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work ergonomics, modeling and simulation

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COMPUTER SUPPORT OF ERGONOMIC ANALYSIS OF WORKING CONDITIONS AT WORKSTATIONS

Abstract

The article shows issues of using computer-aided technologies for ergonomic analysis at worksplaces using a dedicated tool in the Delmia environment. The scope of the ergonomic evaluation has been limited to the analysis of RULA and NIOSH, the data needed for it was gathered on the basis of observation, interview and task analysis. The results of the research showed the strenous nature of the work, therefore improvements within undertaken workplace area were proposed and re-analyzed. The obtained results proved reduction of strenousness, which was the basis for the practical implementation of the proposed changes.

1. INTRODUCTION

Currently, the practice of many industrial plants in connection with the creation and design of work in the workplace very often involves designing the construction and functional concept of the product and the workplace itself. (Klembalska, 2006). Aspects related to ergonomics and work safety are usually taken only when the workplace has been created and is able to function.

The analysis of ergonomics and work safety can be considered from the point of view of the widely understood work environment. (Muszyński, 2016). It is possible to differentiate the factors of the material working environment and technical or organizational factors – fig.1 (Nowacka, 2010).

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Fig. 1. Areas of interest in work ergonomics

In the era of dynamically developing many branches of industry, constantly growing competition, efforts to reduce costs and increase productivity of workplaces, inappropriate shape of workplaces directly affects the decline in work efficiency (Lasota & Hankiewicz, 2015) and the greater number of diseases that workers can be exposed to. In the context of ergonomics, it should also be remembered that in many countries (including Poland), societies are aging constantly, which in the context of the requirements related to the compliance with EN and PN standards and health and safety regulations causes the need to improve work comfort. This condition can be achieved thanks to computer-aided tools in the processes of shaping the surroundings and equipment of workplaces (Zielińska & Kurczyk, 2011).

Among the many possible assessments of the employee's workload associated with taking different positions during the work, commonly used are observational research which do not interfere in the work process, additionally characterized by low cost and ease of use (Genaidy, Al.-Shed & Karwowski, 1994). There are many companies on the market which offers software with modules related to ergonomic analysis. In the case of conducted research, the authors used the environment of Delmia, because it is one of two (apart from Process Simulate) environments most often used by corporations to comprehensively shaping the course of the production process, taking into account ergonomic aspects as well.

2. MODELING AND WORK SIMULATION ON WORKPLACES IN DELMIA SOFTWARE

2.1. General characteristics of the software

Digital Enterprise Lean Manufacturing Interactive Application (Delmia) is a virtual platform for creating simulations in the field of design and production optimization. Specialized software enables precise mapping of objects located in the enterprise (products, processes and resources) significantly increasing the sphere of concurrency over standard CAx phases (Marconi, Germani, Favi & Raffaeli, 2018), initiating the creation of a virtual factory. It allows to (Zielińska & Kurczyk, 2011):

– selection and programming of production means,
– composing the production process,
– verification of workplaces from their ergonomics point of view.

The main advantage of this application is the ability to analyze various variants and solutions of the mentioned elements, well before the implementation phase.

Delmia is a collection of many modules that allows to design and analyze of selected areas of the product life cycle and the functioning of the company (Zielińska & Kurczyk, 2011). From a wide range of modules in Delmia, a module used for carrying out ergonomic analysis is called *"ergonomics"*.

2.2. Delmia's Ergonomics module

Simulation of manual activities and evaluation of ergonomic work in the Delmia environment is possible thanks to a dedicated Ergonomics module. It enables the analysis of manual work performed by the employee in the scope of the production tasks entrusted to him. It also provides information on potential hazards that may arise from inappropriate design or preparation of the workplace and tools. The module has a very wide range of tools that correspond to, among the others (Zielińska & Kurczyk, 2011):

– digital modeling of employees and simulation of interaction with the environment,
– visualization of the digital model of a human being, making it possible to give the employee model the desired anthropometric features (eg. sex, age, etc.)
– simulation of tasks performed by an employee using predefined movements (eg walking, lifting, postponing, etc.),
– ergonomic analysis, comprehensively assessing all elements of employee's cooperation with the work environment (implemented methods are NIOSH 81 and 91, RULA method, energy expenditure and 3D biomechanics analysis), as well as designation of the working zone based on the range of hands,
– quantitative and qualitative analysis of all aspects of the employee's attitude,
– creating dummies through a set of advanced anthropometric tools (to assess the suitability of a product or process).

Such a constructed and equipped platform facilitates proper mapping of the actual state or planned production environment, including the human-object interaction.

2.3. Selected ergonomic analyzes of the Ergonomics module

The RULA (Rapid Upper Limb Assessment) method is used for quickly assess the employee's attitude at the workplace from the ergonomics point of view (McAtamney & Corlett, 1993), especially in cases of complaints on the motor system. This method takes into account the burden on the entire musculoskeletal system, associated with the use of force, to perform a specific task, as well as the need to maintain a proper position of the body (Zielińska & Kurczyk, 2011). Analysis in this method focuses mainly on the load on the neck, trunk and upper limbs. Tests made on many groups of employees, performing work often in forced and unfavorable positions of the body, prove its credibility. In this method, each analyzed attitude is assigned a score on a scale from 1 to 7, and the interpretation of individual point values is given in Table 1.

Tab. 1. Scale and its interpretation in the RULA method

Rating	Interpretation
1–2 pts.	Acceptable attitude
3–4 pts.	The attitude should be analyzed
5–6 pts.	The attitude should be analyzed and soon changed
7 pts.	The attitude should be investigated and immediately changed

The advantages of using the RULA method are certainly the ease of execution and the short time needed to obtain reliable results. It is a very good supplement to other, more complex, ergonomic methods of workplace evaluation, especially those that assess the upper limb load at the first, preliminary stage of assessment (Zielińska & Kurczyk, 2011).

The study also uses the NIOSH equation (the National Institute for Occupational Safety and Health), which is used to assess (classify) certain hazards associated with lifting objects. The application of the updated equation in 1991 takes place mainly in the following situations (Zielińska & Kurczyk, 2011):
- estimation of two-handed risk,
- analyzing and assessing the work of many tasks with lifting,
- assessment of work associated with lifting, which may include rotation of the trunk, repeatability and duration of the task,
- determining the mass of a safe load and posing a health risk by performing a given task,
- identification of tasks posing a threat and taking steps to limit them.

Analysis of this method is a two-step process, firstly the Recommended Weight Limit (RWL) should be determined of formula 1 (Slamková, Dulina & Tabaková, 2010):

$$RWL = L_C \times H_M \times V_M \times D_M \times A_M \times F_M \times C_M \quad (1)$$

where: RWL – recommended weight limit,
L_C – load constant,
H_M – horizontal position factor,
V_M – vertical position factor,
D_M – vertical distance difference factor,
A_M – asymmetry factor,
C_M – correct workpiece handle factor.

As a result of this analysis, the recommended weight limit for a given activity is calculated. This value means the mass of the object that can be lifted by a healthy person in given conditions without the risk of damaging to health. Next step is to determine the index of lifting (formula 2), which means what multiplicity of acceptable load is the actual weight. In order to receive this value, a so-called lifting index (LI), use the following formula (Slamková, Dulina & Tabaková, 2010):

$$L_I = \frac{L}{RWL} \quad (2)$$

where: L_I – lifting index,
L – lifted weight,
RWL – recommended weight limit.

The interpretation of the obtained values is summarized in Table 2.

Tab. 2. Interpretation of results for the NIOSH equation

L_I value	Interpretation
$L_I \leq 0.5$	The risk is small, there is no need to take action.
$0.5 < L_I \leq 1$	Medium risk, risk control is needed.
$1.0 < L_I \leq 2$	The risk is high, a risk-reducing measure is needed.
$L_I > 2$	Very high risk, stop the work and take immediate action to reduce the risk.

3. EXAMPLE

3.1. The run of work on the analyzed workplace

The tests were carried out at the cutting cardboard blocks station with using a band knife attached on a band knife cutting machine. Within the discussed workplace there are: a machine, a table with a sliding top, a pallet with cardboard blocks to be cut and a pallet for covering the cut material. The operator's work consists in picking material from the pallet, transferring it and fitting it properly on the table, making a proper number of reciprocating movements (depending on the target dimensions of the fragment being cut off), and then obtaining the cut elements and placing them on the pallet below the table. Then, with use of a pallet truck, the filled pallet is put aside for transport to the next station. The outlook was visualized in Fig. 2, created on the basis of a model generated in the Delmia's environment.

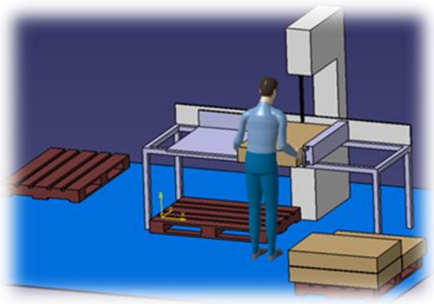

Fig. 2. Approximate arrangement of the workplace elements

The figure also shows the operator performing the material cutting operation. The cardboard block handled by the operator usually has the dimensions 800×600×150 mm and the weight is about 1.0 kg.

From the observation and the interview carried out among the operators of the analyzed workplace, it appears that the work is burdensome due to:

- standing type of work,
- bulky holding of the material during its collection,,
- fatigue resulting from repetitive movements, mainly reciprocating,
- bulky handle for feeding the table,
- additional activities related to the laying of cut elements.

According to noticed discomfort in the group being asked and specified aspects, actions were taken to carry out a virtual analysis of the ergonomic work from the ergonomics point of view.

3.2. Workplace modeling

In order to carry out ergonomic analyzes, a model of the workplace was made (fig. 3) in the Delmia Ergonomics environment, taking into account the essential elements and their parameters (height, mass, etc.) within it and the positions accepted by the operator during the performance of particular activities.

Fig. 3. Examples of the operator's position and attitude

Attitudes and positions of the employee during the work were modeled and prepared both in terms of the RULA method and the NIOSH equation (positions related to lifting). Assuming that the created model reflects the actual condition and character of the position, work was undertaken with conducting ergonomic analyzes. In fact, the model assumed some simplifications, but they did not affect the final results. Only those elements of the workplace were modeled, which are important from the point of view of the operation being performed. Elements that do not affect the work position have been omitted.

3.3. Ergonomic analysis in Delmia Ergonomics

The evaluation of the ergonomics of the operators' work at the test bench was based on the RULA method and the NIOSH equation. The following operations were taken for ergonomic analysis in the Ergonomics module:

- starting cut movement (cutting phase 1),
- ending cut movement (cutting phase 2),
- picking up material for cutting (posture A),
- fixing the material on the work table (posture B).

For all listed activities (pictured in Figure 4), the RULA analysis was carried out, while the A and B attitude was additionally analyzed by the NIOSH equation.

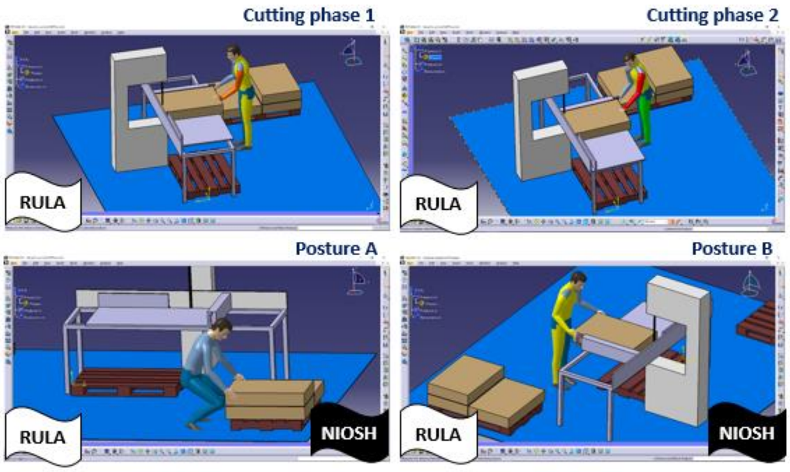

Fig. 4. Positions performed by the operator during work

RULA analysis

Having a built-in position model and selected elements for the study, the RULA analysis in the Ergonomics module was launched next. For the analysis to be carried out, the following parameters had to be additionally specified:

– the analyzed side of the body,
– the characters of the work (permanent/occasional/repeatable),
– indication of whether the arms are supported,
– an indication of whether the hands are tilted enough to cut the axis of the symmetry of the body,
– determining whether the body balance should be included.

Fig. 5 shows the result of RULA analysis showing the load state of individual body segments for the "cutting phase 1" attitude, and the overall point score of this body position is shown in Fig. 6.

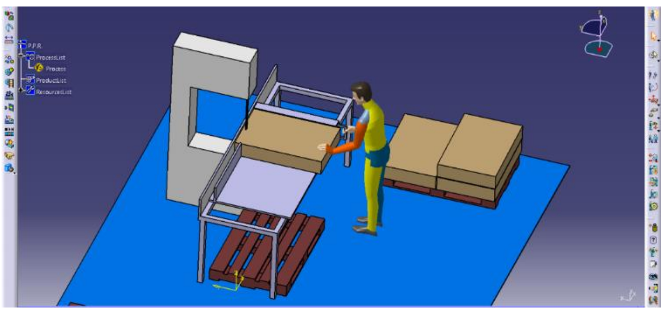

Fig. 5. Visualization of the RULA analysis for the "cutting phase 1"

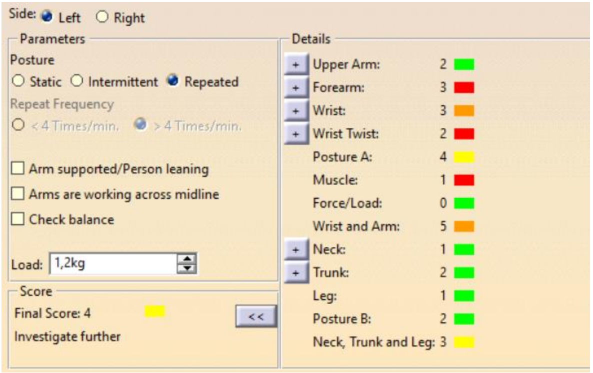

Fig. 6. Score rating of the RULA analysis for the "cutting phase 1"

From Fig. 6, it can be noticed that for such defined parameters, the final evaluation of this attitude is 4. Analogous analyzes were made for the remaining 3 postures, both for the load on the right and left side of the body. Obtaining the results is summarized in table 3. The RULA analysis takes into account the mass of material (1.2 kg, not 1.0 kg) corrected for the resistances arising on the table sliding crane, so that the operator actually manipulates a greater weight.

Tab. 3. The results of the RULA analysis

Posture assessed	The result for the left side of the body	The result for the right side of the body
Cutting phase 1	4	5
Cutting phase 1	6	4
Posture A	5	5
Posture B	4	3

According to the interpretation presented in Table 1, in the case of obtaining results with values of 5 or 6, it means the need to analyze the situation in the position more closely and make appropriate changes to reduce the overall nuisance of work in this position.

NIOSH analysis

Similarly to the RULA analysis, having such a model, it is also possible to carry out an ergonomic analysis of the NIOSH equation to examine the positions made by the worker while picking up items. To carry out this analysis it is necessary to:
– determine the frequency of activities,
– duration of activities,
– holding quality,
– the weight of the object being lifted.

As a result, an index RWL and L_I was obtained, the recommended weight limit for a analyzed activity was calculated. Figure 7 shows the visualization of the position "Posture A" (picking up) and the fragment of the result window.

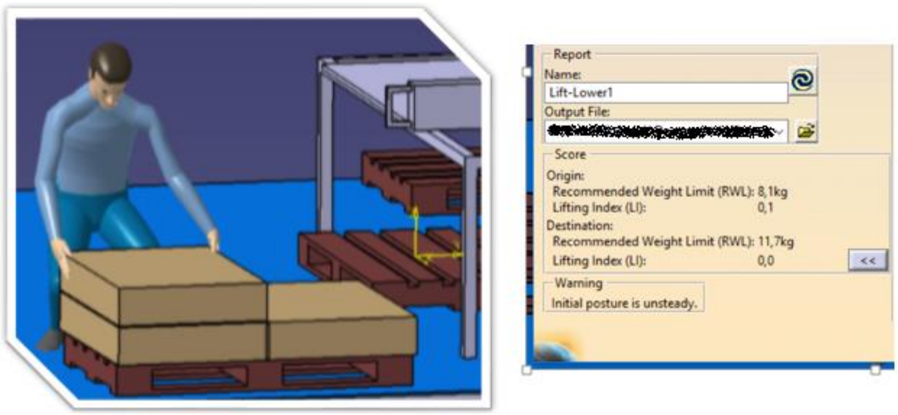

Fig. 7. Position "Posture A" and its final result

The obtained results are presented in table 4.

Tab. 4. The results of the NIOSH equation

Posture assessed	RWL	L_I
Posture A	8.1 kg	0.1
Posture B	11.7 kg	0.0

Based on these results, it can be concluded that for both attitudes there is no risk associated with lifting (L_I index less than 0.5). For posture A, the maximum weight can be up to 8.1 kg, while for posture B – 11.7 kg.

3.4. Suggestions for workplace rationalization

In connection with the alarming results obtained by RULA analysis, changes (improvements) were proposed illustrated graphically in Fig. 8.

Fig. 8. Suggestions for improvements

In order to minimize the weight manipulated by the operator, it was proposed to change the existing rail guides by linear guides. As a result, the friction that occurs, is significantly reduced, thereby reducing the supported weight.

Next, a change of the handle position was suggested in order to "force" another position assumed by the employee during the reciprocating movements. Changing the position of the handle will cause that the operator will have the strength of the whole body, pushing the table forward, and not as it was before, only by the strength of the arm, standing straight to it.

It was also proposed to reorganize the workplace in order to reduce the number of activities performed. The installation of a roll tape within the roll station, whose task will be the self-transferring of cut pieces of material to the pallet outside the cutter-table system, will not only eliminate the need to stack and export the finished pallet out, but also increase the efficiency of the station.

3.5. Modified workplace model and re-analysis

The proposed changes can almost simultaneously be introduced into the current model – without the need to interfere in the actual production environment, which can be associated with many different aspects, such as investment risk, downtime, breakdowns, etc. The effect of the proposal is presented in Figure 9.

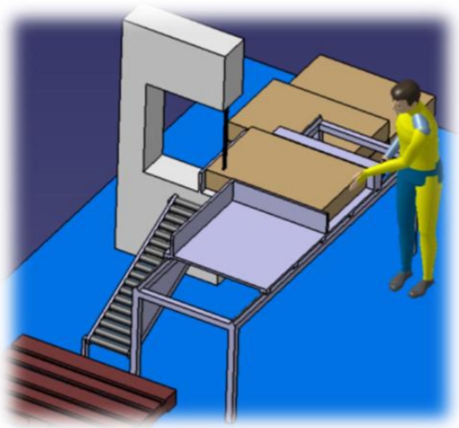

Fig. 9. Visualization of a part of modified workplace after the proposed changes

As a result of the proposed changes, the weight operated by the operator changed (reduction from 1.2 kg to 1.0 kg), the attitude assumed by the operator during the cutting process with the quality of the handle grip and the number of operations performed decreased (however, this is not taken into account in the results of ergonomic analyzes).

Similarly, RULA analysis (Table 5) and the NIOSH equation were performed for the modified position (Table 6).

Tab. 5. RULA analysis results for the modified position model

Posture assessed	The result for the left side of the body	The result for the right side of the body
Cutting phase 1	3	3
Cutting phase 1	3	3
Posture A	3	3
Posture B	3	3

Tab. 6. Analysis results of the NIOSH equation for the modified model

Posture assessed	RWL	Li
Posture A	8.3 kg	0.1
Posture B	14.2 kg	0.0

Fig. 10 presents the results obtained for RULA analysis for variants before and after making changes in the position, both for the right and left side load.

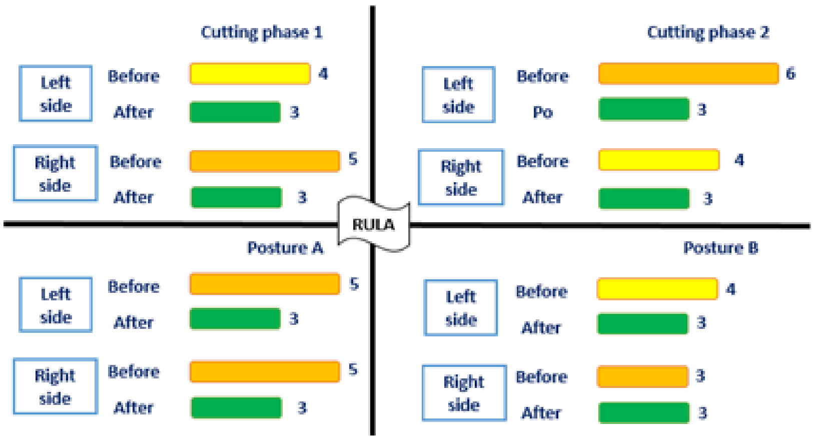

Fig. 10. Graphical presentation of results obtained using RULA analysis

4. SUMMARY

Conducted considerations and obtained results showed the correctness of the analysis in the studied area and proposing specific changes limiting the arduousness of work. Thanks to the workplace model created using the Delmia Ergonomics platform, the RULA analysis quickly obtained information on the most loaded segments of the body. It allowed to identify the main reasons for this condition and to virtually model improvements, re-analyze and verify the effectiveness of their application. In this way, the time to undertake real activities was significantly shortened, the costs of potentially missed changes were reduced, and the whole undertaking related to the evaluation and analysis of the proposal was conducted in a non-invasive manner for the functioning of the workplace. The results of the analyzes carried out in this way may be the basic argument for implementing the proposed changes into the production.

The analysis of the NIOSH equation shows that the mass of material available to the employee is significantly lower than the permissible mass in the positions it adopts. This means that in the future, materials with a larger weight (even up to 8.3 kg) can be cut on these types of workplaces without adversely affecting the comfort of the employee's work.

Designing or simulating workplaces using the "ergonomics" module allows to evaluate them in terms of ergonomic requirements, which in the current functioning of the industry, in addition to solving current problems of work organization, create the opportunity to increase efficiency and economic benefits. The high costs of software are a common obstacle in conducting ergonomic computer analysis. For this reason, only large corporations can afford them, while in the case of smaller companies, the solution may be outsourced to external entities or academic environments.

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