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Ergonomics and Efficiency in a New Attempt to Model Work Processes

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INTRODUCTION

In technical sciences, modeling plays an important role because it identifies processes and relationships that occur in complex technical systems. It refers, among others, to qualitative and quantitative methods of analysis, optimization and experiments as well as to various applications in design, planning, manufacturing, control etc. (Kornaszewski, 2018). Modeling plays no less important role in management and quality sciences. Here, one of the theoretical and practical considerations aspect is the way of describing a real represented system in such a way that it became possible to empirical use of the model and learning from it (Gospodarek, 2009).

Generalizing modeling is an approximate reconstruction of the most important properties of a part of reality. The basic goal of modeling in science is to simplify the complex reality, resulting in a model that undergoes a research process. Modeling is an active process that creates new constructions (Podolsky, 2018). Modeling of work processes helps to understand how processes work in the manufacturing system and what kind of connections exist between them. In addition, after introducing changes related to external factors (competitiveness, demand, market size, etc.) and internal factors (organization of work stations, layout, workflow, automation, etc.) to the actual model of work processes, it is possible to predict how it will behave in the analyzed conditions. The model is used to forecast effects and shapes directions of development opportunities for the enterprise, as it may turn out that the implementation of certain projects is unprofitable due to the final effect.

Modeling of work processes supported by computer techniques is widely used in design (Mleczko, 2019; Kuboszek, 2019), and also allows you to optimize design solutions before starting implementation of work (Kabiesz and Bartnicka, 2018; Górska, 2011).

There are several model classifications. In terms of similarity to the pattern, we can distinguish models (Bielecki, 2001):

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- Normative – selected features are defined as benchmarks;
- Positive – the subject of research is simplified reality.

However, taking into account the criterion of the way of expressing reality, there are models (Bielecki, 2001):

- Verbal;
- Analog (physical or iconographic);
- Formal (mathematical, symbolic, normative);
- Mental informal, based on modeling heuristics.

In addition, we can distinguish models (Bielecki, 2001):

- Specific and abstract;
- Static and dynamic;
- Deterministic and stochastic;
- Heuristic and simulation.

Heuristic models are most often used to map work processes because they include behavioral factors related to employee activities. Mapping of human behavior belongs to the so-called soft modeling. In practice, when modeling work processes, mixed solutions are used that enrich hard algorithmic models with soft techniques (Dias et al., 2020).

ERGONOMIC MODELING

The new approach to model work processes is based on three main methodological assumptions (Eldar and Fisher-Gewirtzman, 2019; Glocka et al., 2019):

- The subject of the study is the human – technical means – environment operating at a given time;
- In all phases of modeling work processes, humanocetric criteria are considered priority and have an equivalent impact on the creation and selection of design solution concepts as technical and economic criteria. When designing technical measures that directly affect humans (e.g. control and signaling elements, vibration, noise, air pollution etc.), ergonomic criteria should be considered the most important.
- Ergonomic criteria are integral elements of work process modeling that must be precisely selected at each design stage to achieve the desired compliance of system features with ergonomic requirements.

Modeling based on ergonomic design is called ergonomic modeling. *"Ergonomic design is the implementation of such a procedure for designing a human – technical object system that creates the best chance of obtaining a design with the desired level of ergonomic quality"* (Tytka, 1986). Three areas of ergonomic factors with correlations have been identified:

- Organizational factors relate to the optimization of the human – technical object – environment system, including their organizational structure, principles and processes;

- Physical factors are associated with human anatomy, including anthropometry, physiology and biological mechanical properties that relate to physical activity;
- Cognitive factors relate to cognitive and mental processes such as perception, memory, reasoning and interaction between people and other elements of the system.

Fig. 1 presents factors supporting decision-making processes during ergonomic design.

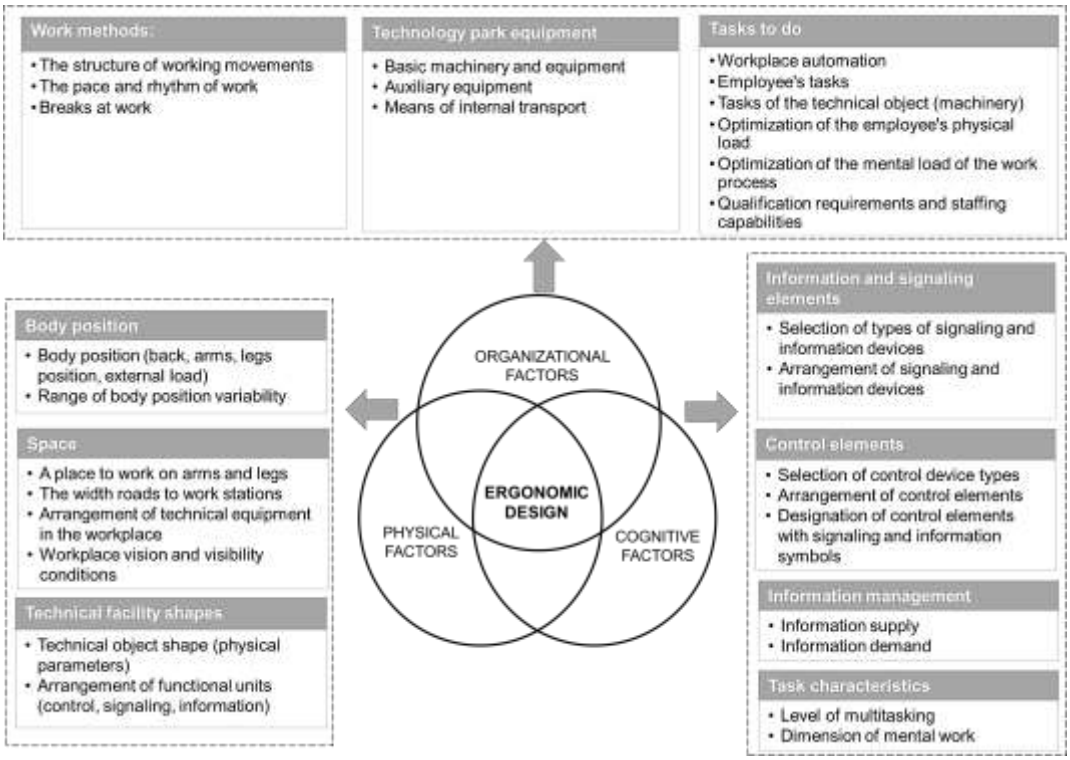

Fig. 1 Ergonomic factors

Ergonomic factors during design are a source of information about the degree of correctness of design performance from the ergonomic point of view. In addition, they can indicate the possibility of using functional solutions that are already used in the real environment and play the role of an ergonomic pattern.

EFFICIENCY OF WORK PROCESSES

The concept of efficiency in the basic meaning is defined as the result of actions expressed by the ratio of achieved effects to incurred expenditure (Szymczak, 1978-1981). In the case of expenditures related to work efficiency, only those expenditures that are directly related to the work performed should be included. In addition, the values of the input measures should be determined in relation to the assumed or obtained effects, because the way of expressing the effects, their measurement, determines the input of expenditures and thus the correctness of efficiency assessment (Skowron-Mielik, 2009). The key meaning in determining the efficiency indicator is the concept of work effect, which is

usually determined by a direct result through the prism of the quantity and value of produced material goods and services. The second approach defining the effects of work is an intangible, non-economic approach defined in the context of actions (behaviors) undertaken by employees. Generally speaking, the effects of work leading to the achievement of a result/effect are both behaviors and results, because the behaviors themselves are the results of mental and physical efforts put into the performed tasks and can be assessed independently of the results (Nowosielski, 2008).
In addition, it should be remembered that the analysis of the effectiveness of the assessment of work processes can be carried out in relation to a single employee (individual work effects), an employee team (group work effects), organizationally separated units of the enterprise (department, division, department) as well as the enterprise and the crew as a whole (Blacksmith, 2013). Fig. 2 presents five types of indicators that describe the effectiveness of work processes.

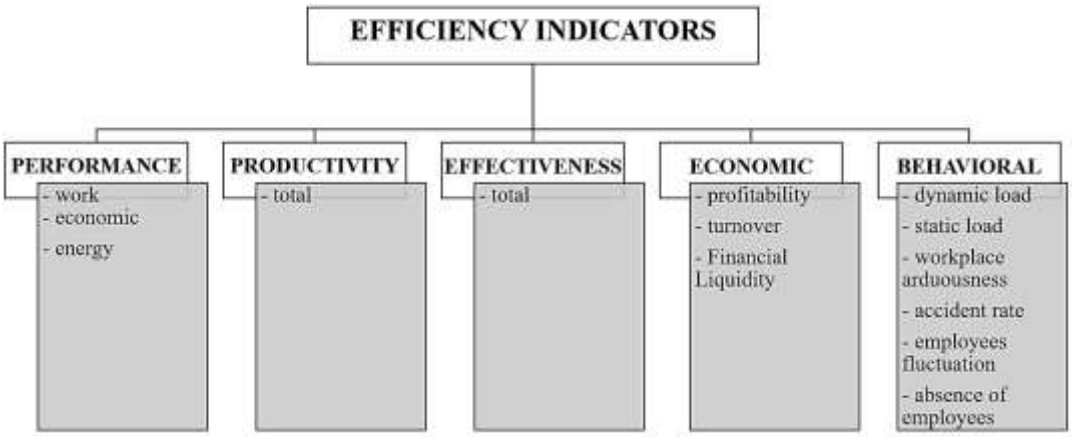

Fig. 2 Efficiency indicators

Efficiency is one of the basic indicators used to describe the current state, functioning and development possibilities of the enterprise. The process of designing safe and ergonomic workplace has a direct impact on the value of the presented indicators. Incorrectly selected somatic relations extend the working time and additionally burden the employee (Bartnicka and Kabiesz, 2019).
Taking into account the background of the considerations, the purpose of the article is to prove that the need of improving safety and ergonomics of the designed workstations leads to improvement of work effectiveness. Technical solutions were presented, which were implemented in a production company in order to improve working conditions and increase the efficiency of work processes.

METHODOLOGY OF RESEARCH

The research was carried out in accordance with the new concept developed to assess the design and optimization of work processes including efficiency and ergonomics. The model (Fig. 3) presents the main variables and ergonomic

factors that have a direct impact on the final result of the efficiency of work processes. It presents the principle of the 9 steps of an integrated procedure, which aims to maximize efficiency and minimize the biological costs of employees. Eight steps are grouped into 3 stages:

- A pre-design phase that includes steps 1, 2 and 3;
- The detailed design and implementation phase, which includes steps 4, 5, 6, 7, 8;
- The management and improvement phase, which is a continuous process.

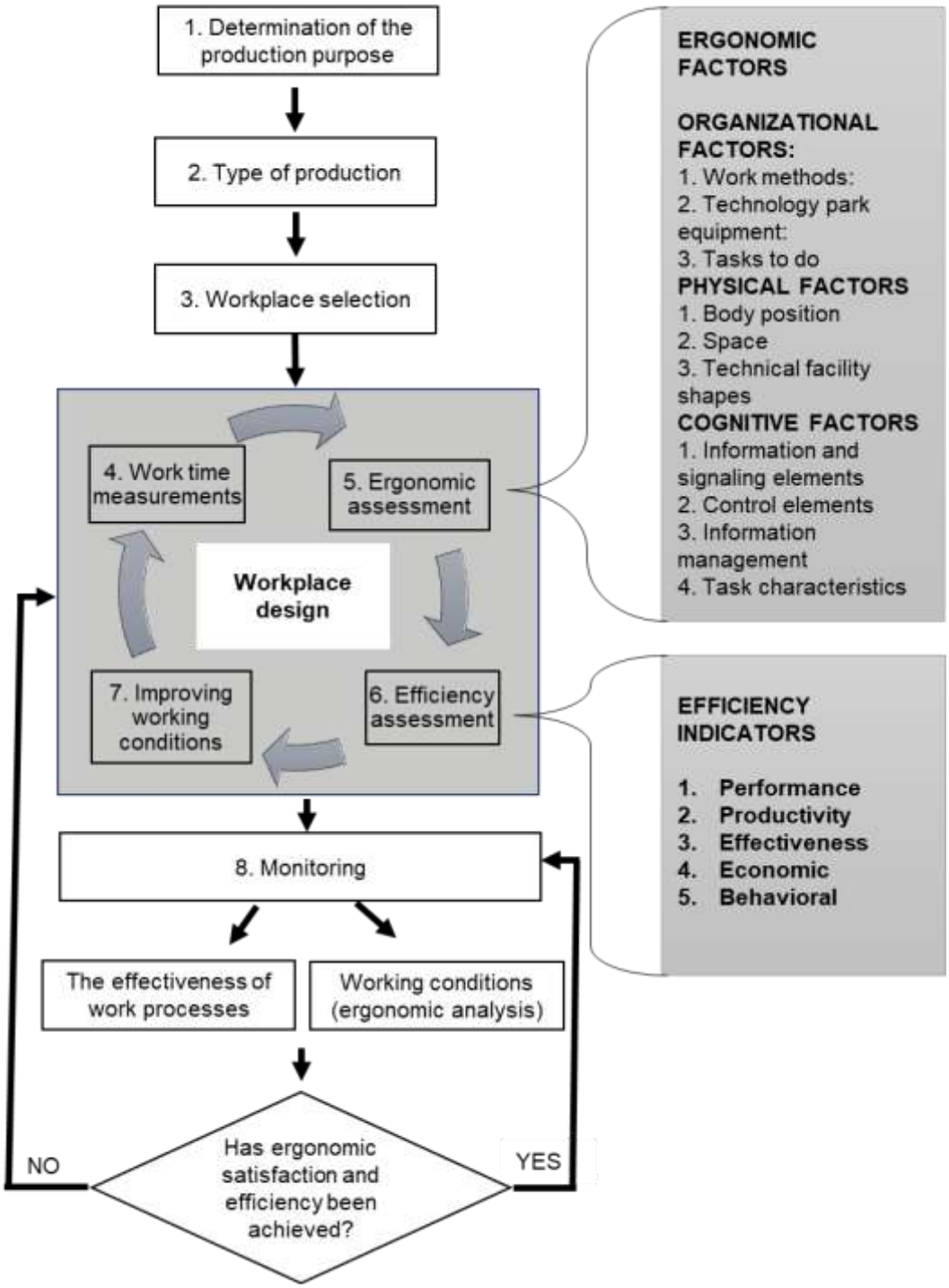

Fig. 3 Model to assess efficiency and ergoquality in production process

The model shown in the Figure 3 has been implemented in a Polish company that produces packaging from paper for food, beverages and consumer goods (*stage 1*). The company is located in the Silesian Voivodeship and employs approximately 500 employees.

Type of production is reproducible with a large number of manual work processes (*stage 2*). The workplace operating the machine for forming paper packaging was selected (*stage 3*) as a subject of examination. The research method used was the method of direct observation combined with video recording and photographic registration what was the basic materials for work time measurements (*stage 4*). In addition, metric measurements of the workplace were conducted. Due to the fact that not all data were measurable according to the input materials received, they were estimated on the basis of the job description, interviews with a representative of the OHS department of the company and the assessor's experience. In the event of fluctuations, doubts or inability to estimate realistically, extreme values have been adopted, i.e. those that increase the risk of undesirable situations.

The research (*stage 5* & *stage 6*) was carried out in three phases:

- Ergonomic and efficiency analysis of current working conditions;
- Ergonomic workplace design;
- Ergonomic and efficiency analysis after implementation of changes in the workplace.

Based on ergonomic and efficiency assessment outcomes, critical points of process were recognized that was a subject of improvement activities (*stage 7*). Monitoring (*stage 8*) is the last stage before a loop representing continuous improvement or continuous maintenance of expected ergonomics and performance indicators.

RESULTS AND DISCUSSION

An analysis of the ergonomic conditions at the workplace while operating the machine for forming paper packaging (Fig. 4) was conducted. The employee operating the machine works in the production hall, where the natural and artificial lighting is available. Due to the number of machines and the specificity of work, noise thresholds are exceeded. During a work shift (i.e. 8h/day) the operator operates the machine for 7 hours and 30 min, i.e. controls the operation of the machine and does activities related to changing the paper roll.

The sequences of work at the analyzed workplace was divided into characteristic activities to provide a detailed analysis of work ergonomics, taking into account the employee-work relationship and the position of the employee during the performance of activities.

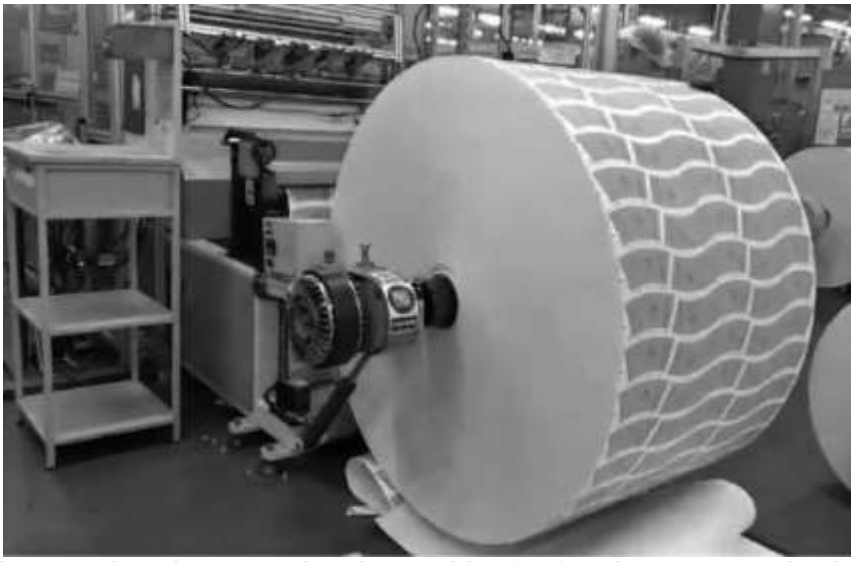

Fig. 4 Workstation operating the machine for forming paper packaging

The following activities were indicated:
1. Pulling off the core with the expansion shaft from the unwinding machine;
2. Insert the expansion roller into the paper roll;
3. Putting the paper roll on the unwinding machine;
4. Pulling the paper roll web through individual parts and machine rollers.

For the ergonomic analysis, the values of the edges were adopted, because they determine the spatial size of the workplace and can significantly influence the formation of overload within the employee's musculoskeletal system:

- Paper roll diameter: 0.87 m;
- Weight of paper roll: 1,228.00 kg;
- Rolling distance of paper roll: 2.5 m;

Due to the variety of activities performed by the operator two methods for ergonomic analysis were used. For the first and second activities, the RULA (Rapid Upper Limb Assessment) analysis was carried out, which assesses the load on the upper limbs (arms, forearms, wrists), as well as the neck and torso taking into account body position and external weight when performing work tasks. Ergonomic analysis for the third activity was carried out using the KIM (Key Item Method), which is used to assess the working conditions for manual transport work. The KIM method is used to determine the scope of ergonomic intervention for mass displacement up to 1000 kg, hence the maximum values for the musculoskeletal load have been adopted in the risk assessment. The fourth step concerning pulling the paper roll web through individual parts and machine rollers was omitted in the ergonomic analysis due to the lack of possibility to redesign the work task due to the machine's design limitations and lack of space in the production hall. Table 1 presents the results of an ergonomic analysis of the working conditions at the selected workplace.

Table 1 Ergonomic assessment outcomes

Type of activity	Risk assessment	Time [s]	Picture showing the activity
Step 1	Medium	50	
Step 2	Medium	23	
Step 3	High	27	
Total task time		**100**	

According to the research it was recognized three activities that significantly affect the musculoskeletal system of the employee. It is necessary to introduce a technical solution for moving paper rolls. Rolling paper rolls weighing 1,228 kg per employee is not allowed. According to the Polish law, the right mass of hand-transfused objects on a horizontal surface with a hard and smooth surface may not exceed 200 kg for one man and 80 kg for one woman (Regulation of the Minister of Family, Labour and Social Policy).

Within the next stage of research, new technical solutions were proposed, which improved employee safety and contributed to the increase in the efficiency of work processes. Due to the precise placement of the paper roll into the machine, it is not possible to transport the paper roll cart. The proposed solutions are:

- Automatic roll transport line (Fig. 5), which after placing the paper roll with the roller carriage to a dedicated place will lead it to the right place. This solution will allow one employee to be transferred to another position where his work will be necessary. This will reduce energy waste and eliminate the risk of rolling material;

Fig. 5 Automatic roll transport line

- Power Pusher (Fig. 6) is a device used for moving heavy materials. The use of the device eliminates the risk of injuries to the employee's musculoskeletal system and allows one person to move a precisely heavy load.

Fig. 6 Power Pusher

Source: http://www.nu-starmhl.com/

After confronting the proposal of ergonomic solutions with the company's management, the proposal of an automatic roller transport line was rejected due to work safety. The transport line would be on a communication route. The Power Pusher device has been implemented into the enterprise, which is used at several workstations for precise movement of paper rolls.

Two different parameters shaping working conditions that are integrated and dependent were improved:

- Effectiveness of work processes, in particular the accident rate. Since the implementation of the new solution within six months at the workplace, no accident at work has been recorded. Before the ergonomic analysis, there

were three accident incidents per year on average. In total, the accident rate in the enterprise decreased by 17%. It is worth noting that salary also affects the absence and turnover of employees. In addition, the time taken to perform Step 3 - applying a paper roll to the machine was reduced by 3 s, so the time to replace the paper roll was reduced by 3%;

- Ergonomics at work, risk assessment performed dropped from high to medium, which significantly improved the comfort and safety of employees.

CONCLUSION

A sequence of modeling work processes was proposed in 8 steps to improve the efficiency and ergonomics of working conditions, followed by its implementation in one of the enterprises. Ergonomic and safety assessment performed for various design solutions allows to determine the best solution of the human-machine-environment system. After the ergonomic intervention three basic improvements were has been achieved: (1) the health and well-being of employees, (2) the employee accident rate decreased, (3) the duration of tasks at the workplace was reduced. The implementation of a technical solution has a direct impact on improving working conditions, because the implementation of organizational solutions, among others a new way of performing activities (sequence of activities, working methods) is very difficult to implement due to the habits acquired by employees. The implementation of healthy habits requires systematic and long-term action to modify previous behaviours. The effect of implementing the technical action is immediate.

A gap was identified, which is the basis for undertaking new research challenges in the area of formulating assumptions for the indicator method determining the load on the musculoskeletal system in manual transport by moving objects over 1000 kg.

ACKNOWLEDGEMENTS

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Abstract: The article presents the relationships between ergonomics and the effectiveness of work processes. A new thematic framework has been developed to evaluate the engineering design of work processes in conjunction with the effectiveness and ergonomics of workplaces. The model presented in the paper takes into account ergonomic factors that have a direct impact on shaping working environment in which a person is located and improving their efficiency. The model was validated in real conditions in the production company. The subject of the research was the work process existing in the plant producing food paper packaging. The main method used to assess working conditions was observation and qualitative and quantitative assessment of operational activities based on video recording. Detailed human actions were analyzed in terms of ergonomic factors to prove the relationship between ergonomics and efficiency. In addition, new technical solutions have been proposed that improve working conditions and the efficiency of the entire work process.

Keywords: ergonomic factors, efficiency indicators, work process modeling