenklatuuri, saavutada kõrgemat paindlikkust ja lühemaid tellimuse täitmise aegu. Võrgustikus tootmise puhul on võimalik arendada töökohti ettevõtete võrgustikus saavutamaks kõrgemat tõhusust ja efektiivsust ning paremaid tulemusi läbi koostöövõrgustiku.

Kolmandas peatükis on kirjeldatud ettevõtte tulemuslikkuse mõjutamist läbi üksikute töökohtade võimekuse optimeerimise. Ettevõtte konkurentsivõime saavutamiseks peab iga töökoht toimima nii efektiivselt kui võimalik. Esitatud on töökoha ja konkurentsivõimelise ettevõtte arendamise kontseptsioonid. Peamised faktorid, mis mõjutavad töökoha toimivust, on töökoha organiseeritus, täpsus, probleemidest ja nende põhjustest teadlikkus, tööga rahulolu ja pidev parendamine. Selleks, et töökoha tulemuslikkust parendada on vaja teada hetkesituatsiooni. Käesolevas töös on kirjeldatud tehnikaid määratlemaks ja lahendamaks probleeme töökohal, grupeerituna eelnimetatud faktorite kaupa. Iga tootmistöökoha jaoks määratletud tegevuse tulemuslikkuse võtmenäitajad peavad olema kooskõlas tootmissüsteemi tulemuslikkuse võtmenäitajatega, mis omakorda peavad olema seotud ettevõtte tulemuslikkuse võtmenäitajatega. Ettevõtte tulemuslikkuse võtmenäitajad peavad arvestama ettevõtte strateegiat. Töös on esitatud tootmistöökohale sobivad tulemuslikkuse võtmenäitajad, mida on võimalik kasutada enamikus tootmisettevõttes. Võtmenäitajate jälgimine ja hindamine ning selle alusel parendusotsuste vastuvõtmine peaks olema korduv tegevus. Välja on töötatud kontseptuaalne töökoha toimivuse parendamise mudel, mis võtab arvesse ettevõtte strateegiat, toimivuse jälgimist ja mõõtmist, kasutades võtmenäitajaid ja asjakohaseid tehnikaid, käitumise hindamist kasutades tegeliku olukorra ja vajaduste analüüsi ning parendusprotsessi, mis baseerub Demingi PDCA tsüklil.

Töö tulemused:

- Välja on pakutud uudsed mudelid masinatööstuse valdkonna väike- ja keskmise suurusega ettevõtetele, mis tulenevad ettevõtte strateegiast ja selle seostest ettevõtte innovatsiooni- ja arengupoliitikaga. Ärimudelite aluseks on ettevõtte tulemuslikkuse positsioneerimine ja võrdlev analüüs.
- Loodud on tehnoloogiliste ressursside ja tehnoloogilise võimekuse mudel, mis aitab määratleda töökoha võimekust (e-)tootmissüsteemis.
- Töökoha võimekuse mudel on eskaleeritud töökohalt tootmissüsteemi võimekusele.
- Väike- ja keskmise suurusega ettevõtetele on välja arendatud kontseptsioon tehnoloogiliste ressursside kasutamiseks võrgustikus tootmises, mis on aluseks vastava (e-tootmise) infosüsteemi loomisele.

Mudelid ja kontseptsioonid on välja töötatud lähtuvalt masinatööstuse valdkonnast, kuid neid on võimalik kasutada ka teistes tootmisega tegelevates tööstusharudes.

Märksõnad: töökoht, tulemuslikkus, ettevõte, strateegia, konkurentsivõime, jätkusuutlikkus, e-tootmine, tootmissüsteem, ontoloogia, ressursside jaotus.

Paper I

Riives, J., Otto, T., Lõun, K. (2007). Methods for enhancing productivity and work efficiency in the workshop. *Journal of Machine Engineering*, 7, 2, 86–95.

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monitoring, human resource management, expert tool, process planning, productivity, eManufacturing

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METHODS FOR ENHANCING PRODUCTIVITY AND WORK EFFICIENCY IN THE WORKSHOP

The use of computer numerical controls (CNC) enables to the transfer the set-up function from the machinists to computer programmers and manufacturing engineers. The workshop productivity increasingly depends on skills and knowledge of whole workshop team. Different equipment and competencies are needed depending on complexity of production. The humans' impact on productivity and the methods for enhancing the productivity and efficiency of work in the machinery workshop environment are described in this paper. The data covering 75 Estonian metalworking and machinery companies has been analyzed. A novel expert tool is introduced, where during the evaluation guess values are assigned onto machinery, products, and staff members of the workshop, reflecting existing and needed levels of competence and machinery, thus helping further process planning.

1. INTRODUCTION

Nowadays production is characterized by large number of orders, continually shortening order times, rise in prices of the resources, and customers' higher demands to quality. This means that pressure to the companies to survive and to be successful. For that reason companies should continually search for possibilities and methods to assure its competitiveness. Productivity is one of the key factors affecting the overall competitiveness of a company.

Productivity can be managed on national, sector or enterprise level. In the enterprise level there are also different possibilities for productivity management, e.g. different measures of productivity can be used or different levels regarded. In this paper parameters influencing productivity on workshop level are analysed, taking under main consideration labour, equipment, and work organization methods, and how these factors influence productivity of workshop.

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2. BASIS FOR PRODUCTIVITY

2.1. ORGANIZATION'S STRUCTURE AND MANAGEMENT

A company is a technologically and legally independent organizational system that uses labour and equipment for manufacturing products or rendering services that respond to special demands. This organizational system is the best described by its structure. The company's structure has to be expedient for realizing business chain in the company. Business chain realizes through the organization's structure. The company's strategy determines the essence of the realization of the business chain and therefore the company's structure (see Fig. 1).

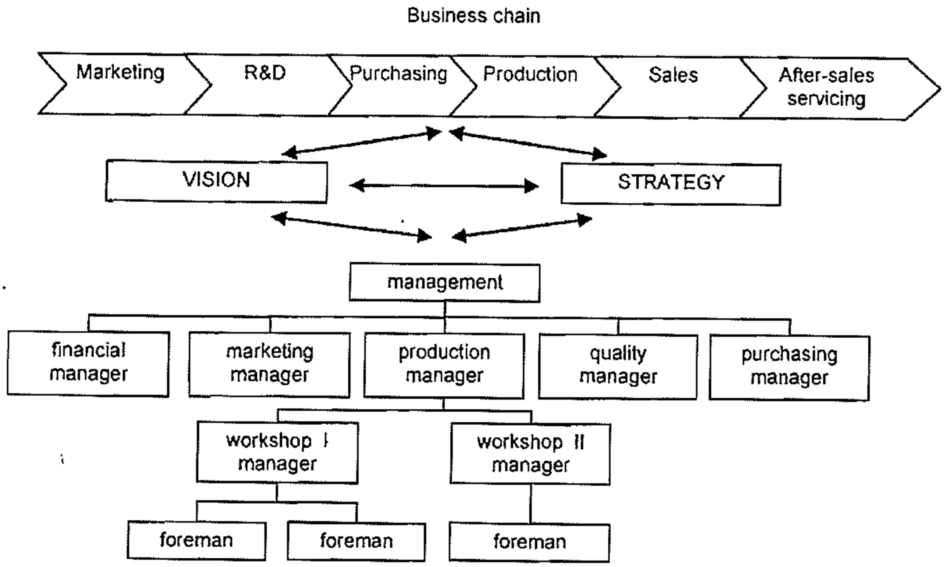


Fig. 1. Business chain as carrier of the company's strategy

2.2. ORGANIZATION AS A SYSTEM

According to the system approach, system is defined in a following way:

- System is a whole that is constitutive of many components (parts);
- System (sub-system) has definable objective;
- Every part of the system contributes to the achievement of the system's objective, but none of the parts is capable to achieve this objective unwittingly or separately;
- Every part has its own objective, but affecting the total system, it depends on other parts. Thus, the parts of the system are mutually dependent;

- It is possible to understand or evaluate single part by its suitability to the system as a whole. But we cannot understand the system by exploring all its parts separately, without forming a whole of them;
- Study about the co-operation of the parts could help us understand, how the system works, but to understand, why this system exists, we have to look outwards the system;
- Looking at the organization, we look at complex social, as well as technical system [4].

Without determining the objective of the system, it is not possible to determine whether the system functions well, poorly or not at all. Company with its fixed structure, departments and management schemes fulfils established objectives in the process of transforming inputs to outputs in effective and efficient way. As presented in Fig. 2, transformation processes proceed by fixed operating processes that take places in different departments [2]. The system can be thought of as a transformation T on inputs I which produces outputs O, this input-output relationship is expressed symbolically by means of the following equation (1):

$$T(I) = O \quad \text{or} \quad T : I \rightarrow O \tag{1}$$

where T – transformation; I – input; O – output.

Focusing on this equation (1) and Fig.2, questions concerning a system usually fall into one of the following categories:

a) System analysis: Clarify contents of T, I, and O;
b) System operation: Given T and I, find O;
c) System inversion: Given T and O, find I;
d) System synthesis or identification: Given I and O, determine a suitable T;

System optimisation: Pick I, O, or T so that a specified evaluation criterion is optimised.

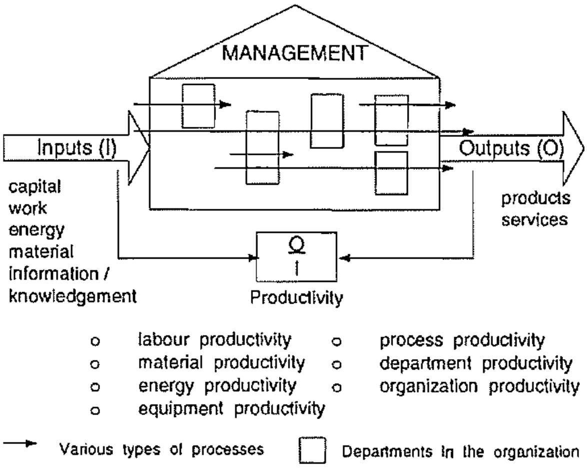


Fig. 2. Organization as a system with measurable value

Departments are the most important elements of the company's structure. Departments may be comprised of some subunits, e.g. various workshops may belong under manufacturing department. These subunits usually have different functional tasks; workshops may have different technological capabilities and automation level.

3. PRODUCTIVITY ON WORKSHOP LEVEL

Productivity on workshop level is largely influenced by following three factors:

1) machine tools used;
2) work organization and management in the workshop and in the company;
3) human resources, employees performing certain tasks.

As follows, influence of these factors to productivity on workshop level is investigated.

3.1. ESSENCE OF PRODUCTIVITY

Productivity is one of the key factors affecting the overall competitiveness of a company. Although the term "productivity" is well-known nowadays, it is often misused and sometimes confused with the term "production". In spite of the various perceptions of productivity, it is universally recognised that most organizations – including firms and non-profit organizations – are input-output systems. This is true also in the case of subsystems in an organization, since any process can be seen as an input-output system. For any process regardless of the scale, inputs i.e., resources are needed to produce the outputs (see Fig. 2). Most productivity models and definitions for productivity aim to consider the efficiency of these systems either directly or indirectly. In this paper, productivity is defined as follows:

"Productivity is a relationship (usually a ratio or an index) between output (goods and/or services) produced by a given organizational system and quantities of input (resources) utilized by the system to produce that output." [5].

Based on the above-said, productivity can be shortly defined as:

$$P = \frac{O}{I} \tag{2}$$

where P – productivity.

Productivity is concerned with the effective and efficient utilization of resources (inputs) in producing goods and/or services (output) [6].

Productivity is an essential factor affecting the profitability and overall competitiveness of a firm. Improving productivity, or any other important factor, is difficult without knowing the impact of the decisions taken. This is why we need tools for measuring productivity [1].

3.2. EQUIPMENT

Technological capabilities of automated manufacturing system evolve on the basis of technological capabilities of machinery (machine tools, presses, casting equipment etc). Technological capabilities can be defined as set of characteristics $\{TB_{TP}\}$ where entities (b_1, $b_2 \ldots b_m$) represent both in qualitative and quantitative way the functional characteristics of this machine tool. The range of production to be manufactured, complexity and quality of products are general measures of technological capabilities. This can be defined as set of technological capabilities needed for processing the details $\{TB_D\}$. This means that, as a rule, for manufacturing simple and uniform products it is not rational to use too complicated machinery (see Eq. 3).

$$\overline{TB} = TB_{TP} - TB_D \tag{3}$$

The unrealized technological capabilities may take quite a big part if manufacturing simple product using complicated machinery. Use of complex machine tool for manufacturing a simple detail is uneconomic. Set of technological capabilities of the machine is determined by analysis of the machine's structure (construction) and parameters characterizing that machine. Therefore, technological capabilities are determined for each machine separately and on the basis of technological capabilities of separate machines belonging into system are formed capabilities of the whole system. In accordance with technological capabilities of machine tools, from the viewpoint of production process, the production systems may be categorized into following groups:

a) single-staged;
b) multi-staged.

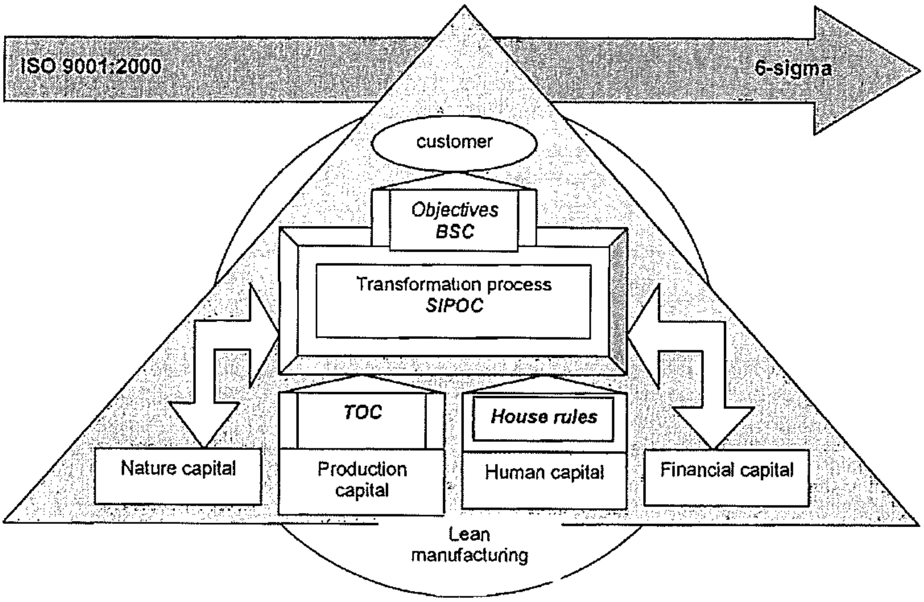
Manufacturing systems with single-staged production process usually consist of poly-functional machine tools (processing centres, flexible manufacturing modules) that can replace each other by their technological capabilities. In this case, technological capabilities of the machines belonging to the system are wide-ranging and by use of these machines it is possible to perform large amount of main operations (milling, turning, boring etc) that are needed for machining the detail.

Majority of manufacturing systems are with multi-staged production process. Such production systems are realized by use of mono-functional machine tools (e.g. drilling machines, boring lathes, grinding machines, milling machine tools etc). Mono-functional machine tools are complementing each other, for total processing of the detail several operations have to be performed and the detail processed passes several processing positions in its technological route.

Thus, technological capabilities play important role in designing operational and route technologies but also in management of whole production process.

3.3. TOOLS FOR THE PRODUCTION SYSTEMS TO RAISE EFFICIENCY AND PRODUCTIVITY

To be effective and efficient, nowadays production systems have to turn attention to continual improvement. There are different methods for continual improvement. Companies having longer lifetimes, face mainly the problem of changing the customs. Often many employees of the company are not interested of changes, because this requires additional efforts, changing the traditions and creates some uncertainty. Meanwhile, standstill leads to stagnation in the company. Companies, that are flexible and able to introduce changes, are more efficient and viable. Owing to the previously-said, it would be important to create flexible system of processes in the company that is able to cope with improvement changes and enables to realize the changes efficiently. The basis for this is implementation of ISO 9001:2000 standard-based quality management system. To establish objectives and measure results (BSC), it is important to know business chain and the organization (see Fig.1). To assure the efficiency, there is Deming's SIPOC model (see Fig. 3).



Where:
ISO 9001:2000 – standard of International Organization for Standardization that is used for elaboration and certification of the organizations' management systems
6-sigma – flexible and comprehensive system to achieve, maintain and maximise business success
Lean manufacturing – excellent system for lessening operating costs, raising quality and creating main values of the organization
TOC – The Theory of Constraints
House rules – instructions used in a company
SIPOC – Suppliers, Input, Process, Output, Customers, enables to get very good overview about the process
BSC – Balanced Score Card

Fig. 3. Model of the use of the production systems

Main process of manufacturing company is production process, its efficiency determines the organization's efficiency and competitiveness. To assure competitiveness, it is essential to raise productivity continually. Very important is human capital, employees, who carry out these processes. Supportive tool is Lean Manufacturing and "House rules" that help employees, especially the new ones. When the organization is achieved its targeted level, it is still possible to smooth the results and for that it would be reasonable to use 6-sigma theory. All above said is presented in the system development model in Fig. 4.

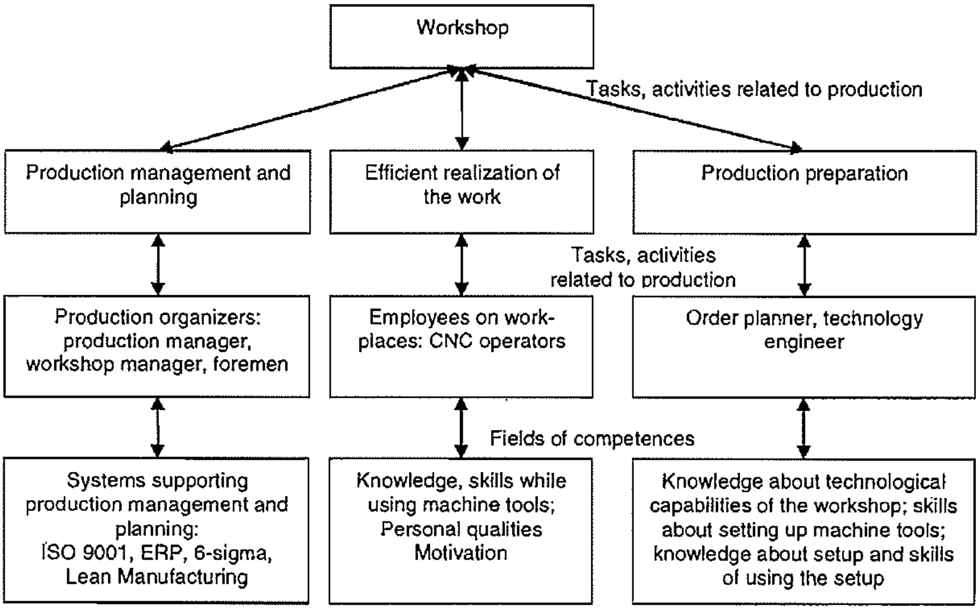


Fig. 4. Development of productivity and competitiveness in workshop

3.4. HUMAN RESOURCES MANAGEMENT IN THE WORKSHOP

Main value of modern production system is human resource. The humans' impact on productivity and the methods for increasing the productivity and efficiency of work can be determined and estimated by evaluation of the competencies of the employees in the certain working environment are described subsequently.

The human's skills, knowledge, experiences, motivation and desire to apply them in a team influence how many pieces he/she could produce during a certain time period using a certain machine with certain technological capabilities. Therefore, using the same machine and applying the same organizational methods, one employee could produce much more details than another during the same time. Influence of human factor to productivity is larger when the process is less automated. Human resource development process in an organization is presented in Fig.5. Basis for human resource development are the organizational strategic tasks and operative actions. The most important that determine how well an employee performs his/her tasks and how productive he/she could be, are levels of skills and knowledge (competences) of performing everyday tasks. A comprehensive research targeted to investigation of needed and existing competencies in different workshops was carried out in Estonia. Data about employees' existing and needed levels of competence was gathered and analysed in case of 75 machine-building, metalworking and apparatus industry companies (see Fig. 6).

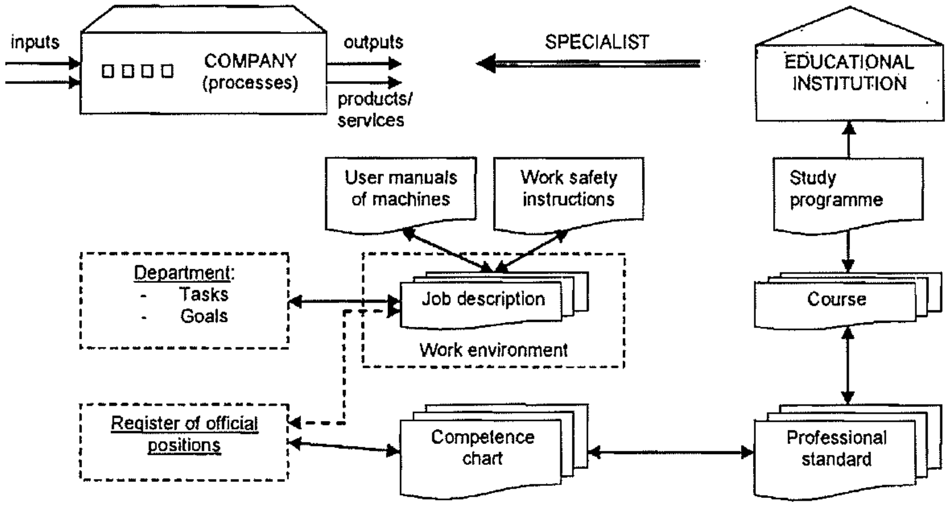


Fig. 5. Human resources development process

Competence chart was taken as basis for evaluating employees' existing and needed level of skills and knowledge. Competence charts were drawn up based on the jobs of the company. Standard competence charts developed during the research were made available to all users in the target region, companies found it easier to draw up their own competence charts. In the elaborated system the user can directly use standard competence charts or draw up individual competence charts with regard to a specific job or person in the company. Competence charts are not some absolutely permanent documents, but are based on the strategic needs of the company and the requirements established to the specific job [4].

The required level of competence shows primarily how extensive the skills and knowledge of people holding the respective position should be in various fields of competence. The basis for the evaluations is:

- the complexity of the structure of the company;
- the complexity and diversity of the processes;
- the complexity and diversity of the products;
- the requirements for the quality;
- production type.

If we establish unreasonably high requirements with regard to an employee, we need to take into account that various jobs require various skills and knowledge that have to be motivated.

From the point of view of clear limitation of the relationship between the employer and the employee it was found to be recommendable to specify the required levels of skills and knowledge as precisely as possible. High requirements of the needed level also require specific training and finding education opportunities by employers. The needed level should be calculated taking into account complexity of the product. In case of simple products needed level in terms of specific skills of workforce can be significantly lower.

In the proposed system, the actual levels (AL) and required levels (RL) are estimated in scale 0-5, where 0 means "the skill has no importance" and 5 means "the skill has high importance". In case the AL<RL, there exists need for additional training. The requirements for the needed level should ideally comply with the existing knowledge and skills of the employee.

The elaborated system also includes expert tool for deciding the needed competence level. In principle, the scales can be combined by own experience, by using the opinion of technical consultant or by integrated expert system. The expert system tool is based upon short questionnaire concerning production and management data. The estimation can be given for engineering staff, management staff or workpeople. The testware solution is realized by database system for monitoring human resources capacity for machinery sector, enabling estimation of existing workforce through web-based interface, called INNOMET. INNOMET is also an acronym for the developed innovative database model for adding innovation capacity of labour force and entrepreneurs of the metal engineering, machinery and apparatus sector.

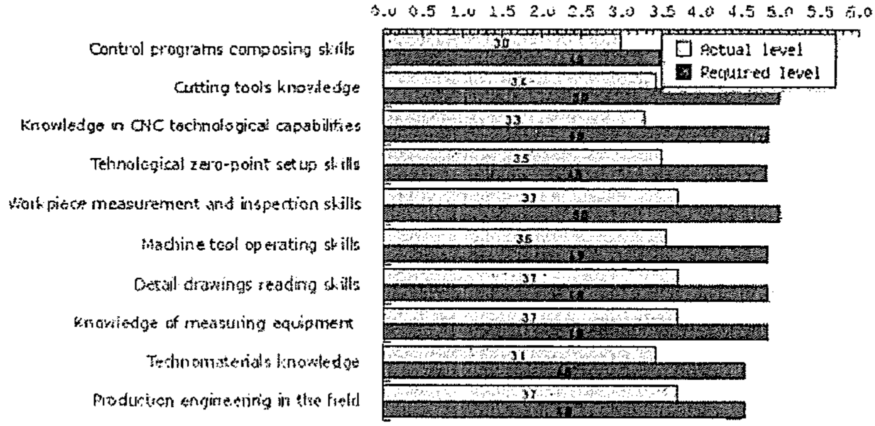


Fig. 6. Overview of skill values for machine tool operator (all regions in Estonia, all sectors of machinery, basic skills level, medium difference between required and actual value, highest to lowest)

The INNOMET system as such identifies the bottlenecks (lack of qualified labour force, development problems related to human resources) of the educational and training system vis-à-vis the existing private sector labour force needs. In development of the system was targeted to supply enterprises and educational institutions with the updated information related to the needs, structure and qualification as well as about the vacancies of finding or requesting needed courses. The processes that the database system enables are:

1) Determination of the Human Resources (HR) competence and the training needs in the company, taking into consideration the strategy of the company and operating needs.

2) Matching the training needs with the capabilities and carrying out the real courses through the system.
3) Fixing the needs for professional examinations and developing the national professional award system in the field of machine building and apparatus industry.

INNOMET is considered as an eManufacturing tool. With the elaborated solution as a transparent and integrated system it is possible to compare and value skills and qualifications both in the industry and in education programmes in all different levels and therefore enable transfer of competencies among countries, regions and also among industrial sectors in long term.

4. CONCLUSIONS

All above-discussed factors – equipment, work organization tools, and human resources – should be viewed and taken into consideration all together and in balance. Numerical control machine tools have wide range of technological capabilities and are very productive, but they are very expensive that influences the price of the products. Therefore, management and organizational methods suitable for the company's development level should be used. Nevertheless, to achieve high productivity, expensive and productive machine tools and organizational methods exploited to some extent are not enough when they are not exploited reasonably and efficiently. Efficiency of exploitation of machine tools and organizational methods depends very much on employees' skills and knowledge – competences. Therefore the authors have turned much attention to elaboration and implementation of employees' competence evaluation and development system (INNOMET).

ACKNOWLEDGEMENTS

Estonian Leonardo Centre (development project INNOMET II - integrated human resources development and monitoring system for adding innovation capacity of labour force and entrepreneurs of the metal engineering, machinery and apparatus sector) is acknowledged research.

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Paper II

Lõun, K., Riives, J., Otto, T. (2008). Necessity for E-manufacturing model in tooling cluster and its essence. *Proceedings of 6th International Conference of DAAAM Baltic Industrial Engineering*. Ed. R.Kyttner. Tallinn: TUT Press, 345–350.

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INDUSTRIAL ENGINEERING
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NECESSITY FOR E-MANUFACTURING MODEL IN TOOLING CLUSTER AND ITS ESSENCE

Lõun, K.; Riives, J. & Otto, T.

Abstract: *e-Manufacturing as a term was introduced some years ago by semiconductor industry, enabling to handle large production quantities in different locations. Globalisation has an effect that nowadays individual- and small-batch-production oriented tooling companies need web-based simple manufacturing, planning, and monitoring systems that could include larger sensor systems and databases. In this paper overview of tooling sector and its necessities towards such manufacturing model are presented, as well as basic concept of e-Manufacturing model for elaboration it in machinery and tool-making sectors.*

Key words: e-Manufacturing, resource allocation, clusters, virtual manufacturing.

1. INTRODUCTION

Tool-making is one field of machine-building, apparatus and engineering industry. Tools are auxiliary means that other enterprises use for manufacture their products. Therefore excessive requirements in quality, reliability, handiness and durability are set for tools. Stamps and moulds belong also under tools. Estonia has long-term experience in manufacturing of stamps and moulds; the larger part of production (about 80%) is exported.

Tool-makers in Estonia are well-organized, belonging to Federation of Estonian Engineering Industry (EML) via Estonian Tool-Makers Association (ESTA). ESTA is also a member of International Special Tooling and Machining Association (ISTMA).

Like other industries, Estonian tool-making cluster is facing very strong international competition. Rivalry in tool-making cluster has even more strengthened due to forceful market approach by tool-makers from China and South-East of Asia. Rise in main resource costs (materials, labour, and energy) during last years has also had strong influence to competitiveness of the companies. Competitiveness of Estonian tool-makers has dropped due to rise in prices of resources, complexity of technological processes needed for manufacturing the tools, and capital-using essence of order handling process. Other tool-making companies in Europe are facing the same situation.

2. ESTONIAN TOOL-MAKING CLUSTER

Estonian tool-making companies have comparatively modern machinery, technology and skilled labour, so it is quite difficult to find soft options for raising the productivity. Therefore modern radical integrated technicoeconomic measures, such as cluster development and e-Manufacturing, should be implemented. Because e-Manufacturing is supported by information technology (such as the Internet) and has the capability in multi-site management, it will foster and improve the competitive capability of manufacturing in the global competition [1].

2.1. Benefits of cluster development

Clusters are often at the core of innovative development. It is widely recognised that innovative companies are in tight cooperation with other companies, investors, educational institutions, and research centres.

Cluster initiatives facilitate acceleration of innovation and then bring them to maturity, thus ensuring the long-term economic success of the companies involved. They present an efficient instrument for the concentration of resources and funding. Through cluster development critical dimensions of knowledge, flexibility, and mobility could be achieved. Mobility can be maximized when there is a local labour market that allows regular flow of people from one situation to another, with diffusion of knowledge.

2.2. Cluster development in Estonian tool-making sector

Cluster development in tool-making sector is contributed by manufacturing products that belong to the same product family – moulds, stamps – by all of the companies belonging to the sector. Although the products itself may be very different by their parameters, functionality and accuracy class, their production is taking place by technologies of quite the same type.

Two important aspects are contributing to cluster development in tooling sector in Estonia:

1) company aspect, characterized by:
   - quite similar structures of Estonian tooling companies;
   - similar order handling processes;
   - quite similar starting point (see Fig. 1).

Data presented in Fig.1 is one of the results of analysis of questionnaires composed by team of experts in Innomet-EST project. Questioning of the companies according to the questionnaire was carried out during November 2007 – January 2008. The results reflect quite similar level of competitiveness of Estonian tooling companies and also need for development activities in order to increase the competitiveness.

2) Production aspect

Main technologies used in tool-making process are: milling, turning, drilling, grinding, assembly, measuring; and specific technologies are: electro-erosion machining, coordinate grinding, micro-welding, fitting.

As products manufactured are complex, have different surfaces, require high processing accuracy, and have high requirements regarding surface quality, then all Estonian tooling companies use numerically controlled machine tools. These machine tools have large technological possibilities, but high cost as well. Therefore these machine tools have to be operated at full capacity and their technological possibilities exploited rationally. Technological capabilities of machine tools used form the company's technological capabilities and nomenclature of products manufactured.

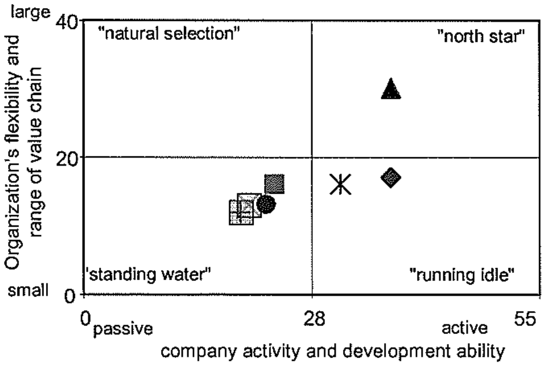

Fig.1. Dispersion of general competitiveness of Estonian tooling companies

The larger are technological capabilities of the company, the more complex and wider nomenclature of products the company is able to produce. Regrettably such machine tools have high investment cost, that excessively raises net cost of the products if these machine tools are not rationally exploited. Hence, the need for every company to specify its technological capabilities and determine to which direction develop its capabilities. Cluster dimension that refers to flexibility and cooperation and assures rational allocation of resources, necessitates some cooperation in taking strategic decisions and setting united strategic objectives.

3. ORDER HANDLING PROCESS IN TOOLING COMPANIES

Typically tool-making companies are oriented to order fulfilment, whereby number of products manufactured for one order is small and similar orders often does not recur again. Therefore tooling companies are typical piece production companies. Order handling process in tooling companies composed by interviews of ESTA members is presented in Fig.2.

From company-side, order is considered as complex of activities that contribute to competitiveness and productivity of the company, if well realized. Main objectives regarding order handling process are:

- determine functional and technical parameters of the product and realize complex technical preparation that would assure technologically rational and smoothly manufacturing of the product;
- elaborate and determine rational manufacturing process, specifying order of performing manufacturing operations as well as resources needed for manufacturing; determine essence of stages of order fulfilment and information flows during order handling process that would assure quality of the performance and possibly short lead time;

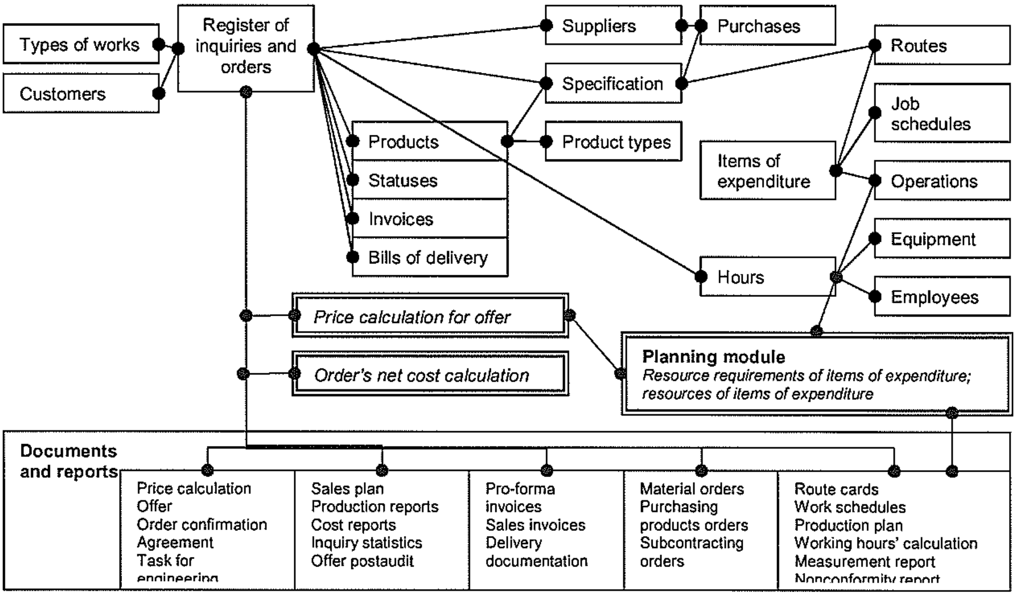

Fig.2. Generalized order handling process in tooling companies

- consider alternative possibilities in manufacturing process with an aim to produce as low net cost as possible;
- determine order of product delivery and relations with the customer after sales (e.g. after-sales servicing).

As it is seen in Fig.2, it is possible to divide order handling process into three groups of components:

- events taking place in order handling process; events include different kind of activities;
- documents and databases that are needed for starting and fixating the activities as well as saving information flows related to the activities;
- information flows that determine interrelated items and periodicity of information change in order handling process.

Events taking place in order handling process are possible to describe as information models that include all previously mentioned components and which aim is to fixate occurrence of this event in detail. As an example, two different events in order handling process are described (see Fig. 3).

Events are divided into three groups by their essence:

- main events – events that are sequential and directly needed for order fulfilment and that essentially influence how well order handling process is carried out. For example, order acceptance is main event that activate order fulfilment process and fixates the nature of the process (see Fig.3);
- support events – events that directly support occurrence of main events;
- ancillary events – events that help carrying out whole order handling process and raising its efficiency in different ways.

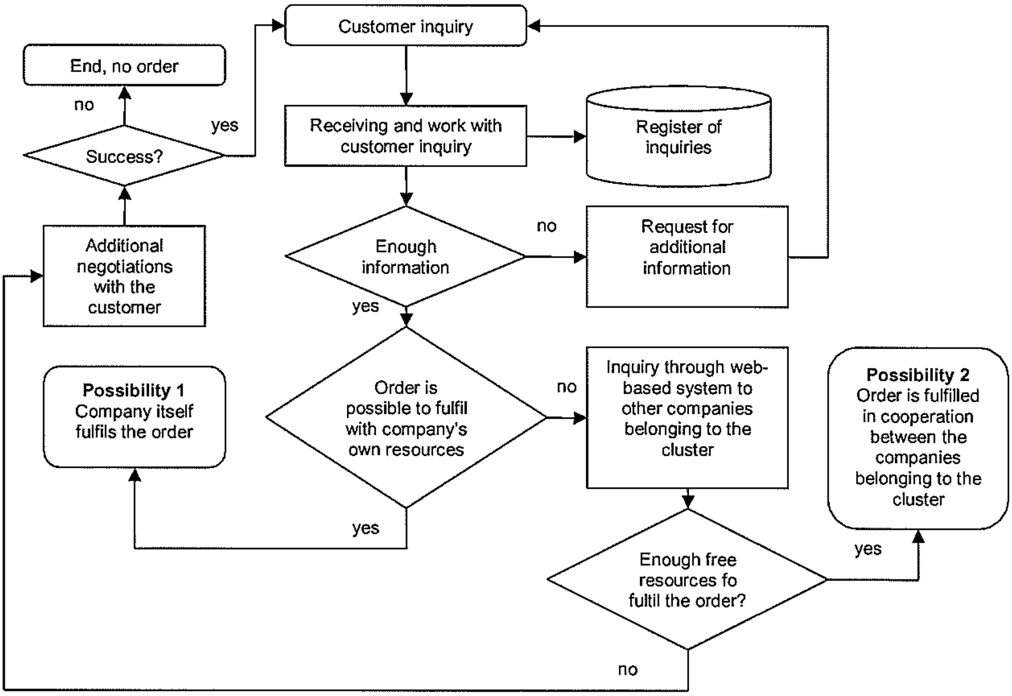

Fig.3. Example of main event – customer inquiry handling – model

For example, competence of employees has influence on quality and productivity of order handling process. Therefore personnel training process may be considered as one important ancillary process in the company that does not realize in real time, but in discrete time regarding order handling process, and uses important resources of the company and has connection with the whole order handling process.

4. E-MANUFACTURING CONCEPT DEVELOPMENT

e-Manufacturing can be determined as "IT-based manufacturing model, optimizing resource handling over entire enterprise and extended supply chain" [2]. e-Manufacturing is systematic methodology that enables to integrate successfully manufacturing operations with functional objectives of the company through the use of Internet and predictive technologies. e-Manufacturing is a concept to integrate all business elements (supplies, manufacturing units, service networks, etc). Using the Internet and the myriad tools that support commerce functions, one can find new customers, reduce the costs of managing orders and interacting with a wide range of suppliers and trading partners, and even develop new types of information-based products, such as remote monitoring and control software and other online services [3].

Sometimes e-Manufacturing is mixed up with other e-terms. How is e-Manufacturing different from e-Business and e-Commerce? The sameway work is different from business and commerce. They are highly related, but not the same [4].

Nowadays manufacturing companies require high degree of product customisation to fulfil market demands. Therefore e-Manufacturing system should fulfil following requirements:

- to be open, and dynamic environment;
- heterogeneous software and hardware applications;
- enterprise integration and cooperation (joint manufacturing systems: ordering, purchasing, design, scheduling and planning, manufacturing, sales networks etc);
- ability to adapt quickly to changes in environment;
- additional resources can be added to the system as required without disrupting other previously established systems;
- the system should be able to detect failures and minimize their impact on the working environment.

Basic architecture of e-Manufacturing system integrates various modules (e.g. some of them described in Fig.3, using the software and hardware components. An illustration of the Internet-based e-Manufacturing system is presented in Fig.4.

e-Manufacturing system development consists of following main stages:

- description of the system architecture and modules;
- system analysis, determination of platforms and software;
- proof of concept (including final formulation of inputs and outputs);
- analysis of rationality of use and realization of process automation instruments (e.g. smart dust);
- implementation of the system in tooling cluster.

As the e-Manufacturing concept determination and realization concerns tooling cluster, main general standpoints are following:

- main events should be described embracing all companies belonging to the cluster;
- describing ancillary events is every company's self decision (but agreements inside the cluster would be recommendable here, too).

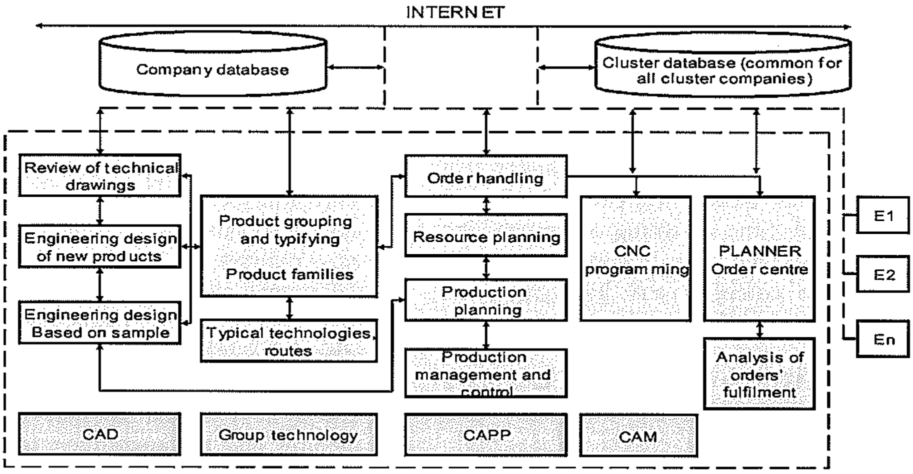

Fig.4. General concept of Internet-based e-Manufacturing system

5. CONCLUSION

As tooling companies are producing complex products and orders usually do not repeat for the same product and the companies are already having modern technology and equipment, then it is quite difficult to find possibilities to raise competitiveness of the companies by using easy methods. Therefore new solutions as cluster development and e-Manufacturing have to be exploited. Through cooperation between companies belonging to the cluster optimal resource allocation is possible to achieve and to share technological resources inside the cluster to achieve more optimal use of the resources. The described model is in development in Estonian machinery sector.

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Paper III

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E-manufacturing concept solution for tooling sector

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Abstract. E-manufacturing as a term was introduced some years ago by semiconductor industry, enabling to handle large production quantities in different locations. Due to globalization, nowadays individual and small-batch production oriented tooling companies need web-based simple manufacturing, planning and monitoring systems that could include larger sensor systems and databases. In this paper an overview of the tooling sector and its needs for such a manufacturing model as well as a new concept of the e-manufacturing model for SMEs of machinery and tool-making sectors are presented.

Key words: e-manufacturing, resource allocation, tooling, virtual manufacturing.

1. INTRODUCTION

Since 1990s, system theory has strongly influenced process management. Instead of examining single enterprises, nowadays networks of interacting enterprises (production systems or supply chains) are analysed. Estonian tool-making industry has long-term experience in manufacturing of stamps and moulds; the larger part of production (about 80%) is exported. Typical for tool-making industry is manufacture-to-order and non-repetitive manufacturing environment. In this environment, the need to work together and to provide cost-effective management of the whole production system is challenging. Tool-makers in Estonia are well-organized, belonging to the Federation of Estonian Engineering Industry (EML) via Estonian Tool-Makers Association (ESTA). ESTA is also a member of the International Special Tooling and Machining Association (ISTMA).

E-manufacturing (e-mfg) is the application of open, flexible, reconfigurable computing techniques and communications for the enhancement of efficiency of the whole supply chain. As e-mfg is supported by information technology (such as the Internet) and has the capability in multi-site management, it will foster and improve the competitive capability of manufacturing in the global competition [1]. e-mfg can be determined as IT-based manufacturing model, optimizing resource handling over the entire enterprise and extended supply chain [2]. Using the Internet and tools that support commerce functions, one can find new customers, reduce the costs of managing orders and interacting with a wide range of suppliers and trading partners, and even develop new types of information-based products, such as remote monitoring and control software and other online services [3]. Sometimes e-mfg is mixed up with other e-terms. e-mfg includes also design of manufacturing and business strategy, sales and marketing, e-procurement, shop-floor operations, enterprise application integration, supply chain collaboration, transactional e-business – providing real-time visibility and collaborative engineering [4,5].

Some research groups [6] have concluded that in e-mfg simpler algorithms can be used, but one must be ready to accept solutions of inferior quality. In first e-mfg solutions in semiconductor industry the ratio of the volume of the product was very high, whereas the equipment necessary for production is expensive and difficult to transport and install [7]. One important characteristic of semiconductor capacity planning is that both the product demand and the manufacturing capacity are sources of uncertainty. As is the case in hi-tech industries, the market has a demand structure that is intrinsically volatile [8]. If e-mfg was successful in case of the semiconductor industry, one can expect good results also using similar approach in the tooling industry.

In order to resolve the information exchange problems, a standardization approach has been at the core of most research efforts. Technical standards for product information and CAD/CAM documents have been realized by Standard for the Exchange of Product Model Data–STEP. The main problem is that the used Semantic Web technologies and tools require considerable technical expertise, and are thus not well suited for users outside the field of computer science. This makes it hard for domain experts and ontology engineers to work together on e-manufacturing tasks [9,10]. Another e-mfg related problem is that the bandwidth and the inherent delays of TCP/IP impose a strong constraint to the teleoperation systems through the Internet [11]. Although several commercial CAD systems offer interference inspection functions, these systems are very expensive and inadequate to perform collaborative work over the Internet [12]. Therefore a Best-Matching Protocol for geometrical as well as supplier matching has been proposed [13]. Thus results of this approach have been promising: after implementation of e-mfg principles the required time for mould manufacturing was reduced by 35.6% in 2006 compared to 2004, and the time required for designing a mould was reduced by approximately 40% [14].

The aim of this paper is to elaborate new management and planning models and decision processes to increase the efficiency of the entire supply chain, not only of an individual manufacturing company.

2. ESTONIAN TOOL-MAKING INDUSTRY

Estonian tool-making companies have comparatively modern machinery, technology and skilled labour, so it is quite difficult to find soft options for raising the productivity. Therefore modern radical integrated techno-economic measures such as cluster development and e-mfg, should be implemented.

Nowadays manufacturing companies require high degree of product customization to fulfil market demands. Therefore e-mfg system should fulfil the following requirements:

- to be an open and dynamic environment;
- heterogeneous software and hardware applications;
- enterprise integration and cooperation (joint manufacturing systems: ordering, purchasing, design, scheduling and planning, manufacturing, sales networks etc);
- ability to adapt quickly to changes in environment;
- additional resources can be added to the system as required without disrupting other previously established systems;
- the system should be able to detect failures and minimize their impact on the working environment.

2.1. Benefits of cluster development

Clusters are often at the core of innovative development. It is widely recognized that innovative companies are in tight cooperation with other companies, investors, educational institutions and research centres.

Cluster initiatives facilitate acceleration of innovation and then bring them to maturity, thus ensuring the long-term economic success of the companies involved. They present an efficient instrument for the concentration of resources and funding. Through cluster development, critical dimensions of knowledge, flexibility and mobility can be achieved. Mobility can be maximized when there is a local labour market that allows regular flow of people from one situation to another, with a diffusion of knowledge.

2.2. Cluster development in Estonian tool-making sector

Cluster development in the tool-making sector means manufacturing products that belong to the same product family (moulds, stamps) by all of the companies belonging to the sector. Although the products themselves may be very different by their parameters, functionality and accuracy class, their production is carried out by technologies of similar type. Two important aspects, contributing to cluster development in Estonian tooling sector, are the company aspect and production aspect.

2.2.1. *Company aspect*

The company aspect is characterized by similar structure of Estonian tooling companies, similar order handling processes and quite similar starting points (Figs. 1, 2).

Data presented in Figs. 1, 2 is based on the results of questionnaires of the Estonian engineering enterprises research [15]. This research covered 60 machine-building companies in Estonia, but for analysing competitiveness and productivity of tooling companies, only the data about tooling companies was used for our research. As competitiveness of a company depends mostly on the company itself, questions were directed to competitiveness, human resources and innovation issues in the company.

Competitiveness was determined by experts. It is expressed by company's activeness and development ability (reflected on the x axis) and flexibility and compass of the value chain (reflected on the y axis). Points reflecting these two dimensions were summed for each tooling company. Maximum points in case of activeness and development ability were 55 and in case of flexibility and compass of value chain 40 (Fig.1).

On the basis of possible combinations of the two main dimensions shown in Fig. 1, four different scenarios are formed for the economic development that in previous investigations [16] have been marked with the names "Stagnant water", "Natural selection", "Idling speed" and "North star". These scenarios represent various development paths and lead to various states, whereas it is possible to switch over from some (not from all) development paths to the other ones in the course of the process. "Stagnant water" is a scenario where enterprises continue the previous very slow (too slow) restructuring; "Idling speed" is a scenario where the state is active and tries to do something significant, but that does not match the goals; "Natural selection" is a scenario where enterprises become

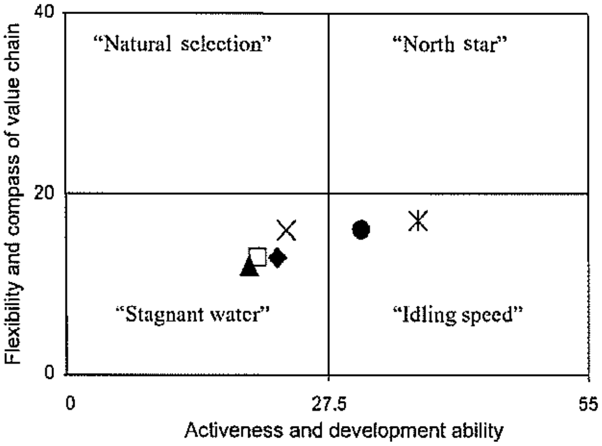

Fig. 1. Competitiveness of Estonian tooling companies.

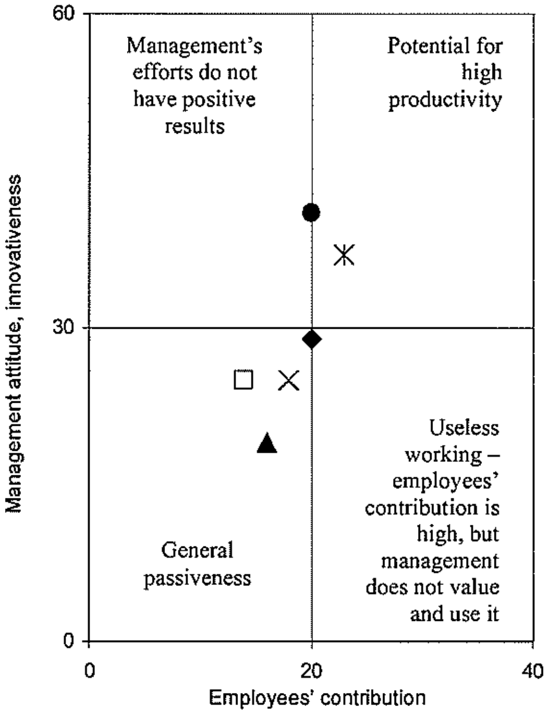

Fig. 2. Comparative analysis of Estonian tooling companies regarding productivity.

active, but their activities are mainly individualistic; "North star" is a scenario where a leap in development could be made by connecting the enterprises' readiness and ability to change with the supporting activities of the state.

In the case of productivity, it was determined by experts that productivity of the company depends on the employees' contribution to raising the productivity (x axis) and management's attitude and innovativeness (y axis). Points reflecting these two dimensions were summed for each tooling company. Maximum number of points in case of employees' contribution to raise productivity was 40 and maximum number of points in case of management's attitude and innovativeness was 60 (Fig. 2).

On the basis of possible combinations of these two main dimensions, illustrated in Fig. 2, four different scenarios are formed: "General passiveness", "Useless working – employees' contribution is high, but management does not value and use it", "Management's efforts do not have positive results" and "Potential for high productivity". As it is seen in Fig. 2, Estonian tooling companies should make efforts to reach the scenario "Potential for high productivity".

Questioning of the companies according to the questionnaire was carried out during November 2007–January 2008. Dots in Figs. 1 and 2 represent different Estonian tooling companies and their location regarding the competitiveness and productivity. The results, presented in Figs. 1 and 2, reflect quite similar level of competitiveness and productivity of Estonian tooling companies and also the need for urgent development activities in order to increase the competitiveness and productivity and to assure companies' sustainability.

2.2.2. Production aspect

Main technologies used in the tool-making process are milling, turning, drilling, grinding, assembly and measuring. Specific technologies are electro-erosion machining, coordinate grinding, micro-welding and fitting.

As the manufactured products are complex, have different surfaces, require high processing accuracy and have high requirements regarding surface quality, all Estonian tooling companies use numerically controlled machine tools. These machine tools have large technological possibilities, but high cost as well. Therefore these machine tools have to be operated at full capacity and their technological possibilities exploited rationally. Technological capabilities of machine tools that are used form the company's technological capabilities and nomenclature of products manufactured.

Regrettably such machine tools have high investment costs that excessively raises net cost of the products if these machine tools are not rationally exploited. Hence, the need for every company to specify its technological capabilities and to determine in which direction to develop its capabilities.

Consequently, it is essential to determine the structure of the production system that creates prerequisites for efficient and effective functioning. Determination of the structure of the production system is a process of sequential decisions, which leads to the configuration of the system, possible transport routes, storage principles, but also to basic organizational measures. Solving the optimization task, it is possible to determine the nomenclature and number of main machine-tools. The aim is to minimize the objective function F:

$$F = \sum_{j=1}^{J} (X_j K_j E_H + C_j \sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_{ikj} t_{ikj}) \rightarrow \min, \tag{1}$$

subjected to constraints:

$$\sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_{ikj} t_{ikj} \leq X_j F_j \eta_j, \; j = 1, 2, ..., J, \tag{2}$$

$$\sum_{j=1}^{J} Y_{ikj} = A_i, \quad k = 1, 2, ..., K; \quad i = 1, 2, ..., I, \tag{3}$$

where

$X_j \geq 0$, $Y_{ikj} \geq 0$ (X_j and Y_{ikj} are integers),

i – workpiece type, $i = 1, 2, ..., I$;

A_i – amount of production programs of workpiece i;

j – type of the machine-tool, $j = 1, 2, ..., J$;

t_{ij} – production time of workpiece i using machine-tool j;
J_i – number of machine-tools that enable producing workpiece i;
I_j – amount of workpiece types that is possible to manufacture using machine-tool j;
k – type of manufacturing operations, $k = 1, 2, ..., K$;
J_k – amount of machine-tool types that enable processing operation k;
t_{ikj} – time of performing operation ik using machine-tool j;
F_j – effective working time of the machine-tool j;
η_j – planned workload coefficient of machine-tool j;
K_j – cost of the machine-tool j;
E_h – machine-tool utilization coefficient;
C_j – cost of machining using j type machine-tool a minute;
X_j – number of j type machine-tools;
Y_{ikj} – number of i type workpieces, for which the processing operation k is made using machine-tool j.

3. ORDER HANDLING PROCESS IN TOOLING COMPANIES

Typically tool-making companies are oriented to order fulfilment, whereby the number of products in an order is small and similar orders recur seldom. Therefore tooling companies are typical engineer-to-order non-repetitive production companies. Order handling process in tooling companies, based on interviews of ESTA members, is presented in Fig. 3.

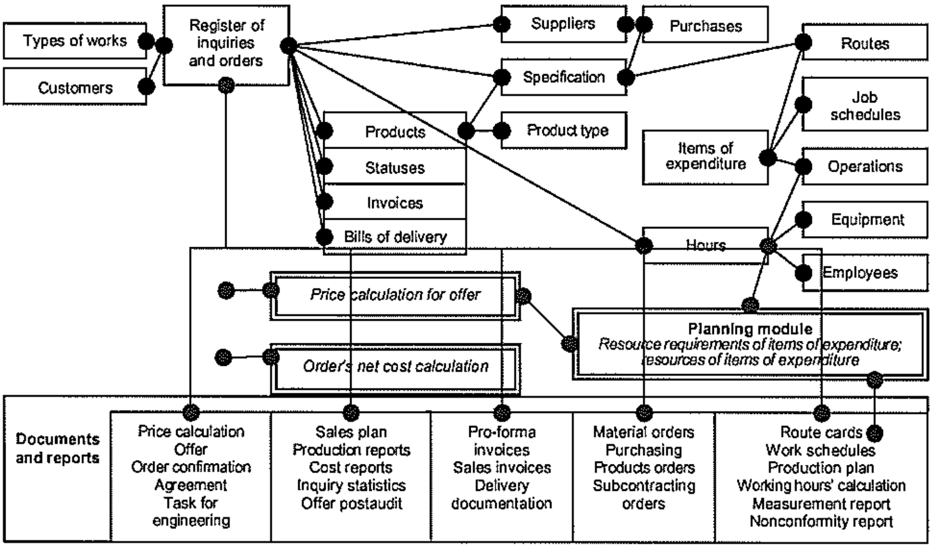

Fig. 3. Generalized order handling process in tooling companies.

Usually, some degree of abstraction is necessary by modelling the products. Thus, some parts may be left out of the model completely. Others may be aggregated and represented in the model as a single, "generic" component. The summarized characteristics of the aggregated components must be checked to see if they represent the situation correctly. Production planning method for a supply chain in such a low-volume and make-to-order manufacturing environment has been developed at Tallinn University of Technology, where key performance indicators are used to analyse real enterprise data comparing it with a modelled ideal manufacturing system [17].

From the company side, an order is considered as a complex of activities that contribute to technologically rational and economical manufacturing of the product. Main objectives regarding the order handling process are:

- to determine functional and technical parameters of the product and realize complex technical preparation that would assure technologically rational and smooth manufacturing of the product;
- to elaborate and determine rational manufacturing process, specifying the order of performing manufacturing operations as well as resources needed for manufacturing; to determine the essence of stages of order fulfilment and information flows during order handling process that would assure quality of the performance and possibly short lead time;
- to consider alternative possibilities of the manufacturing process with the aim to produce at as low net cost as possible;
- to determine the order of product delivery and relations with the customer after sales (e.g. after-sales servicing).

As it is seen in Fig. 3, it is possible to divide the order handling process into three groups of components:

- events, taking place in the order handling process (events include different kind of activities);
- documents and databases that are needed for starting and fixing the activities as well as saving information flows related to the activities;
- information flows that determine interrelated items and periodicity of information change in the order handling process.

Events, taking place in the order handling process, can be described as information models that include all previously mentioned components and the aim of which is to fix the occurrence of the events in detail. The e-mfg system is a set of related models (Fig. 4).

The number of models depends on the complexity of the system. In Fig. 4, a set of main models that may belong to the e-mfg system, is presented (additional models can be included). In the case of each model, the following should be described:

1) architecture – process management, realization principles;
2) application – planner that gives information about employing the model, how and in what conditions the model should be employed;

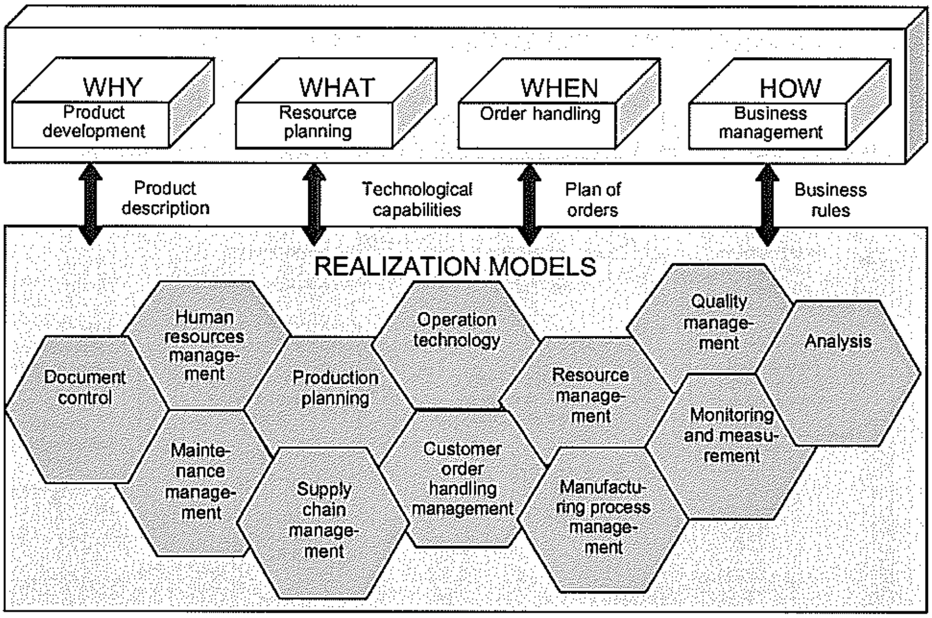

Fig. 4. e-mfg system as a set of related models.

3) expert for helping decision-making – essential information is gathered from the environment and expert offers optimal solution; decisions made are saved together with the description of the circumstances that were the basis of decision-making, this enables learning of the system and making new decisions based on the previous experience.

Events are divided into three groups:

1) main events – events that are sequential and directly needed for order fulfilment and that essentially influence how well the order handling process is carried out; for example, order acceptance is a main event that activates the order fulfilment process and fixes its nature (Fig. 5);
2) support events – events that directly support the occurrence of main events;
3) ancillary events – events that help carrying out the whole order handling process and raising its efficiency in different ways.

For example, competence of employees influences the quality and productivity of the order handling process. Therefore personnel training may be considered as an important ancillary process that uses important resources of the company and has connections with the whole order handling process.

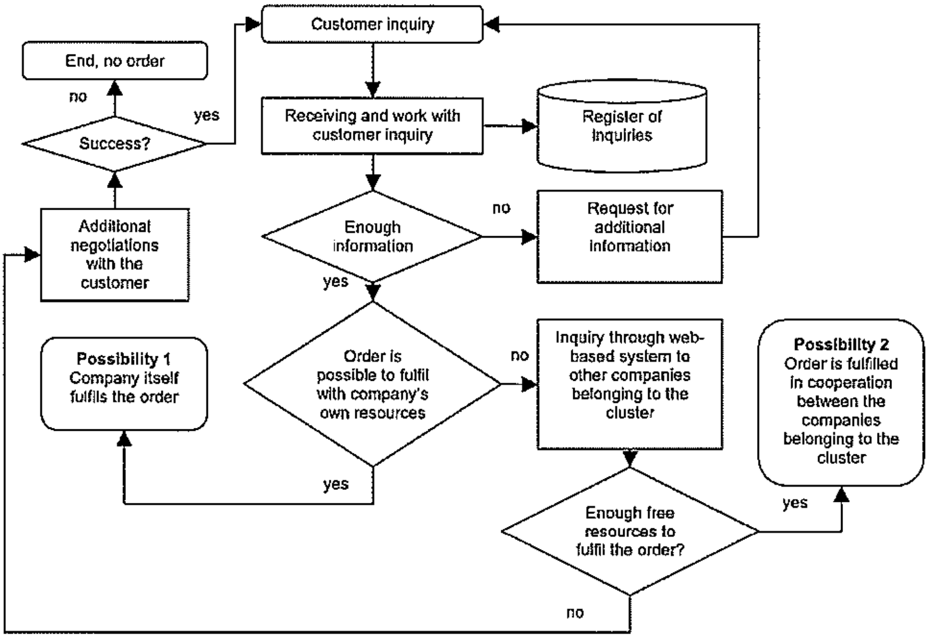

Fig. 5. Example of a main event, the customer inquiry handling model.

4. DEVELOPMENT OF THE E-MANUFACTURING CONCEPT

Basic architecture of the e-mfg system integrates various modules using software and hardware components. A vision of the Internet-based e-mfg system is presented in Fig. 6.

The e-mfg system development consists of the following main stages:
- description of the system architecture and modules;
- system analysis, determination of platforms and software;
- proof of the concept (including final formulation of inputs and outputs);
- analysis of the rationality to use process automation instruments (e.g. smart dust);
- implementation of the system in the tooling cluster.

As concept realization of the e-mfg concerns the tooling cluster, the main general standpoints are the following:
- main events should be described by embracing all companies belonging to the cluster;
- describing ancillary events is every company's own decision (but agreements inside the cluster would be recommendable here, too).

We have defined e-manufacturing for supply chain (SC) management as a system that tries to fulfil the following goals:

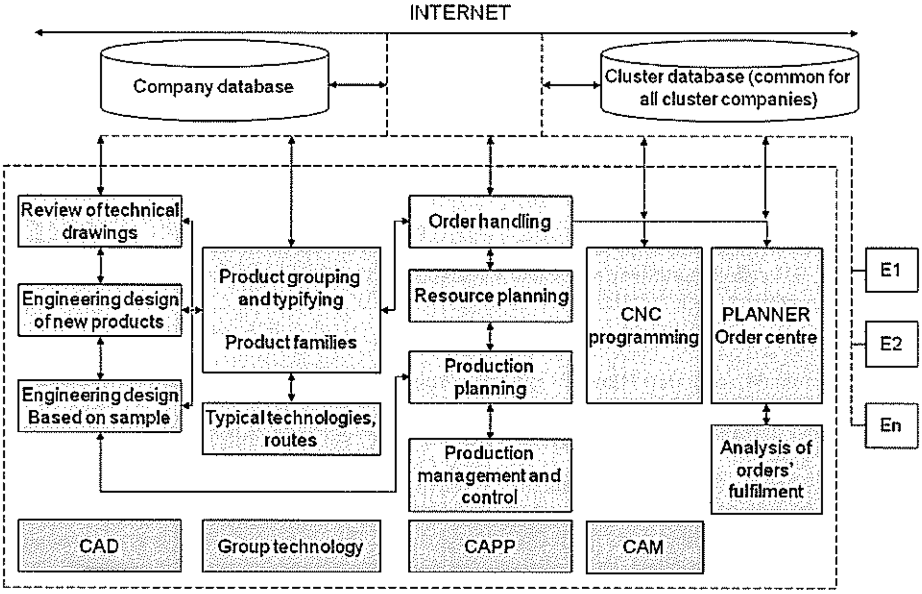

Fig. 6. General concept of an Internet-based e-mfg system.

1) to assure that the investments in SC applications are aligned with SC strategy;
2) to assure that the investments in SC, related to the implementation of e-manufacturing, generate business value;
3) to mitigate the risks that are associated with the SC-related e-manufacturing.

5. CONCLUSIONS

Tooling companies manufacture complex products with individual orders usually different from each other. The companies are already supplied with modern technology and equipment. Therefore it is quite difficult to find possibilities to raise competitiveness of the companies by using traditional methods. Therefore new solutions as integrated production system development and e-manufacturing are to be exploited. Through cooperation between companies, belonging to the system, optimal resource allocation is possible to share technological resources inside the cluster to achieve better use of the resources. The described model is being developed for SMEs in Estonian machinery sector.

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E-tootmise kontseptsioon tööriistatootmise sektorile

Kaia Lõun, Tauno Otto ja Jüri Riives

E-tootmine on mõiste, mis kasvas mõned aastad tagasi välja pooljuhtide tööstusest, võimaldades hallata eri asukohtades suuri tootmiskoguseid. Globaliseerumise tõttu vajavad ka tänapäeva üksik- ja väikeseeriatootmisele orienteeritud tööriistatootmise ettevõtted veebipõhist lihtsat tootmise juhtimise, planeerimise ning monitooringu süsteemi, mis võib sisaldada ka suuremaid andursüsteeme ja andmebaase. Artiklis on antud ülevaade tööriistatootmise sektorist ja analüüsitud selle vajadust uue tootmismudeli järele, samuti on esitatud e-tootmise mudeli kontseptsioon masina- ning tööriistatootmise sektori väikeettevõtetele.

Paper IV

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Evaluation of the operation expedience of technological resources in a manufacturing network

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Abstract. Cost-effective manufacturing and technology-based manufacturing are basic keywords in contemporary manufacturing. Efficiency and productivity require extremely good job management, correlation of resources and competencies to production requirements, as well as continuous monitoring of possible wastes and additional expenditures, i.e. real efficiency of the continuous improvement process. In the current article the methodology of technological resources and competence management evaluation in terms of manufacturing system ontology are analysed in pre-order and post-order fulfilment stages. The expedience of resources operation and order outsourcing, but also corresponding risk management principles are analysed. The elaborated methodology enables enterprises to implement a more rational utilization of manufacturing resources by estimating the influence of existing competencies and technological possibilities into productivity and efficiency.

Key words: e-manufacturing, system ontology, technological resources, requirement analysis, system behaviour.

1. INTRODUCTION

The value of a product in an enterprise forms during realization of different business processes. Basically, business processes are structures and targeted sets of elementary events, functioning by fixed rules. Certain resources and knowledge are required for the occurrence of elementary events. Process efficiency can be expressed through the cost or time of the exploited resource.

The main part of the added value to the customer is created by the production system. Therefore the production system plays a central role in every manufacturing company. At the same time, production is one of the systems, which have the most complicated configuration and functionality in the company where various technological processes run simultaneously. Technological resources constitute an important part of the production system, characterized by technological possibilities. They determine the nomenclature of workpieces that can be produced in a certain production system.

Make-to-order (MTO) production needs availability of different technological resources and high flexibility. If machine tools of a manufacturing system have more technological capabilities [1,2], they enable wider production nomenclature, higher accuracy and complexity. Technological possibilities and the competence of employees have direct influence on the workstation productivity and therefore on the whole manufacturing process productivity and efficiency [3]. Every new manufacturing order challenges both technological resources and specific competencies while exaggerating becomes costly. Optimal use of technological resources facilitates efficiency and productivity. Analysis of necessary technological possibilities and competencies (requirements loop) before every order, and analysis of efficiency of performance (behaviour loop) after fulfilment of an order are necessary. Performance appraisal analysis sustains essential part in the continuous improvement process. Irrational prolongation of the production time is directly related to insufficient technological possibilities, and idle time rate increase refers to the absence of necessary competence.

Ensuring efficiency in a single enterprise becomes an increasingly sophisticated task as the nomenclature of products expands, clients' expectations to quality grow higher, and technological improvement is needed to ensure competitiveness. As a solution, attention is directed towards the development of production networks and clusters, enabling rational resource sharing and limitation of expenses. Networking presumes the possession of adequate information about partners' technological capabilities. Therefore development of a web-based information system with corresponding database is inevitable. Rational decision-making for such information system is not possible without estimation of the outsourced work amount, distances between subcontracted workplaces, but also possible risks of involving partner enterprises.

2. ONTOLOGY OF A PRODUCTION SYSTEM

A system is a set of interacting or interdependent entities forming an integrated whole. Most systems share common characteristics, including structure, behaviour, interconnectivity and functions [4]. A system may consist of subsystems. A company is a system that operates in a certain location and in a certain customer-oriented field of activity. A company may belong to a group (network), whereby its belonging to the network may be abstract (undetermined) or the company may have certain connections or functions in the network. One example of determined belonging to the network is the cluster structure [5].

The increasing product complexity and emerging manufacturing globalization require the cooperation and coordination of manufacturing enterprises [6]. The resource sharing and reuse among these enterprises are essential for achieving efficiency and competitiveness. Manufacturing companies may operate in networks, complementing each other via technological resources. With an aim to make collaboration more efficient, information systems are developed that enable to describe technological resources of a company, determine expediency of their use, analyse the rate of use of the resources and, if necessary, make exchange transactions, offering unemployed resources and buying necessary resources with the aim of mutual benefit. This information system requires unified ontology and semantics from the viewpoint of system development as well as system use.

A standardized terminology needs to be semantically consistent across the organization boundaries, since the communication aspects of information require that communicating parties have the same understanding of the meaning of the exchanged information [7–9]. Representation of knowledge is also a medium for human expression [10]. An important contribution to the success of Internet is its openness, so anyone can contribute to the body of information [11] in terms of common taxonomy. An approach to defining manufacturing taxonomy and axioms, based on a manufacturing system engineering (MSE) ontology is presented in Fig. 1.

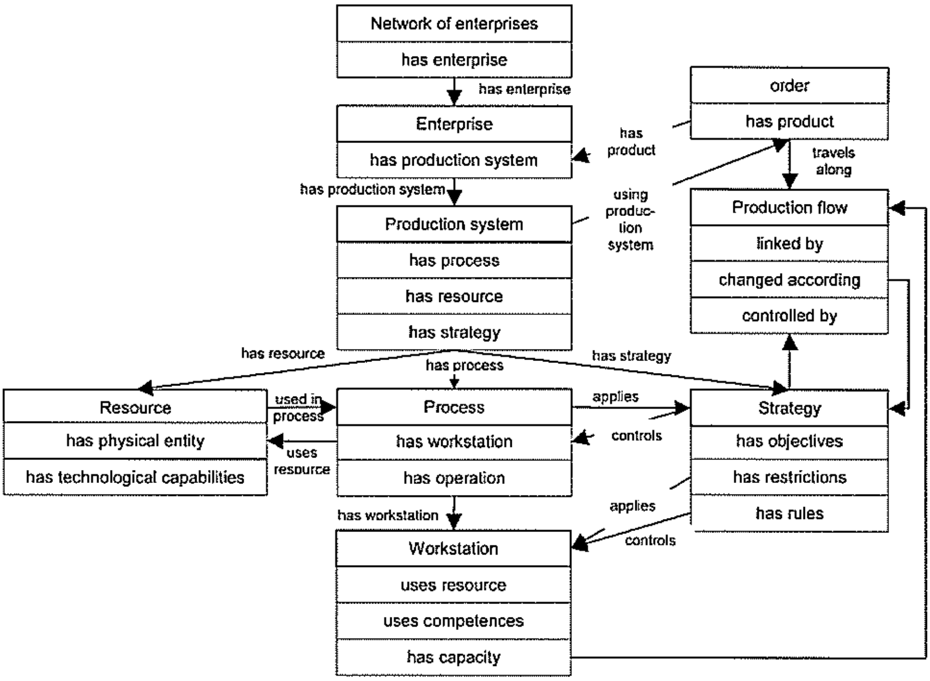


Fig. 1. Model of the ontology of a production system.

The production system has certain resources, processes and strategies (Fig. 1). Production system is characterized by physical environment (number, type, model of machine tools, their layout and location) and functional environment that is expressed by technological possibilities of machine tools. Machine tools have mutual logistical relations inside the system as well as with the external environment.

Technological possibilities of a company's production system depend mainly on the technological possibilities of the machinery (machine tools, presses, welding equipment etc). Technological possibilities can be defined as a set of characteristics of a device (machine tool, industrial robot, manufacturing cell) for producing a specific workpiece or performing a certain technological task. Manufacturing a product requires implementing a certain amount of technological possibilities. When the necessary parameters for manufacturing a product exceed technological possibilities of a machine tool, the use of different machine tools is required. While manufacturing simple and similar products, it is usually not economically reasonable to use too complicated equipment.

Technological possibilities of the equipment, belonging to the production system, determine greatly the essence of the processes taking place in this system and are also a basis for forming possible strategies.

In addition to the technological environment (machine tool with its technological possibilities) the machine tool operator with his/her competences belongs to the workstation. The human's skills, knowledge, experience and motivation to apply them in a team influence how many pieces he/she can produce during a certain time period using a certain machine with certain technological possibilities. Therefore using the same machine and applying the same organizational methods, one employee can produce much more details than another during the same time. Influence of the human factor to the productivity is larger when the process is less automated [12]. This combination (machine tool with its technological possibilities and machine tool operator with its competence) determines technological capability of a workstation and forms the basis when determining the company strategy and order portfolio and planning production flows. Raising efficiency of the production flow begins with raising the workstations' productivity through the development of technological capabilities and competence.

3. A MODEL FOR ANALYSING THE CAPABILITIES OF THE MANUFACTURING SYSTEM

Business strategies of small and medium-sized enterprises (SME) are mostly based on order-centred manufacturing. Make-to-order is a production environment in which a product is produced according to customer's order. The final production is usually a combination of standard and custom-designed items to meet the specific needs of a customer. In such type of organization the sequence of the main business processes is usually the following:

Sell – Design – Produce.

MTO organizations have typically discontinuous flow of operations, which are highly customized and often use unique production methods. The manufacturing processes must be highly flexible, but quite often are not very cost effective. As identified by Toyota's Chief Engineer, Taiichi Ohno, in the Toyota Production System seven forms of waste are distinguished [13]: inventory, delay, motion, transportation, overproduction, overprocessing and defects.

Production planning task becomes even more difficult when products are quite different by complexity and technology. Additional costs are typically caused by poor organization of production (delays or unsuitable use of resources), unpractical production structures (excessive transportation times) and incompetence (lacking of needed competence analysis).

According to the system development and behaviour ontology, we can distinguish two decision-making circles (Fig. 2). The basic loops are:

- requirement loop, defining technological possibilities/competencies required for order fulfilling; it relates these to existing possibilities/competencies and technological capabilities of the production system;
- behaviour loop, observing the correspondence of performance level activities to order fulfilment measures of efficiency and compares outputs with expert estimation of the system capability.

The correspondence of the manufacturing needs (resources, competencies) to the manufacturing system capability (technological possibilities of technological devices, existing competencies) determine the success of the manufacturing process (productivity, efficiency). Overestimation of technological possibilities and existing competencies causes additional cost to manufacturing. Underestimation of the capabilities brings along uneven resource allocation or possible profit loss.

Requirement loop is carried out by comparing the required needs and manufacturing feasibility expert estimation. As indicated in Eqs (1) and (2), required

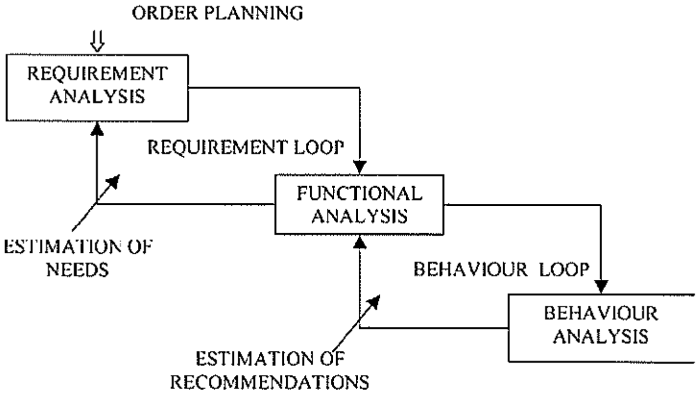


Fig. 2. Event and process engineering design model, proceeding from the needed complexity.

needs are based upon the number of necessary parameters $\bigcup P_w$ (product dimensions, manufacturing accuracy, surface finishing, surface roughness, etc) compared with the number of production system parameters $\bigcup P_s$ and needed competencies $\bigcup S_w$ to existing competencies $\bigcup S_s$ [14]

$$\bigcup_{i=1}^{p} P_{Wi} \leq \bigcup_{i=1}^{p} P_{Si}, \tag{1}$$

where p is the number of technological parameters,

$$\bigcup_{i=1}^{q} S_{Wi} \leq \bigcup_{i=1}^{q} S_{Si}, \tag{2}$$

where q is the number of competencies.

Expert estimation of the utilization expedience can be given regarding the following aspects:

s_1 – estimation of technological resources (manufacturing methods, technological possibilities), $s_1 = \{0,1\}$;

s_2 – estimation of the manufacturing competence (necessary and existing skills and knowledge), $s_2 = \{0,1\}$;

s_3 – estimation of the manufacturing organization structure (workshop layout, level of automation, complexity of the manufacturing path), $s_3 = \{0,1\}$.

Complex estimation of the utilization expedience is $S = s_1 \times s_2 \times s_3$. It is the decision of the management, based upon experience and behaviour loop results.

While analysing the behaviour of the production system we can perform order-based comparison of system parameters with overall economic parameters and make strategic decisions in terms of product mix, order fulfilment, enterprise technological excellence or management strategies. Corresponding parameters are shown in Table 1.

Utilization rate U_{ind} is expressed as

$$U_{\text{ind}} = \frac{T_{\text{m}}}{F}, \tag{3}$$

where T_{m} is the machine tool using time and F is the overall working time.

Table 1. Performance indicators for order fulfilment analysis

No	Performance indicator	Primary factor influenced by the performance indicator
1	Utilization rate	Overall equipment effectiveness (OEE)
2	Setup rate	Cost
3	Flexibility index	Cycle time
4	Idle-time rate	Productivity
5	Non-productive time rate	Productivity
6	Variance index	Cost
7	Fulfilment rate	Productivity

Utilization rate of machine tools indicates the rate of useful, productive time of machine tools compared with overall working time (workload). Workload of machine tools depends on the number of shifts. In case of one-shift work, usually utilization rate of machine tools between 75%–85% is considered effective.

Also overall equipment effectiveness (*OEE*) could be used to quantify how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run. *OEE* breaks the performance of a manufacturing unit into three separate but measurable components: availability, performance, and quality (Eq. (1)). Each component shows an aspect of the process that can be targeted for improvement. Availability represents the percentage of scheduled time that the operation is available to operate, often referred to as uptime, performance represents the speed at which the work centre runs as a percentage of its designed speed, and quality represents the good units produced as a percentage of the total units started. *OEE* may be applied to any individual work centre, or rolled up to department or plant levels. This tool also allows for drilling down for very specific analysis, such as a particular part number, shift, or any of several other parameters. It is unlikely that any manufacturing process can run at 100% *OEE*. Many manufacturers benchmark their industry to set a challenging target, 85% is not uncommon:

$$OEE = A \times P \times Q, \tag{4}$$

where A is availability, P is performance and Q is quality.

The setup rate is defined as

$$S_{\mathrm{ind}} = \frac{T_{\mathrm{sp}}}{T_{\mathrm{m}}}, \tag{5}$$

where S_{ind} is the setup rate and T_{sp} is the setup time (time needed for converting a manufacturing process from running the current product to running the next product).

Setup rate indicates the percentage of time needed for converting a manufacturing process from running the current product to running the next product, compared with overall working time of machine tools. The less time is needed for setup compared with overall working time of machine tools, the higher is efficiency.

Flexibility index is defined as

$$F_{\mathrm{ind}} = \frac{nT_{\mathrm{sp}}}{NT_{\mathrm{ct}}}, \tag{6}$$

where n is the number of different types of workpieces in a time period (nomenclature), N is the production amount of workpieces in a time period and T_{ct} is the average cycle time in a time period.

Cycle time is measured by the amount of time per unit (e.g., hours/part). Cycle time is a measure of throughput (units per a period of time), which is the reciprocal of the cycle time. Lead time and cycle time are related to work in progress (W) in the entire process, in a relationship described as:

$$L = T_{\mathrm{ct}} \times W, \tag{7}$$

where L is the lead time and W is work in progress, and

$$L = \frac{W}{T}, \tag{8}$$

where T is throughput.

Lead time is measured by elapsed time and can be expressed as a sum of transportation time, setup time, control and measurement time, operation time and idle time.

Idle time, also called waiting time, indicates stoppage of work of employees or machines or both due to any cause:

$$I_{\mathrm{ind}} = \frac{T_{\mathrm{i}}}{L}, \tag{9}$$

where I_{ind} is idle time rate and T_{i} is idle time.

Non-productive time T_{nt} consists of all times when no value is created to the customer:

$$T_{\mathrm{nt}} = T_{\mathrm{tr}} + T_{\mathrm{sp}} + T_{\mathrm{mc}} + T_{\mathrm{i}}, \tag{10}$$

where T_{tr} is transportation time and T_{mc} is measurement and control time.

Also non-productive time rate T_{ind} can be calculated:

$$T_{\mathrm{ind}} = \frac{T_{\mathrm{nt}}}{L}. \tag{11}$$

Variance index V_{ind} and fulfilment rate R_{ind} can be calculated as

$$V_{\mathrm{ind}} = \frac{n}{N}, \tag{12}$$

$$R_{\mathrm{ind}} = \frac{q}{Q}, \tag{13}$$

where q is orders fulfilled in time period and Q is total number of orders per time period.

After a positive decision of order fulfilment in an enterprise, the optimal use of production system resources is essential, targeted to optimized resources allocation.

4. OPTIMAL USE OF TECHNOLOGICAL RESOURCES IN PRODUCTION FLOW ORGANIZATION

Performance of a manufacturing system is realized through completing technological tasks. The result depends on the fact how production system is organized, tasks formed and forwarded to workstations. Inputs to this activity are production volume and product mix. The main parameters, describing expediency of the use of technological resources, are:

- extent of using technological resources;
- extent of using machine tools;
- extent of flexibility – exchangeability of technological resources.

Factors that determine how well production system is realized are the following:

- suitability of the company's technological resources to the company's profile;
- efficiency of use of these technological resources in production.

The optimal manufacturing planning is traditionally based on the use of mathematical programming by optimizing the objectives that represent the results we want to achieve and considering possible constraints existing in production. This approach can be used in determining optimal number of machine tools.

The choice and type of machine tools have a strong direct influence on the efficiency of the company. Capacity decisions have a major impact on all other production planning issues (e.g., aggregate planning, demand management, sequencing and scheduling, shop floor control). Once we have decided that we need to add capacity, the question arises: how much and when should capacity be added? To estimate the need for using additional resources and the optimal level of inventory, both product-mix planning and aggregate planning models can be used. In both models decisions are related to corresponding constraints. For the need to increase (decrease) the accessible capacity, different tools of sensitivity analysis or post-optimality analysis can be used.

Optimizing technological routes and dividing production operations among workstations are the most essential tasks in addition to determining the number of required resources. The model for determining numerically technological resources is the following:

$$\min \sum_{j=1}^{J} (X_j P_j + C_j \sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_i k_j t_{ikj}), \tag{14}$$

subject to constraints:

$$\sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_{ikj} t_{ikj} \leq X_j F_j \eta_j, \quad j = 1, 2, \ldots, J,$$

$$\sum_{j=1}^{J} Y_{ikj} = N_i, \quad k = 1, 2, \ldots, K, i = 1, 2, \ldots, I,$$

$$X \geq 0, \quad X_i = int,$$

$$Y_{ikj} \geq 0, \quad Y_{ikj} = int,$$

where i is the type of processed workpiece (from the product mix), N_i is production amount of workpieces in a time period, j is the type of the machine tool, I is the number of types of possible workpieces for processing using machine tool j, k is the number of processing types, J is the number of types of machine tools, which enable to perform the processing type k, t_{ikj} is time of realization of the process ik using machine tool j, F_j is effective work time front of the machine tool j, η_j is planned loading coefficient of machine tool j, P_j is the price of the machine tool j used for processing workpieces of type i (from the product mix), C_j is the cost of a working hour of machine tool j, X_j is the number of machine tools of type j used for processing workpieces of the type i (from the product mix) and Y_{ikj} is the number of workpieces of type i used for processing operation k using machine tool of the type j.

Exploitation of machine tools has to be as unvaried as possible. Bottleneck cannot be evoked at a machine tool, which has several technological possibilities. Hence the need for choosing processing methods in the phase of composing manufacturing routes and alternative routes, if necessary. Therefore, the expert system should belong to the information system of technological resources management.

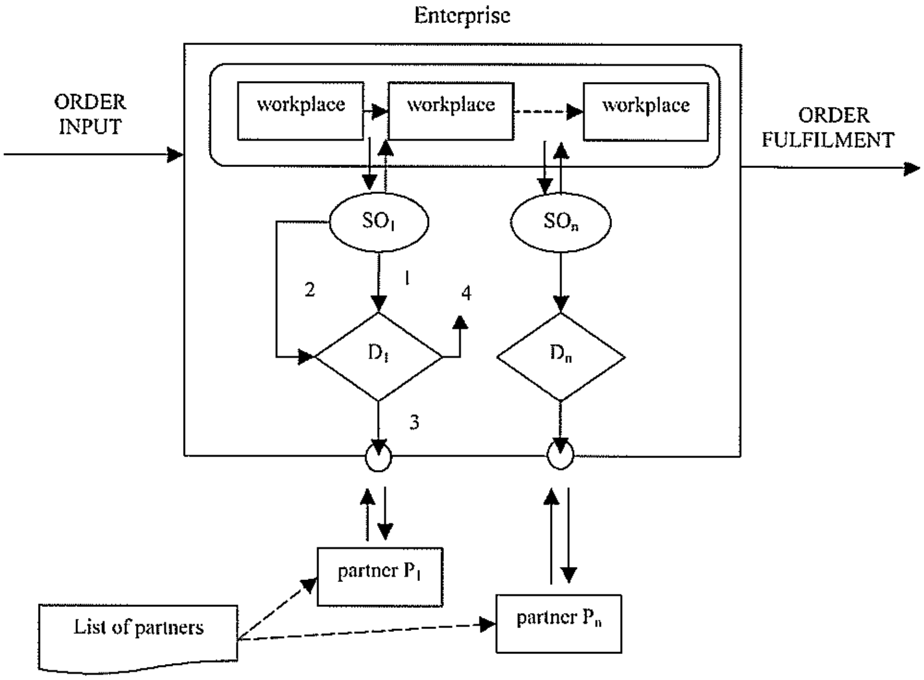
5. NETWORK MANUFACTURING AND RISK ASSESSMENT

Every order has to be fulfilled in time and according to quality requirements. The main problem lies in cost optimization. If the company lacks previous experience, competencies and technological possibilities (Fig. 2), possible risks arise with fulfilling the order in time and with high quality, and staying on the planned level of expenses at the same time. In this case, network of partners can be used.

Network manufacturing and formation of clusters have increased considerably in recent years. The main cause lies in customers' pressure on quality and order fulfilment time, but also in need to minimize production costs. It is quite difficult and is not always beneficial to strive for technological consummation. When a company has defined its technological capabilities on both levels, production system and work places, it expects it from other partners as well. Thus, a network with certain resources and capabilities is created that can increase or decrease, depending on circumstances.

E-manufacturing (e-mfg) can play a key role in improving the efficiency, throughput and responsiveness of a company. E-mfg is the use of (web-based) information technology to exchange efficiency of manufacturing and related processes. E-mfg is the application of open, flexible, reconfigurable computing techniques and communication for the enhancement of efficiency of the whole supply chain. As e-mfg is supported by information technology (such as Internet) and has the capability in multi-site management, it will foster and improve the competitive capability of manufacturing in the global competition [15]. E-mfg can be determined as IT-based manufacturing model, optimizing resource handling over entire enterprise and extended supply chain [16]. Using Internet and tools that support commerce functions, one can find new customers, reduce the costs of managing orders and interacting with a wide range of suppliers and trading partners, and even develop new types of informationa-based products, such as remote monitoring and control software and other online services [17]. The emphasis is on the aspect that decisions made by implementing e-mfg affect the whole supply chain and they must always be made to benefit the entire supply chain, not just an individual manufacturing company.

Outsourcing single parts of an order presumes risk assessment and making certain decisions (Fig. 3).



SO – places, where it is decided whether to perform an action by itself or to outsource
D – decision about performing by oneself or outsourcing
1 – risk assessment (what are the risks when performing by oneself or outsourcing)
2 – analysis of technological capabilities of a partner
3 – outsource is more effective than performing an action by oneself
4 – performing an action is more effective than outsourcing

Fig. 3. Generalized scheme of network manufacturing.

It is possible to determine the basis for creating a network of possible partners by collecting and analysing data that can be used for outsourcing part of the orders. Mainly three types of risk factors exist for outsourcing an order to possible partners:

- partner's location;
- technological capability of the partner;
- trustworthiness of the partner.

When planning to use several partners for order fulfilment, the transport routes should be optimized and minimum length of transport routes should be determined:

$$\min \sum_{i=1} \sum_{j=1} f_{ij} d_{ij} p(j), \tag{15}$$

where f_{ij} is the flow matrix F, whose (i, j) element (part of product) represents the flow between facilities i and j, d_{ij} is the distance matrix $D\ (i, j)$, the elements of which represent the distance between locations i and j, and $p\ (j)$ is the location to which the facility (partner j) is assigned.

Risk assessment consists of an objective evaluation of risk, in which assumptions and uncertainties are clearly considered and presented. Part of the difficulty of risk assessment is that both quantities, in which risk assessment is concerned, potential loss and probability of occurrence, can be difficult to measure. This problem and extent of faults can be decreased by creating empirical information basis in the company. Parameters, forming the information base, are the following:

- nature of orders (parametrical and functional description of products);
- evaluation of company's technological capabilities (utilization rate index);
- analysis of company's performance in order fulfilment (Table 1);
- lengths of transport routes in case of network manufacturing;
- index of technological capabilities of partner companies;
- index of trustworthiness of partner companies.

On the basis of these expert estimations, it is possible to evaluate the risk R_{total} of outsourcing parts of the order to partner companies:

$$R_{\text{total}} = \sum L_i P(L_i), \tag{16}$$

where L_i is the magnitude of the potential loss when the risk of type i occurs and $P(L_i)$ is the probability that the risk of type i occurs.

Types of the risk i may be different, for example, delayed delivery time for product assembly, work does not respond to quality requirements, fluctuation in the product price, etc.

Estimation of the total risk that may occur in case of network manufacturing helps to minimize potential losses to the company that arise because of overestimating the partners' capabilities. Presuming that technological processes are becoming more and more complicated and installing all of them economically inefficient, network manufacturing becomes more perspective.

6. CONCLUSIONS

The key factors that can influence the company's production capability have been investigated. Technological possibilities play an important role in designing operational and route technologies but also in management of the whole production process. Framework of the technological resources management system and network manufacturing with the aim to optimize the use of technological capabilities and to increase efficiency through extended use and exchange of technological resources were presented. Information system for resource management inside one company as well as in the network of companies can be one part of the more wide e-manufacturing system. For smooth performance of the resource management system as a part of more wide e-manufacturing system, unified ontology and semantics are needed. Ontology model is important from two aspects:

1) explaining products flow through the production process with the aim to optimize production costs and analyse other parameters that can help to minimize the lead time;
2) building up architecture for e-manufacturing system software.

The results of this phase are used for further development of the database and system for controlling, managing and exchanging manufacturing services, based on technological resources of the companies in the network.

Standardization is important not only regarding exchange of information in the manufacturing network within and between the companies, but also regarding working methods, etc. It will increase quality and productivity and decrease cost, making cooperation more efficient.

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Tehnoloogiliste ressursside kasutamise otstarbekuse hindamine tootmisvõrgustikus

Kaia Lõun, Jüri Riives ja Tauno Otto

Tänapäeva tootmist iseloomustavad põhimärksõnad on kuluefektiivne tootmine ja tehnoloogial põhinev tootmine. Efektiivsuse ja tootlikkuse saavutamine eeldab väga head töökorraldust, ressursside ning kompetentsi täpset vastavust tootmisnõuetele ja kõigi võimalike raiskamiste ning lisakulutuste pidevat jälgimist ja kohest reageerimist nendele ehk parendamisprotsessi pidevat reaalset toimimist. Käesolevas artiklis on lähtutud tootmissüsteemi esitluse ontoloogiast ja kirjeldatud tootmisressursside ning tootmiskompetentsi haldamise metoodikat nii tellimuse täitmise eelses kui ka järgses staadiumis. Samuti on esitatud ressursside

jaotuse ja tellimuse osade väljamüümise otstarbekuse ning vastavate riskide haldamise üldised põhimõtted. Kirjeldatud põhimõtete järgimine ettevõttes võimaldab tootmisressursse ratsionaalsemalt kasutada ja hinnata olemasoleva kompetentsi ning seadmete tehnoloogiliste võimaluste mõju tootlikkusele ja ettevõtte efektiivsusele.

Paper V

Lõun, K., Riives, J., Otto, T. (2012). Workplace performance and capability optimisation in the integrated manufacturing, *Proceedings of 8th International Conference of DAAAM Baltic Industrial Engineering*. Tallinn: TUT Press, 518–523.

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WORKPLACE PERFORMANCE AND CAPABILITY OPTIMIZATION IN THE INTEGRATED MANUFACTURING

Lõun, K.; Riives, J. & Otto, T.

Abstract: *Globalization and higher competition sets companies a demand to search for possibilities how to improve performance and competitiveness. Main resources influencing company's performance are human resources and their skills and competences and machine tools with their technological possibilities. Human resources with their skills and competences and machine tools with their technological possibilities form technological capability of workplace. In this article, role of workplace as one key parameter in formation of company's performance and competitiveness is analysed.*

Key words: production capacity, factory of the future, workplace, lead time, lean manufacturing, optimization of resources.

1. INTRODUCTION

In nowadays, manufacturing enterprises have to meet a hard competition and increasing global demands for more functional products with higher quality. This has caused changes from traditional order fulfilling structures to demand-driven, customized manufacturing with lower waste and "Lean" and "Green" principles introducing, often referred to as the Factory of the Future (FoF) [1].

A company is an entire system that has to find the most effective and efficient ways to use its resources and carry out activities for continual improvement with an aim to be competitive and efficient. The aim of all organisations is profitability and therefore to create outputs that are worth more than the inputs.

Company's performance directly depends on the management of value creation processes: the performance is generated by the efficacy of goods-and-services production processes, associated with external factors of market positioning [2]. This starts from the performance of the workplaces. In the current article the methods and tools for workplace performance optimization are given.

2. ROLE OF A WORKPLACE IN PRODUCTION SYSTEM EFFICIENCY

The performance of the goods-and-services production system [3, 4] is generated by single workplaces. The performance of workplaces is generated by the competencies available, depending on two main factors: (i) the levels of competencies available and (ii) the ability to allocate and coordinate competencies along business processes [2]. Another factor influencing performance of a production system is technological possibilities of machine tools. Research carried out in the framework of INNOMET-EST project [5] showed that technological level of the company and existing competences [6] have direct impact on productivity, competitiveness and sustainability of an organization [7]. Engineering of production systems is described in literature [4, 8] and product manufacturing process and structure of production times in [9].

Workplace is a part of production system that plays certain role in product's manufacturing process. This role is described by (i) technological possibilities of machine tools and (ii) competences (knowledge, skills and personal abilities) of personnel [6]. Together these form capability of workplace that is an important parameter in production planning process [10].

Manufacturing time is a sum of times of different operations belonging to production process: processing, assembly, setup, transport, measurement and control, time for ancillary actions as cleaning, etc, and idle time. If we look at production process in wider concept, not only as pure manufacturing process, times for order revision, technological preparation and design, materials purchasing, storage, delivery, etc are added. Main operations of production process, where tangible assets are created, are manufacturing and assembly, but also surface processing operations. Operations in production in which value is created, are manufacturing and assembly. Non-productive operations occur with manufacturing process [11]. With an aim to minimize time for non-productive operations, lean production principles are implemented [12]. Main typical places and causes for occurrence of non-productive times are:

- Machine-tool and its technological possibilities (e.g. automation rate, spindle speed range, work piece and cutting tool changing time, rapid traverse, etc);
- Worker and its competences;
- Workplace organization;
- Organization of work in manufacturing unit;
- Order handling process (procurement, variability in processes, prevention of non-conformities etc).

Non-productive times in some extent are unavoidable, but every organization should seek for possibilities to minimize them.

Workplace is an important part of the production system. Describing workplace, important characteristics are its location, place in production system and technological capabilities of workplace [13]. Technological capabilities of the workplace are a sum of technological possibilities of the machine tool and competences of the worker. Location of workplace is important in the viewpoint of estimating alternative routes. In case of network manufacturing, location of a workplace in the same route could be also in some other company. Usually, alternative workplaces are possible to use. To minimise transport time, locations of workplaces should be as close to each other as possible or single-level processing should be used [10]. In the viewpoint of optimal use of technological resources, the most appropriate resource for a certain operation should be used. For describing a workplace, two indicators are used, which are also used for initial estimating expediency of the route (see eq. 1).

$$W = \{P_i, M_i\},\ i = 1, 2, ..., m \qquad (1),$$

where W – workplace, P – location of workplace; M – machine tool, i – number of locations and machine tools.

We assume that there is one machine tool with certain technological possibilities in one workplace. Technological possibilities of a machine tool give preconditions to carry out certain operations and processing of the detail [14]. If technological possibilities are not appropriate for processing requirements (e.g. shape of surfaces, accuracy of processing etc), then this machine tool cannot be used for the operation [13, 14]. In the same time, technological possibilities of a machine tool are not possible to use without competences of a machine tool operator. List of competences is formed by combination of technological possibilities of a machine tool and operations needed to process a certain product. Technological possibilities of machine tool and competences of machine tool operator determine workplace capability (see eq. 2).

$$C = (\{V\}, \{K\}) \qquad (2)$$

where C – workplace capability, V – technological possibilities of machine tool, K – competences of machine tool operator.

Processing time depends on main and ancillary times that are directly connected to technological possibilities of machine tool and competences needed to use them. The aim is to minimize machining time that creates preconditions to minimize net value of the operation and cost and duration of processing.

Workplace's capacity creates preconditions for achieving efficient realization of manufacturing operation (see fig.1). In case of insufficient conditions, it would be more reasonable not to take the order or consider the possibility of outsourcing. The more complicated and complex are the products, the more actual and effective could be network manufacturing [14, 15].

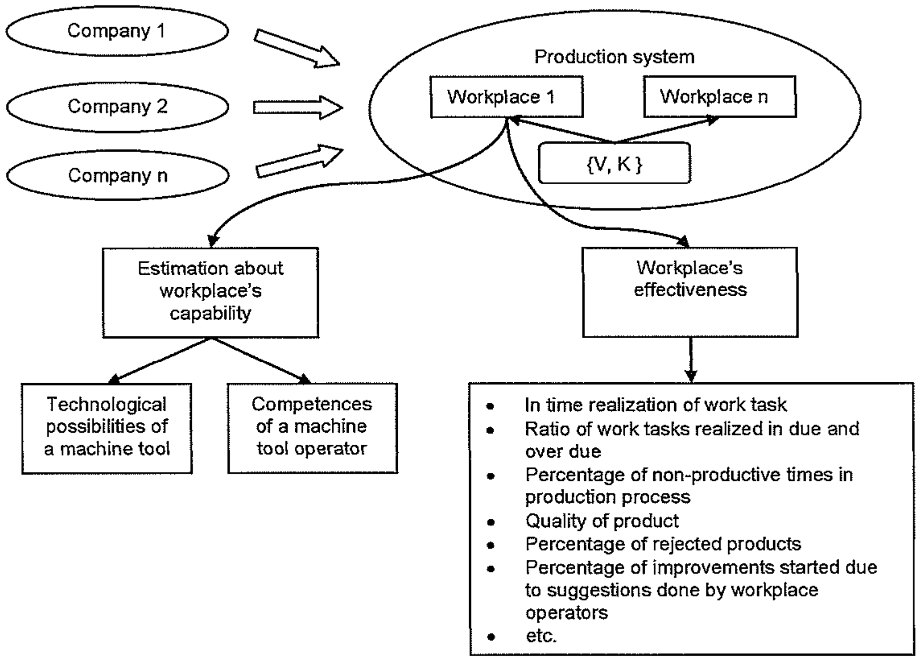

Fig.1. Description of capacity and effectiveness of a workplace

3. OPTIMIZATION OF WORKPLACE EFFECTIVENESS

Estimating the rate of fulfilment of strategic objectives, determining Critical Success Factors (CFS) and related Key Performance Indicators (KPI) is essential [16, 17, 18]. Roots of the effectiveness of a workplace lie in production planning and are realized via order handling process in different workplaces. Production planning task becomes even more difficult as manufactured products are often quite different by complexity and technology. Additional costs typically are caused by poor organisation of production, unpractical production structures, and incompetence of workers.

In [10] was described event and process engineering design model proceeding from the needed complexity. The basic loops in this model are:

- requirement loop, defining technological possibilities/competences needed for order fulfilling; it associates these with existing possibilities / competences and production system technological capabilities;
- behaviour loop, observing performance level (activities) according to order fulfilment measures of efficiency and

compares outputs with expert estimation of system capability.

Requirement loop is a tool of planning. It determines requirements for realizing a certain operation in a workplace. Researches [5, 11] have shown that productivity of a workplace decreases in case of lack of needed competences. The necessity for competences depends on complexity of work tasks [6, 7]. To carry out tasks successfully and with high productivity, level of existing competences has to be higher or at least equal of the level of competences needed. If not so, a company should calculate the rationality of accepting this order. One rational way would be outsourcing the order (fully or partially). Preconditions for development of network manufacturing are good overview about technological possibilities of partner companies, efficient tools for offer and order management and efficient collaboration with partners [10]. Additionally, actual level of technological possibilities has to be equal or somewhat higher of the level of technological possibilities needed for manufacturing the product [13]. To analyse impact of different technological parameters of a machine tool to the criteria of effectiveness (e.g. productivity or net value), the method of Lagrange multipliers could be used [19]. Complexity and high cost of technologies creates the necessity for network manufacturing. Behaviour loop is for measuring work efficiency and for realizing continual improvement principles (see Fig. 2). KPI-s are planned for workplaces taking into account the competences of the operator and technological possibilities of the machine tool of this workplace. We have transformation process where inputs (competences, technological possibilities) become outputs as the result of processes taking place in workplace. Typical outputs demonstrating effectiveness and efficiency of the process are quality, productivity (number of products produced in certain time), net value of the product etc. In reality, deviations may occur, so planned outputs are not achieved: quality non-conformances, time overlapping, resource overlapping etc. These losses have negative impact on the performance, e.g. nonconforming quality means increase of costs because of re-processing or producing new product and/or exceeding time limits. Therefore estimating the performance and analysing the results is very important.

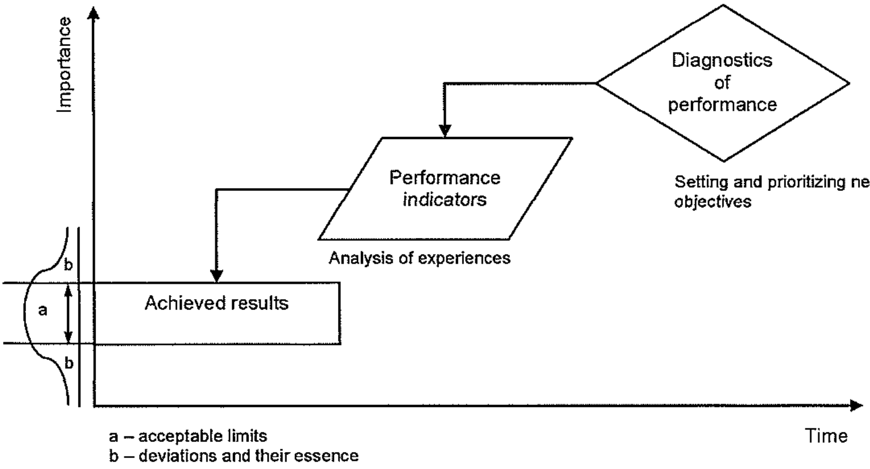

Fig.2. Behaviour Loop interpretation

These losses can be estimated by following quadratic loss function (see eq.3) [20].

$$L(y) = K\,[(y-m)^2 + \sigma^2] \qquad (3)$$

where L is the loss, $K = \mathrm{A} / \Delta$, A – loss per unit item, Δ = upper tolerance limit / lower tolerance limit, Y, σ – the mean and standard deviation of the capability, respectively, m – target value.

Additional costs are caused by defects or scrap that occurs after processing and their correction means extra cost because of rework.

To avoid excessive costs, performance indicators should be determined on the basis of experiences that are obtained in order handling. These performance indicators (complexity of processed details, batch sizes, order handling deadlines, productivity etc) are basis for decision-making in the planning phase, but also give input to improvement process. To start improvement actions, occurrence of waste and its reasons have to be determined. This has to be done on workplace basis.

So we reach to proactive (preventive) actions [21, 22] which percentage should increase. In organizational behaviour the proactive behaviour (or proactivity) by individuals refers change-oriented and self-initiated behaviour in the workplace. Proactive behaviour involves acting in advance of a future situation, rather than just reacting. Proactive behaviour can be contrasted with other work-related behaviours, such as proficiency, i.e. the fulfilment of predictable requirements of one's job, or adaptivity, the successful change initiated by others in the organization. Proactivity that originates from workplace is bearer of transformation and improvement process in the organization. Transformation process itself, reactivity and proactivity are main functional processes that company should continually manage, measure and improve.

4. CONCLUSIONS

The article material is approved by the consortium of companies belonging into Innovative Manufacturing Engineering Systems Competence Centre IMECC and the theoretical results are used in e-manufacturing system development, available as demo version at http://www.imecc.ee/.

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Paper VI

Lõun, K., Lavin, J., Riives, J., Otto, T. (2013). High performance workplace design model. *Estonian Journal of Engineering*, 19, 1, 47–61.

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High performance workplace design model

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Abstract. Processes are very fast in contemporary dynamic, turbulent and continually changing world. Systems supporting these processes become more and more complicated and are in mutual interaction. Design of high performance workplaces becomes more and more important for achieving competitiveness. In the current article workplace capability, formed by capability of technological resources and human resources, as well as lean manufacturing principles are analysed with an aim to design high performance workplaces.

Key words: workplace, technological resources, lean manufacturing, critical success factors, key performance indicators, process improvement, e-manufacturing.

1. INTRODUCTION

System is a set of interacting or interdependent entities that have certain functions and objectives. Workplaces are the elements that form systems in organizations. Workplaces have important role in every company and therefore the development and raising the performance of workplaces are critical for every company [1].

Traditionally a company is characterized by its structure, processes and technological possibilities of machine tools [2,3]. Entire view is more complicated, every level of industrial world [4] has its own place and role in creating a full image of the industry as well as in formation of objectives and increasing the rate of fulfilment of these objectives of an organization and its units. In Fig. 1, structural levels of the industrial world and general estimation criteria as well as conditional time delay between action and expected result are shown.

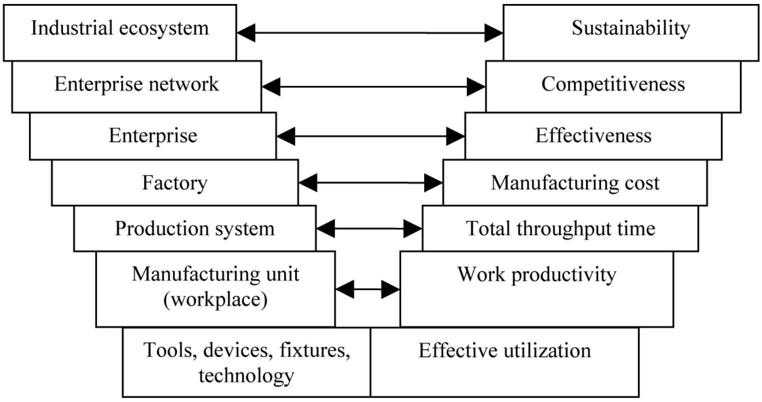

Fig. 1. Event–result interaction in practical structuring of a product – process levels towards intelligent network manufacturing.

In Fig. 1, only general (traditional) indicators [5] are presented, certain result indicators are connected with them. Indicators that are relevant for the strategy are called critical success factors (CSF). CSFs present the success of the company, business, project, process, etc. They monitor the achievement of the mission (Fig. 2). Company's strategic objectives are based on the mission that describes the company's main reason of existence [6]. Strategy is developed, based on the analysis of the operating environment of the company that allows describing the current situation and forecasting the future. One instrument for strategic communication is balanced scorecard (BSC) [6] that links performance metrics, derived from the enterprise strategy with the company's vision and strategic critical success factors, objectives and resources (Fig. 2).

Once the CSFs for each perspective are identified, it is important to identify the key performance indicators (KPI). KPIs quantify the objectives and reflect strategic performance and success of a company (or a process or a workplace). The application of KPIs provides executives with a high-level (company level) or real-time view about the progress in a process or workplace level. The main groups of KPIs are described in [7].

Production performance design matrix in a company and the general picture of a production performance monitoring system is presented in [8]. Starting from [8] and taking into consideration [9,10], the performance description model is given in Fig. 2. The model consists of three related parts:

– phase of forming company's objectives and tasks;
– phase of planning activities (for subunits, processes, workplaces etc);
– phase of estimating the results (results of simple events and actions as well as processes, projects or company as a whole).

The aim of the model is to consider a company as a system that is a part of the economic environment and to connect clearly different levels of company activities and theories used for estimating their performance.

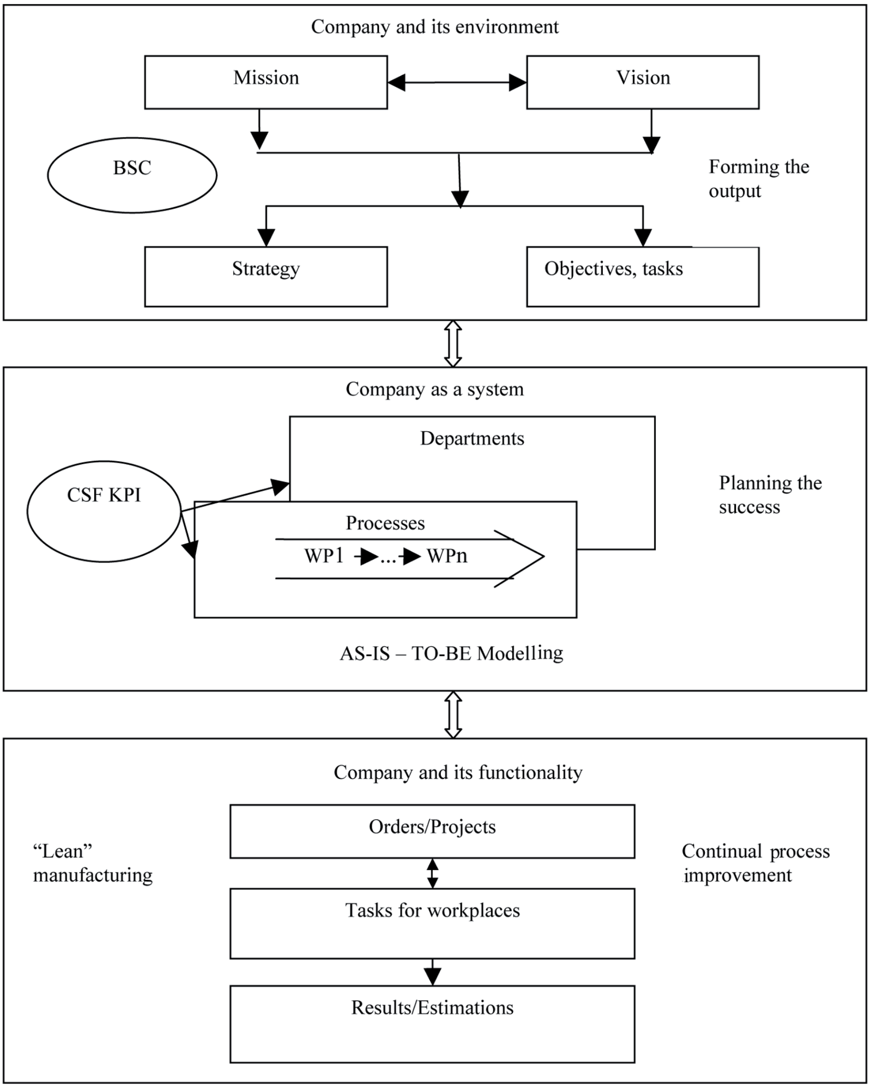

Fig. 2. Performance description model on the company level.

Cluster, company, manufacturing unit, and workplace – all these are complex and multifunctional systems and different indicators are used for the measurement of their performance and success. Performance and development are integrated with the aim to develop the system. Systems' engineering is an interdisciplinary process that ensures that the customers' needs are satisfied throughout the system's entire life-cycle [11–13].

Functional development of the connection between management and workplaces is an important challenge and objective of intelligent manufacturing. To achieve effective and flexible connection between management and workplaces, well-functioning model for estimating performance of workplaces has to be developed. At the same time, effective performance of workplaces is possible only when all requirements to the workplace are fulfilled.

2. MAIN PRINCIPLES OF WORKPLACE DESIGN

Workplace is an important part of the company, business process or production system. Workplace is designed for carrying out certain tasks. Essence of the workplace is described in [14]. Describing workplace in a production system, the important characteristics are its location, place in the production system, functionality and technological capabilities. Technological possibilities [15] of a machine tool and competences of its operator [16] determine the workplace capability. Workplace capability forms the basis for determining which details it is possible to process at this workplace, and creates preconditions for efficient performance (productivity, products' quality, expedient use of work time, accuracy of fulfilling work tasks, etc).

Activity–result relationship is general. Better results, compared with competitors, create preconditions for greater success in global market. Management theories [17] refer to the effectiveness of teamwork; quality management is based on the Deming's Plan (P) – Do (D) – Check (C) – Act (A) circle and process management principles [18,19]. According to these theories and practical experience with implementing quality management systems in different companies, it is clear that role and importance of every workplace performance plays more and more important role in the effectiveness of a manufacturing company (Fig. 3).

Leadership, formation of strategies, providing resources and assuring competitiveness are tasks of the management. Activities for continuous improvement that assure quality and ensure productivity, take place at the workplace. Performance of workplaces makes basis for the whole company's success and effectiveness. Therefore critical success factors or global achievement results are not enough. Processes have to be managed on the basis on actions taking place in workplaces, and their evaluation, analysis and decisions.

Workplace is part of a system that belongs to some unit (e.g. production unit, production system). Thus hierarchy of systems is formed in every company that has certain capability (technological possibilities and competence) and results that enable to estimate their success (depending on the hierarchy of the system in economic environment). Description of the capability and effectiveness of a workplace is presented in [1]. Workplace is a very important part of a production system or production process, because in a manufacturing process the workplace is a part of a chain of organizational-technical activities and fulfils functional tasks prescribed by production technology. Workplace has to enable manufacturing products that meet the quality requirements and to operate successfully. Workplace productivity is usually used for estimating workplace success [14]. Although productivity measurement is important, it does not allow to estimate

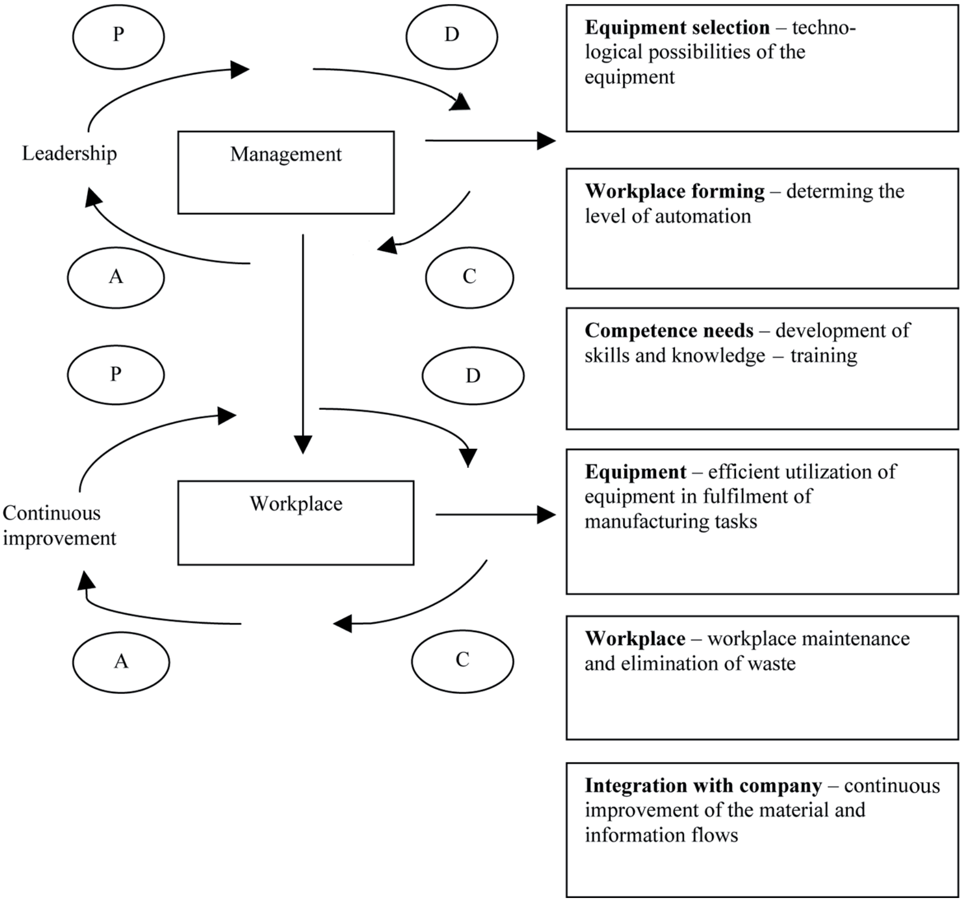

Fig. 3. Steps in workplace development.

adequately the capability of the workplace. The complexity of relations, related to the fulfilment of work tasks and groups of factors having influence to workplace performance, is illustrated in Fig. 4.

In Fig. 4 there are presented influence factors that could be divided into four groups:

- work preconditions;
- workplace specifications;
- source factors;
- impact factors.

As important as the essence of a workplace is its place in the order handling process. Essence and role of the workplace in the order handling process (Fig. 5) is based on the model of ontology of a production system [7].

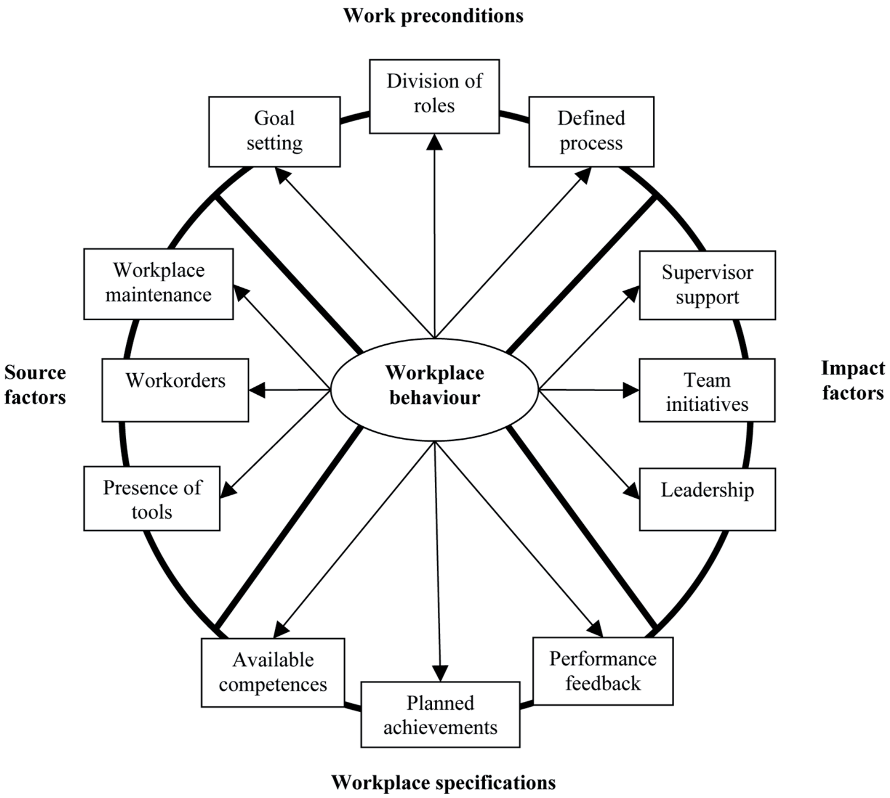

Fig. 4. Factors having influence on workplace effectiveness.

3. MODEL FOR WORKPLACE PERFORMANCE ESTIMATION

Offer and order handling is viewed as a complex activity. Effectiveness of this activity forms the basis for the company's effectiveness and profitability. How effectively are workplaces organized and how effectively they fulfil work orders, influences directly effectiveness of order fulfilment. Machine time (main time with support time) rate to the duration of the production cycle in a workplace should be as high as possible. To achieve this, workplace centred methods to raise effectiveness should be used (Fig. 5).

In Fig. 5, the following abbreviations are used 5S – workplace organization method, including sorting, setting in order, sweeping, standardizing and sustaining the practice; JIT – just-in-time; 7waste – seven wastes of lean philosophy that do not add value (transportation, inventory, motion, waiting, overproduction, overprocessing, defects – the Kaizen methodology for continual improvement); Kanban – a scheduling system for lean and just-in-time production.

Production system is a number of workplaces that are used to perform certain manufacturing operations according to the manufacturing process and technology. Structure of the manufacturing process (Fig. 6) creates basis for company's

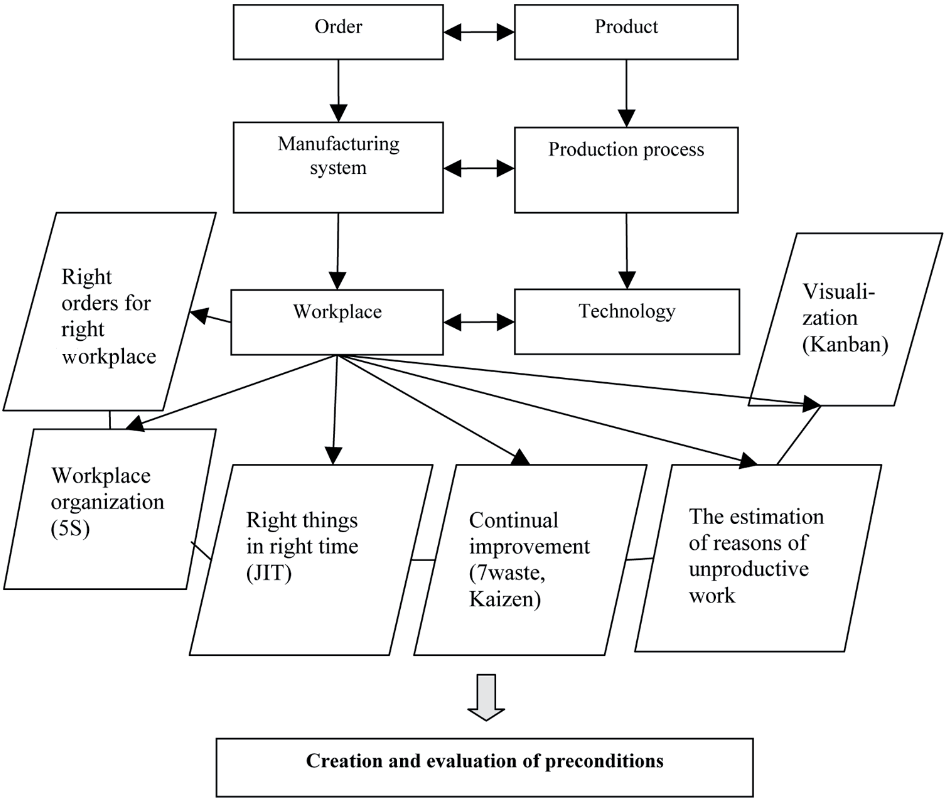

Fig. 5. Success factors of a workplace.

technological capability and possibilities to raise productivity by using rational technologies.

Technological improvements are usually expensive and their influence is considerable only by implementing cost-effective work organization at the same time. Main elements used in cost-effective work organization, related to the workplace, are presented in Fig. 5.

Technological preparation, related to product manufacturing and production planning, creates prerequisites for effective work at the workplace. Preparation should not be underestimated because it creates preconditions for zero defects manufacturing, achievement of planned productivity, etc (optimization of manufacturing routes, use of resources, etc).

Elaborating operation technology, one aim is to minimize product manufacturing costs at the workplace (Fig. 6). As usually different products have to be manufactured that requires different resources, use of alternative routes should be considered, with an aim to minimize throughput time at the same time. From here arises a task of modelling uncertainties and variability in the manufacturing environment [20]. Network manufacturing possibilities should be also considered for achieving the best results.

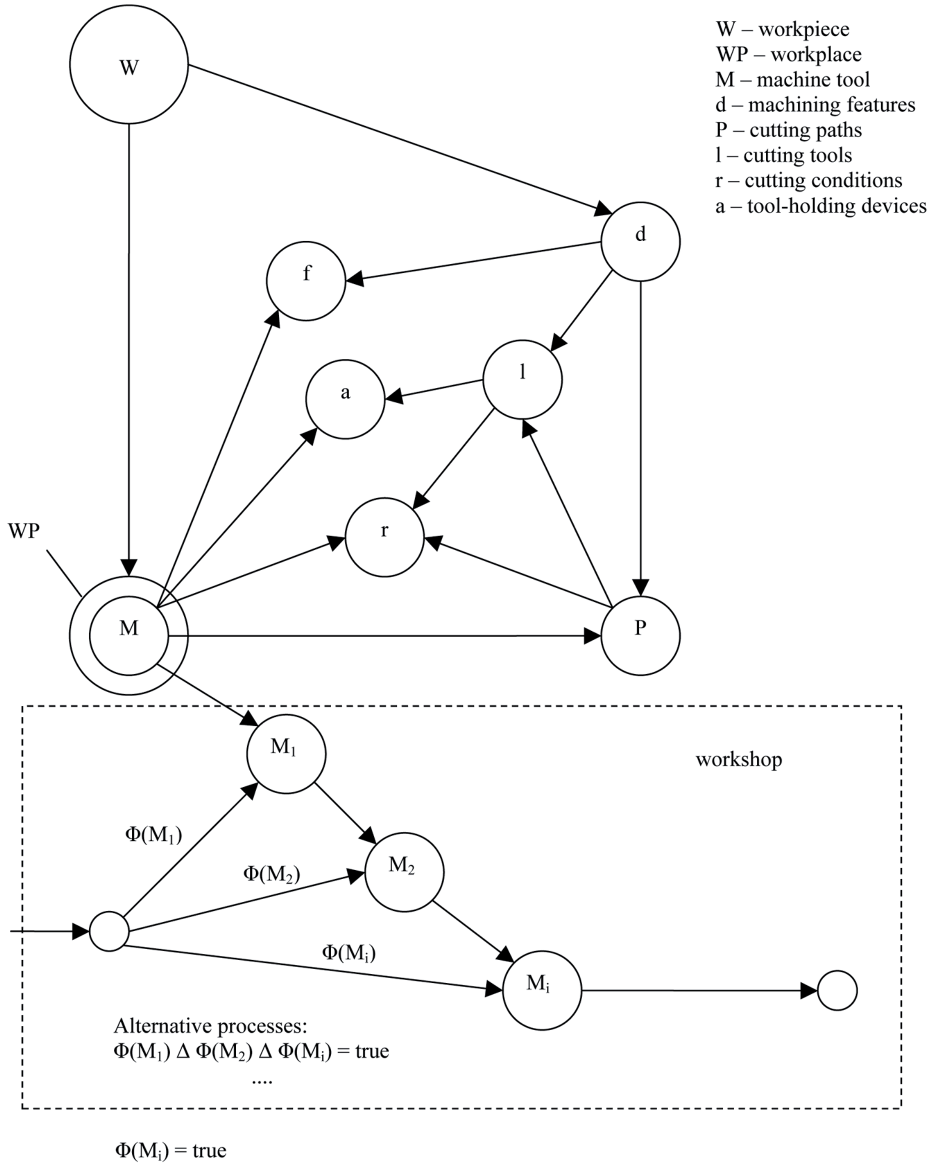

Fig. 6. Structure of the production process.

Use of planning models creates preconditions for minimizing operation cost and shortening the cycle time of product batch, but does not assure elimination of possible waste and fulfilment of planned tasks. Therefore the implementation of a complete model of performance is important.

Important is to pay attention to implementation principles of cost-effective manufacturing (eliminate waste). Hence, important criteria for evaluating workplace performance are:

- evaluation of the conformity of technical realization to the requirements;
- evaluation of preconditions for effective manufacturing.

Every workplace and department, participating in the order handling process, should know its tasks and seek for maximum efficiency and effectiveness in accomplishment of its tasks. Results are seen after the tasks (activities according to work order) are finished (Behaviour loop). Monitoring the results and comparing them with planned results is an important action in estimating the workplace performance.

Conceptual model of a high performance workplace is presented in Fig. 7. The model enables the following procedures:

- estimation of the suitability and readiness of the workplace for carrying out planned tasks;
- estimation of the workplace performance;
- comparison of the planned and actual results and presenting main nonconformities;
- risk assessment and determination of its importance;
- finding inputs for improvement the process and analysis for raising effectiveness.

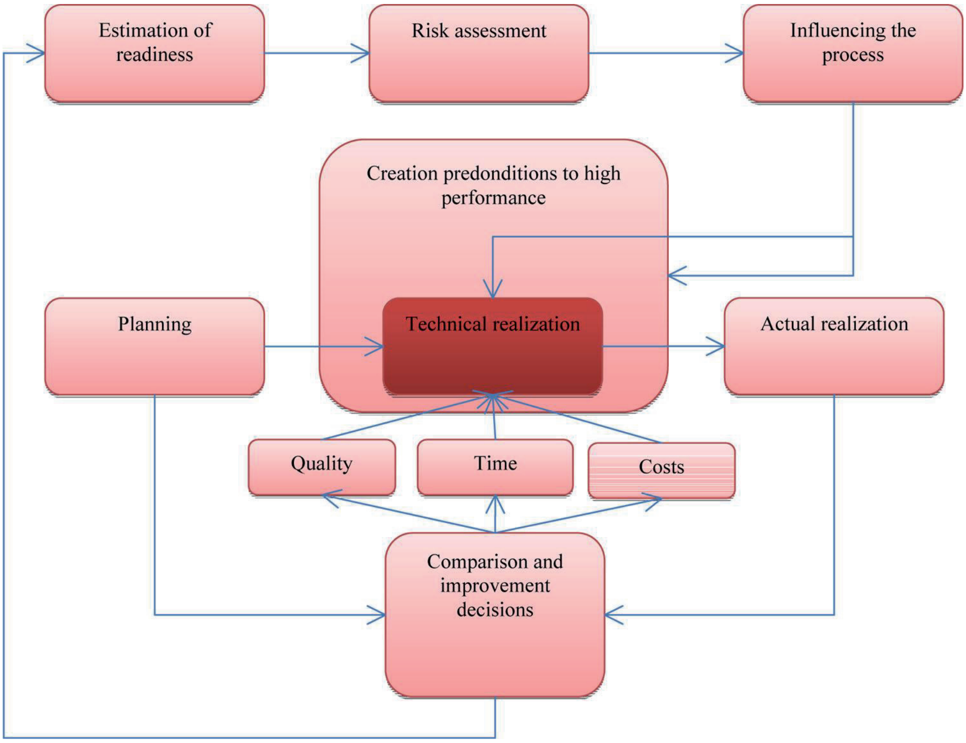

Fig. 7. Conceptual model of workplace effectiveness.

Estimation of the technical realization could be viewed from three viewpoints.

1. Quality of technical realization Q depends on the ratio of high-quality products to the total number of manufactured products:

$$Q = \frac{K_k}{K_s} \times 100\%, \tag{1}$$

where K_k is the number of high quality products and K_s is total number of manufactured products.

2. Estimation of the realization time (time spent for realization) T:

$$T = \frac{T_t}{F} \times 100\%, \tag{2}$$

where T_t is the time, needed for fulfilling the orders and F is the work time fund

$$T = \frac{\Sigma T_H}{F_s}, \tag{3}$$

where T_H is total time spent for order handling and F_s is the shift's work time fund.

3. Estimation of costs related to technical realization K is calculated as

$$K = 1 - \left| \frac{K_t - K_p}{K_t} \right|, \tag{4}$$

where K_t is actual costs and K_p is planned costs.

Index of efficiency of technical realization of a workplace can be calculated as

$$I = QTK. \tag{5}$$

Quantitative assessments are made possible by the estimation of technical realization level, while evaluations of the creating preconditions for efficient manufacturing are rather qualitative [21,22]. Such evaluations are comparative, e.g. 20 keys (20 focus areas that will help the organization to build a sustainable continuous improvement culture), EFQM (European Foundation of Quality Management Excellence model), SPICE (Software Process Improvement and Capability Determination), etc. By evaluating creation of preconditions for efficient manufacturing, the following aspects are important:

- maintenance of the work environment – 5S;
- preventive maintenance and repair of manufacturing equipment;
- work organization and motivation system;
- management and information flows.

Effectiveness of order handling, effectiveness and competitiveness of a company are based on the performance of workplaces. Order handling is a complex activity that comprises the whole company. All employees have to give their dedication to fulfil their tasks in time and with high quality.

Every company seeks continual improvement. Main characteristics of effectiveness (evaluation factors based only on time) are presented in Table 1.

Explanation of the notations used in Table 1 is the following.

T_{TH} is the order fulfilment time, i.e., time for completing the whole order handling process, starting from receiving an order from the customer until the delivery of the product to the customer. In broader sense, order fulfilment time reflects the time it takes to respond to customer orders. Sometimes a more narrow approach is also used, which is the time period from the receipt of the order and until it is available for packing or shipment. This is also called as the production lead time.

T_{TS} is manufacturing throughput time (also known as throughput time) – the period required for a material, part or subassembly to pass through the manufacturing process. Throughput time could be expressed as the sum of the cycle time, transportation time, final control time and idle time:

$$T_{\text{TS}} = T_{\text{SM}} + \sum_{i=1}^{r} T_{R_i} + \sum_{i=1}^{c} T_{C_i} + \sum_{i=1}^{x} T_{X_i}, \tag{6}$$

where T_{SM} is the cycle time, T_{R_i} is the summarized transportation time in the manufacturing process, r is the number of transportation operations, T_{C_i} is the summarized final control time, c is the number of final control actions, T_{X_i} is the summarized idle time and x is the number of different types of the idle time.

Table 1. Analysis of effectiveness of a workplace and process

Elements of evaluations	Elements of analysis
Order fulfilment time (T_{TH})	Use of working time (importance of value creating time in production process)
Importance of manufacturing in order fulfilment process, % ($T_{\text{TS}}/T_{\text{SM}}$)	Main reasons of non-productive work
Importance of cycle time in throughput time, % ($T_{\text{SM}}/T_{\text{TS}}$)	Level of achieving the objectives Index of employee satisfaction
Importance of machining time in cycle time, % (T_m/T_{SM})	Contribution of a employee as a team-member
Importance of loading and unloading time in cycle time, % (T_p/T_{SM})	Dynamics of effectiveness (changes and improvements in production process)
Importance of setup time in cycle time, % (T_s/T_{SM})	Cost factors and their dynamics in production process
Importance of machining time in cycle time, % (T_m/T_{SM})	Quality assurance
Importance of idle time in throughput time, % (T_X/T_{TS}) and in order fulfilment time, % (T_X/T_{TH})	

T_{SM}, the cycle time, is the period required to complete an operation or a job from start to finish. Cycle time consists of different times:

$$T_{\mathrm{SM}} = \sum_{i=1}^{m} (T_{m_i} + T_{p_i} + T_{s_i} + T_{k_i}), \tag{7}$$

where m is the number of machine tools used to manufacture the product, T_m is the machining time, T_p is the workpiece loading and unloading time in the machine tool, T_s is the machine tool setup time (a period required to make a machine tool ready to fulfil an operation) and T_k is the measurement and control time of the machine tool during fulfilling an operation.

Machining time directly creates value to the product. Workpiece loading and unloading time depends highly on the automation rate. Typically workpiece loading and unloading time is minimized, using, for example, two-position working tables (at one side machining takes place, at the other side loading or unloading of the workpiece). Machine tool setup time depends on the operator's competences but also on technological possibilities of the machine tool. Idle time is non-productive time (during which an employee is still paid) of employees or machine tools or both, due to work stoppage from any cause. Reasons of idle time could be different, e.g., waiting for materials or instructions, waiting previous operation to be finished, walking from one department to another but also power failure, waste of time by the operator (laziness, no motivation). Idle time could be divided into normal idle time and abnormal idle time. Some idle time always remains, but it should be kept as low as possible. Therefore especially roots of abnormal idle time should be found out and eliminated.

4. INTEGRATION OF A WORKPLACE WITH THE PROCESS AND THE SYSTEM

The process organization in a company is the central part of the process-oriented corporate design [23]. While the organizational structure divides the company into partial systems (departments, workshops, units, etc) with their determined capabilities [1], the process orientation deals with the execution of orders (in the company level) and tasks (in the workplace level) in the timely oriented sequence with the flow of simple events.

Process is a sequence of simple events that are in chronological, spatial and logical order that makes inputs into outputs for purpose in the best possible way. System is a set of processes or processes realized in a certain system on the basis of workplaces. The more different are orders, the more flexible has to be the system and the more complicated is fulfilling the work orders at workplaces. Workplace has a leading role in the manufacturing process because it is the executor of a simple event or manufacturing operation according to the planned manufacturing technology (Fig. 6). Planning is based on production volumes (objectives) and uses mathematical methods for optimizing theoretical results of a process (routes and tasks to workplaces for a day, shift, etc).

Table 2. An example of the system–process–workplace integration

Goals	Activities
System goal	The evaluation of the suitability of producing certain products in a certain production system, rational use of technological capabilities
Process goal	The evaluation of alternative routes based on the net cost of the product and more effective use of resources
Workplace goal	Reducing idle time by analysing and eliminating the reasons of its occurrence
Personal goal	Improving competences and making suggestions to create preconditions for productive work (see Fig. 5)

The objectives of the company under review must be determined in order to evaluate the analysed as-is model [23–25]. As-is models could be supported by the reference models and/or benchmarking. The primary goal of as-is modelling is the presentation of existing structures and processes in a company. Using an as-is model, the existing process and its planned outputs, depending on the determined inputs, form the basis. As-is model is a structured reflection of reality. Process is described by a flow-chart, connecting simple events, their executors and expected (planned) results. Additional important goal of the as-is analysis is to create a list of weaknesses and potential improvements as completely and consistently as possible, based on collected models. Processes are bearers of simple events and generate measurable outputs. The most important reference point of the to-be modelling is definition of the performance of the process. The to-be models must achieve an operable degree of detailing to be able to evaluate in detail the resulting effects on the organization, the activities to be carried out, and the communication links between them with respect to different core parameters [23].

As-is and to-be modelling makes the connections between the objective and the result. Process plays central role in modelling, and connections of the process with the system and workplaces are analysed. The system creates preconditions for planned realization of a process and workplaces have to assure efficient fulfilment of the tasks. Improvement activities begin from employees, who carry out their tasks at workplaces. An example of system–process–workplace integration for improving the organization's effectiveness and competitiveness is presented in Table 2.

5. CONCLUSIONS

The key factors that can influence the company's workplace performance have been investigated. Workplaces play an important role in the organization's competitiveness. Connections between the system, processes and workplaces and a framework of the workplace performance model with the aim to optimize the efficiency of workplaces and competitiveness of the company have been presented.

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Suure jõudlusega töökoha loomise mudel

Kaia Lõun, Jaak Lavin, Jüri Riives ja Tauno Otto

Tänapäeva dünaamilises, turbulentses ja pidevalt muutuvas maailmas toimuvad protsessid väga kiiresti. Neid toetavad süsteemid muutuvad järjest keerukamateks, põimuvad üksteisega ja mõjutavad üksteist vahetult. Seetõttu muutub suure jõudlusega töökohtade loomine ettevõtete konkurentsivõime saavutamise seisukohalt üha olulisemaks. Käesolevas artiklis on analüüsitud tehnoloogiliste ja inimressursside koostoimes tekkiva tehnoloogilise efektiivsuse ning kulusäästliku juhtimise põhimõtteid eesmärgiga kujundada suure jõudlusega töökohti.

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Matsi, B., Otto, T., Lõun, K., Roosimölder, L. (2009). Data Mining in Production Management and Manufacturing, *DAAAM International Scientific Book 2009*. Ed. Katalinic, B. Viin: DAAAM International, 97–106.

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Karjust, K., Kers, J., Kiolein, I., Kokla, M., Küttner, R., Lavin, J., Lavrentjev, J., Lumiste, R., Lõun, K., Mõtus, L., Naams, I., Otto, T., Pohlak, M., Raba, K., Riives, J., Reedik, V., Roosimölder, L, Saks, A., Talkop, A., Tähemaa, T., Veinthal, R. (2011). Uuenduslik tootmine – käsiraamat. Tallinn: TTÜ Kirjastus.

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Lõun, K., Riives, J., Otto, T. (2012). Workplace performance and capability optimization in the integrated manufacturing. – *Proceedings of 8th International Conference of DAAAM Baltic Industrial Engineering, 19–21 April 2012.* Tallinn: TTÜ Kirjastus, 518–523.

Lõun, K., Lavin, J., Riives, J., Otto, T. (2013). High performance workplace design model. – *Estonian Journal of Engineering, 19, 1, 47–61.*

7. Teised uurimisprojektid
   2010–2013 Interreg IVA projekt Innoreg – Uudsete äristruktuuride arendamine konkurentsivõime tagamiseks (SFE23)
   2010–2012 Innovatsiooni arendamine mehhanotehnika valdkonna ettevõtluses (Archimedes, 1.2.0402.09–0052)

2009–2010 REKK, AKREDIT projekt – kutseõppeasutuste riikliku tunnustamise süsteemi väljatöötamise ja rakendamise sisutöörühma töös osalemine

2008–2009 PREMIO (Erasmus) – ettevõtluse ja innovatsiooni edendamine e-õppekursuse väljatöötamise ja juurutamise teel

2007–2008 Veebipõhise sündmustel põhineva tootmissüsteemi (e-tootmise) eeluuring

2007–2008 Innomet-EST projekt (ESF meede 1.1, projekt nr 1.0101-06-0396) täiendõppe ja inimressursiarenduse infosüsteemi laiendamine Eestis

2006 METNET – masinaehituse, metalli-, aparaadi- ja elektroonikatööstuse ettevõtete koostöövõrgustiku loomine

2006 SA INNOVE õpipoisi projekt „Töökohapõhise õppevormi (õpipoisikoolituse) rakendamine kutseharidussüsteemis”

2005–2006 INNOMET II (ESF meede 1.1) – Innovaatilise inimressursside arendussüsteemi rakendamine Eestis

CURRICULUM VITAE (CV)

1. Personal data

Name	Kaia Lõun
Date and place of birth	26.09.1977 Tallinn
Nationality	Estonian
e-mail	kaia.loun@mail.ee

2. Education

Educational institution	Graduation year	Education
Tallinn University of Technology	2005	Industrial engineering and management / MSc
Estonian Business School	1999	International business management / BBA
Tallinn 60th Secondary School	1995	Secondary education

3. Language competence/skills

Language	Level
Estonian	High (fluent)
English	High (fluent)
Spanish	Basic

4. Special courses

Period	Educational or other organisation
Oct. 2011	TUT, Department of Machinery, Doctoral school of energy and geotechnology – course “Product development”
September 2006	SEI – EU environmental management and auditing system (EMAS) assessors’ course
December 2004	Bureau Veritas Eesti OÜ – Environmental management system, new version of international standard ISO 14001:2004
December 2003	Estonian Ministry of Environment, SEI – EU environmental management and auditing system (EMAS) training course

April 2003	Bureau Veritas Eesti OÜ – Occupational health and safety management system (OHSAS 18001) lead auditors' course
June 2002	EMI-ECO – Development and auditing of environmental management systems
February 2002	Tallinn Business School – Production planning course
May 2001	Bureau Veritas Eesti OÜ – IRCA/IATCA registered ISO 9000:2000 auditors/lead auditors course
September 2000	Estonian Centre for Standardisation – ISO 9000:2000 introducing course
May 2000	Business Grain Eesti OÜ – New approach to quality management systems

5. Professional employment

Period	Organisation	Position
Since Oct. 2011	MTÜ Mehhatroonika Assotsiatsioon (Association of Mechatronics)	Project manager
Since Aug. 2009	OÜ IMECC	Communication manager, financial manager
Since Oct. 2008	OÜ Rantelon	Quality manager
2007–2009	TTÜ	External lector
2006–2008	Estonian Civil Aviation Administration	Quality management expert
Since 1999	OÜ J.R.Technoconsult	Consultant / project manager
1996–1998	AS Pelaskon	Assistant

6. Scientific work
   Publications:

Lõun, K., Tammoja, P. (2004). Quality Functions as Key Factors for Organization Development. – *Proceedings of the 4th International Conference*

*of DAAAM, Industrial engineering – new challenges to SM*E. Tallinn: TUT Press, 257–260.

Riives, J., Otto, T., Lõun, K. (2007). Human resources development process in the company based on competence charts. – *Innovative development of human resources in enterprise and in society*, Tallinn: TUT Press, 22–37.

Riives, J., Otto, T., Lõun, K. (2007). Methods for enhancing productivity and work efficiency in the workshop. – *Journal of Machine Engineering*, 7, 2, 86–95.

Lõun, K., Riives, J., Otto, T. (2007). E-manufacturing as a web-based decision-making support for collaborating SMEs in machine-building cluster. – *Annals of DAAAM for 2007 & Proceedings of the 18th International DAAAM Symposium*. Vienna: DAAAM International, 427–428.

Lõun, K., Riives, J., Otto, T. (2008). Necessity for E-manufacturing model in tooling cluster and its essence. – *Proceedings of 6th International Conference of DAAAM Baltic Industrial Engineering*. Ed. R.Küttner. Tallinn: TUT Press, 345–350.

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Lõun, K., Riives, J., Otto, T. (2011). Evaluation of the operation expedience of technological resources in a manufacturing network. – *Estonian Journal of Engineering*, 2011, 17, 1, 51–65.

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Lõun, K., Lavin, J., Riives, J., Otto, T. (2013). High performance workplace design model. – *Estonian Journal of Engineering, 19, 1, 47–61.*

7. Other research projects

2010–2013	Interreg IVA project Innoreg – Development of novel business structures for assuring competitiveness (SFE23)
2010–2012	Development of innovation in mechatronics (Archimedes, 1.2.0402.09-0052)
2009–2010	REKK, AKREDIT project – Elaboration of accreditation system for vocational education institutions
2008–2009	PREMIO (Erasmus) – Promotion of entrepreneurship and innovation through develpoment and implementation of e-course
2007–2008	Preliminary research about event based production system in web environment (e-manufacturing)
2007–2008	Innomet-EST project (ESF 1.1, project no 1.0101-06-0396) Enlargement of human resources development system in Estonia
2006	METNET – development of collaboration network of machinebuilding, metalworking, apparatus and electronics industry companies
2006	SA INNOVE project „Implementation of workplace-based studying in vocational education system”
2005–2006	INNOMET II (ESF 1.1) – Development and implementation of innovative human resources development system in Estonia

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

1. **Jakob Kübarsepp**. Steel-bonded hardmetals. 1992.
2. **Jakub Kõo**. Determination of residual stresses in coatings & coated parts. 1994.
3. **Mart Tamre**. Tribocharacteristics of journal bearings unlocated axis. 1995.
4. **Paul Kallas**. Abrasive erosion of powder materials. 1996.
5. **Jüri Pirso**. Titanium and chromium carbide based cermets. 1996.
6. **Heinrich Reshetnyak**. Hard metals serviceability in sheet metal forming operations. 1996.
7. **Arvi Kruusing**. Magnetic microdevices and their fabrication methods. 1997.
8. **Roberto Carmona Davila**. Some contributions to the quality control in motor car industry. 1999.
9. **Harri Annuka**. Characterization and application of TiC-based iron alloys bonded cermets. 1999.
10. **Irina Hussainova**. Investigation of particle-wall collision and erosion prediction. 1999.
11. **Edi Kulderknup**. Reliability and uncertainty of quality measurement. 2000.
12. **Vitali Podgurski**. Laser ablation and thermal evaporation of thin films and structures. 2001.
13. **Igor Penkov**. Strength investigation of threaded joints under static and dynamic loading. 2001.
14. **Martin Eerme**. Structural modelling of engineering products and realisation of computer-based environment for product development. 2001.
15. **Toivo Tähemaa**. Assurance of synergy and competitive dependability at non-safety-critical mechatronics systems design. 2002.
16. **Jüri Resev**. Virtual differential as torque distribution control unit in automotive propulsion systems. 2002.
17. **Toomas Pihl**. Powder coatings for abrasive wear. 2002.
18. **Sergei Letunovitš**. Tribology of fine-grained cermets. 2003.
19. **Tatyana Karaulova**. Development of the modelling tool for the analysis of the production process and its entities for the SME. 2004.
20. **Grigori Nekrassov**. Development of an intelligent integrated environment for computer. 2004.
21. **Sergei Zimakov**. Novel wear resistant WC-based thermal sprayed coatings. 2004.

22. **Irina Preis**. Fatigue performance and mechanical reliability of cemented carbides. 2004.

23. **Medhat Hussainov**. Effect of solid particles on turbulence of gas in two-phase flows. 2005.

24. **Frid Kaljas**. Synergy-based approach to design of the interdisciplinary systems. 2005.

25. **Dmitri Neshumayev**. Experimental and numerical investigation of combined heat transfer enhancement technique in gas-heated channels. 2005.

26. **Renno Veinthal**. Characterization and modelling of erosion wear of powder composite materials and coatings. 2005.

27. **Sergei Tisler**. Deposition of solid particles from aerosol flow in laminar flat-plate boundary layer. 2006.

28. **Tauno Otto**. Models for monitoring of technological processes and production systems. 2006.

29. **Maksim Antonov**. Assessment of cermets performance in aggressive media. 2006.

30. **Tatjana Barashkova**. Research of the effect of correlation at the measurement of alternative voltage. 2006.

31. **Jaan Kers**. Recycling of composite plastics. 2006.

32. **Raivo Sell**. Model based mechatronic systems modeling methodology in conceptual design stage. 2007.

33. **Hans Rämmal**. Experimental methods for sound propagation studies in automotive duct systems. 2007.

34. **Meelis Pohlak**. Rapid prototyping of sheet metal components with incremental sheet forming technology. 2007.

35. **Priidu Peetsalu**. Microstructural aspects of thermal sprayed WC-Co coatings and Ni-Cr coated steels. 2007.

36. **Lauri Kollo**. Sinter/HIP technology of TiC-based cermets. 2007.

37. **Andrei Dedov**. Assessment of metal condition and remaining life of in-service power plant components operating at high temperature. 2007.

38. **Fjodor Sergejev**. Investigation of the fatigue mechanics aspects of PM hardmetals and cermets. 2007.

39. **Eduard Shevchenko**. Intelligent decision support system for the network of collaborative SMEs. 2007.

40. **Rünno Lumiste**. Networks and innovation in machinery and electronics industry and enterprises (Estonian case studies). 2008.

41. **Kristo Karjust**. Integrated product development and production technology of large composite plastic products. 2008.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

67. **Martinš Sarkans**. Synergy Deployment at Early Evaluation of Modularity of the Multi-Agent Production Systems. 2012.

68. **Sven Seiler**. Laboratory as a Service – A Holistic Framework for Remote and Virtual Labs. 2012.

69. **Tarmo Velsker**. Design Optimization of Steel and Glass Structures. 2012.

70. **Madis Tiik**. Access Rights and Organizational Management in Implementation of Estonian Electronic Health Record System. 2012.

71. **Marina Kostina**. Reliability Management of Manufacturing Processes in Machinery Enterprises. 2012.

72. **Robert Hudjakov**. Long-Range Navigation for Unmanned Off-Road Ground Vehicle. 2012.