MANUFACTURING INTELLIGENT DESIGN AND OPTIMIZATION PROCESSES

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The use of computer numerical controls (CNC) enables 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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METHODS FOR ENHANCING PRODUCTIVITY 
AND WORK EFFICIENCY IN THE 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).

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

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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):

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

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 $T$;

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

![Fig. 2. Organization as a system with measurable value](image-url)
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:

\[ P = \frac{O}{I} \]  

(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).

\[
\overline{TB} = TB_{TP} - TB_D
\]

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).

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.

![System Development Model](image)

**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).

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.

![Graph showing 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)](image)

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).

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