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# Faults and the physical workload in sawing and packing-related woodworking processes when considering potential ergonomic solutions

H. Kalkis[1,2,*], Z. Roja[3] and S. Babris[4]

[1]Riga Stradiņš University, Faculty of European Studies, Dzirciema street 16, LV-1007 Riga, Latvia
[2]University of Latvia, Faculty of Business Management and Economics, Aspazijas blvd 5, LV-1050 Riga, Latvia
[3]University of Latvia, Ergonomic Research Centre, Jelgavas street 1, LV-1004 Riga, Latvia
[4]BA School of Business and Finance, K. Valdemara 161, LV-1013 Riga, Latvia
[*]Correspondence: henrijs.kalkis@gmail.com

**Abstract.** The forest sector is a high-risk economic sector in Latvia, one in which manual work, awkward postures, the tightening up of individual muscle groups, and work monotony still exists. The aim of this study was to analyse the physical workload and fault modes, and their effects on the sawing and packing processes in woodworking when considering potential ergonomic solutions. Results show that packing operators and saw operators alike are exposed to severe loads, and these results coincide with survey results in which employees in these professions complain about the physical load and mention lower back pain. Fault modes and their effects on the sawing and packing processes were analysed using Failure Mode and Effects Analysis, and the main errors which were revealed in packing operations were related to machinery and lifting equipment, as well as to ergonomics and errors involving the human factor. The risk priority was calculated in terms of a figure. Financial indices were compared before and after any potential improvement in the sawing and packing processes. Analysis proves that investments in the improvement of ergonomics in relation to the automation of the production process saves human resources and is economically favourable when it comes to ensuring the sustainable development of the business in question.

**Key words:** ergonomics, load, forest sector, operations, failure modes.

## INTRODUCTION

In Latvia, the forest sector plays a vital role in the development of the national economy, employing between 45,000–50,000 people as it does. The forest sector comprises the forestry and wood industries. It is a high-risk economic sector, one in which manual work still exists. According to recent statistics, occupational illnesses are caused by ergonomic risks at work such as heavy manual work, awkward postures, the tightening-up of individual muscle groups, work monotony, lifting and moving heavy loads, work intensity, repetitive movements, and so on. According to the research that has been carried out by other authors, the most common occupational illnesses are carpal tunnel syndrome (NIOSH, 2004), arthritis in the wrists, back pain spondylosis, osteochondritis (Rossignol et al., 2005; Garg et al., 2007), hearing impairment (Robinson et al., 2015) and, quite often, obstructive pulmonary diseases (Carosso et al., 1987; Mandryk et al., 1999; Soytas, 2006; Thepaksorn et al., 2017).

Production processes in the century of modern industrialisation are closely related to the human factor. The human factor refers to the existence of a human interaction with technology, equipment, and the daily working environment (Sanders & McCormick, 1992).

Musculoskeletal disorders (MSD) are associated with high costs to employers such as absenteeism, lost productivity, increased health care, disability, and compensation costs for workers. Work-related MSD cases are more severe than the average non-fatal injury or illness (Bernard, 1997). As observed by Adei & Kunfaa (2007) in their study of wood processing industries in Ghana, occupational exposure to ergonomic hazards in the wood-processing industries were due mainly to lifting weights and uncomfortable posture during working hours. Workers had to remain in a standing position for as long as seven hours of an eight-hour shift, and back pain was the main complaint that resulted from awkward work postures such as prolonged standing, bending, or kneeling.

Rather often, a number of new businesses at the start of their activities, particularly small or medium-sized businesses, do not have a clear long-term business strategy, and have not yet developed a system which would ensure balanced interaction between technological processes, human resources, and the environment. Having something like this in place would facilitate the quality of their final product, ensuring that it corresponds to the needs of their clients and enabling them to compete successfully in a progressive business environment on the local market and in foreign markets as well. Successful competition, based on free market principles, is the basis of any state economics. Scientists point out that 'progressive work and a progressive business environment mean continuous, dynamic development and reform, as well as investment in technology and human resources' (Kramer et al., 2007). Therefore it is essential that new forms and methods are sought out in order to facilitate work productivity and increase the economic effectiveness of the organisation, and not decreasing product quality and retaining human resources. In the development of contemporary technology, the human factor and ergonomics both play a significant role in raising levels of work productivity. Around the world, there is a good deal of research available concerning the well-being of employees in an organisation and perfection of technology (Drury & Fox, 1976; Dul & Neumann, 2009). The significance of the human factor in the management and control of process quality has been proven. In particularly it is justified in the work of 'Ergonomics in total quality management: how can we sell ergonomics to management?' (Lee, 2005), in which employee participation is emphasised: employees are the first to evaluate their work, after that the problems are analysed by specially-organised expert groups which work out suggestions for improving the work. Such an approach increases work productivity, decreases the costs involved in the work, and improves safety at work. The process is part of ergonomics management, which has the aim of adjusting work process for an employee, changing their behaviour in a positive direction, and particularly emphasising their loyalty to the organisation. Nowadays ergonomics management in organisations, as well as process management, are of great significance in business to ensure the effectiveness of the organisation. This is a new approach to business, one in which the ergonomic aspects and values are taken into account in terms of business strategy, which includes ensuring the provision of adequate process management and the profitability of the business. The costs involved in ergonomic measures or solutions are easily understandable, as they are fixed financial means for improving the equipment being used, the acquisition of more modern equipment, the training of employees, etc. At the same time, evaluating benefits is more difficult, as they are related to a decrease in costs due to illnesses being suffered by employees, reduced losses due to goods not being produced within a certain time period, and so on. In addition, there are benefits which are difficult to convert into monetary value: the satisfaction of employees, loyalty to the business, etc. The costs involved in the provision of ergonomic solutions can be single (in terms of capital investments) and long-term. If the equipment and spare parts are produced on-the-spot, the costs are determined by using accounting information and personnel costs. Work will not be effective and process quality will not be achieved if an employee does not receive due attention. This is one of the most significant factors which can positively influence work effectiveness, the competitive ability of the business, and the satisfaction levels of clients (Brown et al., 2001). Global industrialisation and modern technology not only increases work effectiveness, but rather often causes problems which are of an ergonomic character such as, for example, work-related muscular-skeletal disorders (WRMSD).

The aim of this study was to analyse physical workload, fault modes, and the effects of these in terms of the sawing and packing processes in woodworking while considering potential ergonomic solutions.

## MATERIALS AND METHODS

The research was carried out at a medium-sized woodworking business with a total of 86 employees. The background factors for the subjects are presented in Table 1.

For the research twelve saw operators and nine assembly operators were selected – all male, all right-handers of various age groups with a length of service which ranged from less than a year to 25 years. The mean age for saw operators was 36.7 ± 4.3, but for packing operators it was 33.4 ± 3.7. The selection criteria for being involved in the research were as follows: in the compulsory health check-up no health problems had been found which were due to the heavy physical manual work, and all of the subjects selected agreed to participate in the study.

**Table 1.** Background factors for the subjects, with standard deviation (SD) and range

| Occupation (length of service) | n | Mean age ±SD | Range |
|---|---|---|---|
| Saw operators | 12 | 36.7 ± 4.3 | 20–58 |
| (0–5 years) | 4 | 25.5 ± 7.5 | 20–32 |
| (6–15 years) | 4 | 34.6 ± 3.1 | 25–41 |
| (> 15 years) | 4 | 46.2 ± 6.9 | 29–58 |
| Packing operators | 9 | 33.4 ± 3.7 | 19–61 |
| (0–5 years) | 3 | 24.2 ± 2.5 | 19–26 |
| (6–15 years) | 3 | 36.4 ± 4.0 | 25–38 |
| (> 15 years) | 3 | 43.8 ± 3.2 | 32–61 |

Job requirements for saw operators were as follows: sawing logs into planks on a horizontal, one-ribbon saw. As part of this process, the operator manually pushes the saw in order to produce the planks. Then two operators manually take the plank off the ribbon. The other process that was studied is packing. During the packing process, operators manually lift and move the materials, piling them in big packs. Then each ready pack is wrapped with polythene and a binding hoop (involving manual work). The amount of packing work is not regular – it depends on the amount of units that have been produced.

In order to include employees in any improvement in their working conditions and to discover what the employees involved think of the existing working conditions, a questionnaire was worked out. It included questions which covered the physical load at work, work intensity, and the psychosocial working conditions (the weight of the mass to be lifted, lifting frequency, whether the mass is easy to grip, whether the working space is sufficient and one's body position is comfortable, and whether the task to be performed corresponds to the employee's abilities). The questionnaire also included questions covering the working environment (restricted work posture, uneven floors, microclimate parameters, and lightning), and psychosocial risks (the conformity of rest break frequency with the work being carried out, unexpected changes in workload, errors at work, defective production, bad relations with the line manager, a lack of support from colleagues, and insufficient training, plus leisure time activities: smoking, alcohol consumption, and physical activities).

The Key Indicator Method was used to determine physical workload, and to assess the lifting, holding, and carrying of heavy loads, and also to analyse manual handling operations (Steinberg & Caffier, 1998; Klussmann et al., 2010).

By means of this method it is possible to identify overloaded lifting activities or the moving of heavy loads, or the carrying out of other dynamic operations. When this method is applied, actions which are related to the moving of heavy loads are assessed using points, including the length of the physical workload (in terms of hours), the weight of the object to be moved (in terms of kilogrammes), the state of the worker's body, and the conditions in which the work is carried out.

According to the Key Indicator Method, the total workload score can be calculated as follows:

$$WL = (M + S + A) \times I \quad (1)$$

where WL – workload (total score); M – value points which are dependent upon the weight of the load to be moved; S – value points which are dependent upon the position of the body during the performance of operations; A – value points which are dependent upon the working conditions; I – value points which are dependent upon the length of a work shift. As the investigation was carried out for multiple workers, the details collected were statistically analysed and mean values were calculated with a standard deviation (SD) for each value point.

The identification criteria for physical load is also taken into account and, according to this method, four categories can be deduced to demark the levels of hard work (light, moderate, hard, and very hard). These are shown in Table 2.

Fault modes and their effects on the sawing and packing processes were analysed by using Failure Mode and Effects Analysis (FMEA) (Tague, 2004; American Society for Quality, 2013). Today FMEA is widely used in various fields such as, for example, the automotive, nuclear, healthcare, and manufacturing industries (Juang et al., 2016).

**Table 2.** Key Indicator Method workload assessment criteria with categories showing levels of hard work

| Description | Points | Risk height |
|---|---|---|
| Minimum physical load<br>no significant endangerment to health | < 10 | I |
| Increased physical load. Overload possible for persons of low physical ability (workers over 40 or younger than 21; 'beginners' | 10 to 25 | II |
| Significantly increased physical load. Overload possible for persons of normal physical ability | 25 to 50 | III |
| Physical overload possible for everyone | > 50 | IV |

Levels of danger and the priority level for these faults are determined by the Risk Priority Figure (RPF). The RPF is a mathematical calculation of the numerical 'Severity, Probability, and Detection' ratings and is calculated by using this formula:

$$RPF = (Severity) \times (Probability) \times (Detection) \quad (2)$$

The three risk factors, severity, probability, and detection are estimated with the help of a value scale which ranges from one to ten (Pillay & Wang, 2003). The RPF is used to prioritise items that require additional planning or action. The higher the RPF value of a failure mode, the higher is the degree of priority for any necessary improvements.

Evaluation points according to the FMEA method were determined for the following elements: 1) processes; 2) possible type of fault in process; 3) possible effects of the fault; 4) possible reasons for the fault; 5) existing management; 6) improvement action for suggested ergonomics.

FMEA has been carried out using the computer program, Xfmea, which was produced by the American corporation, 'ReliaSoft', which allowed the potential RPF to be calculated if the manual work is substituted by an automatic process (Reliasoft XFMEA software, 2011).

Cost-benefit calculations in relation to occupational health and safety issues (Devisilov, 2007) were carried out additionally in order to analyse potential economic effectiveness if ergonomic solutions are introduced into the sawing and packing processes in a woodworking enterprise. Losses ($S_j$) were compared before and after the institution of ergonomic solutions, evaluating costs, or providing compensation in cases of accidents, trauma, or occupational illnesses. Losses ($Z_n$) due to production which has not been carried out, or which has been delayed or returned before any ergonomic solutions were determined; total losses (S) were determined due to capital investments (A) for economically-improved systems and exploitation (L), as was any increase in business profits ($\Delta P$), annual economic effectiveness (EG), and the absolute economic effectiveness of potential investments (EA) were determined. In calculations, the formulas given by the methodology for an assessment of economic effectiveness were used (Devisilov, 2007).

## RESULTS AND DISCUSSION

### Questionnaire results

Those employees who were involved in the study were divided into two groups: saw operators (n = 12) and packing operators (n = 9) by age and length of service in the profession. Saw operators (n = 12) were aged between 20–58 with a length of service of 33.33% of workers between zero to five years, 33.33% between six to fifteen years, and 33.33% of more than fifteen years. Packing operators (n = 9) were aged between nineteen and 61, with a length of service in the profession of 33.33% for workers between zero to five years, 33.33% between six to fifteen years, and 33.33% of more than fifteen years.

In summarising the acquired questionnaire results it was concluded that employees in the sawing and packing processes were mainly subjected to the following ergonomic risks: heavy manual work (72%), physical load (54%), repeated and frequent movements of the arms and body, and awkward work postures (47%). Nearly all employees (83%) recognised that the aforementioned ergonomic risks were increased by other risks in the work environment (such as chemicals, noise, vibration, and lighting), and that the work is intensive, and that the short breaks that are permitted at work are insufficient. The saw operators lift and move heavy loads of a weight that is between 10–20 kg, between 200–250 times within a single shift, while the packing operators lift and move heavy loads weighing between 50–60 kg, between 150–160 times within a shift. The lower back, legs, and arms are exposed to physical loads during the work process. Stress at work was mentioned by 24% of the employees who were asked. A total of 76% of participants in both of the groups being studied indicated high requirements at work, a lack of management support and low levels of monitoring of the work process, errors at work, and defective production. Nearly all of the participants (86%) admitted smoking and imbibing alcohol in moderate doses in their leisure time. They do not carry out any physical activities. A total of 87% of participants considered that in order to lighten the manual work, the introduction of mechanisation is necessary in the sawing and packing processes. Only 13% of workers considered that the number of employees should be increased.

### Physical load analysis

Using the Key Indicator Method, a total assessment of workload was carried out and the degree of risk $R_d$ was determined (see Table 3).

**Table 3.** Key Indicator Method results (L – load weight, P – work posture, C – work conditions, I – work intensity), standard deviation (SD), workload score (WL), risk degree ($R_d$)

| Professions | L±SD | P±SD | C±SD | I±SD | WL | Risk degree $R_d$ I – V | Potential Risk degree $R_d$ I – V |
|---|---|---|---|---|---|---|---|
| | Number of points | | | | | | |
| Saw operators (n = 12) | 4.4 ± 1.3 | 3.5 ± 1.8 | 1.3 ± 0.7 | 3.1 ± 1.6 | 32.98 | **III** | **II** |
| Packaging operators (n = 9) | 3.6 ± 1.9 | 4.2 ± 1.3 | 1.6 ± 0.4 | 3.6 ± 1.8 | 32.34 | **III** | **II** |

In evaluating the physical load, it should be noted that packing operators and saw operators are exposed to severe loads which correspond to 'Risk Degree 3'. This coincides with survey results in which employees of these professions complained of physical load and mentioned pain in the lower back. More often at their work places, defective production occurs or the work cycle is delayed due to accidents. This results in a decrease in the amount of materials being produced and a reduction of the economic effectiveness of the business. Therefore, improvements or modernisation are needed in a number of production processes. Ergonomic measures could create opportunities for the essential improvement of working conditions for packing and saw operators. In the process of sawing wood with a one-ribbon saw, the operator pushes the saw, sawing one plank at a time; removing the sawn timber is something that has not been mechanised; this is manual work. While changing the equipment to a frame-saw with an automated log-feed and plank-sorting line, the mechanisation of the work process is achieved which is something that is much more effective, ie. the amount of produced materials grows almost fifteen times and the time used in sawing 90 $m^3$ of timber decreases threefold. In one packing process in production, two employees are involved who manually lift and pack the ready product (140 times in a shift, moving stacks of planks with a total mass of between 40–50 kg). In introducing an automated hoist, the same work could be carried out by just one employee. The physical load in the work process would be significantly reduced, since a packer would not need to manually lift heavy stacks of planks. The number of movements which involve bending the body, which in the existing process rather often reaches more than a thousand movements in a shift, would also decrease. Apart from that, due to the introduction of ergonomic measures, productivity would rise by nearly four times, while packing work which involves 100 $m^3$ of production would require almost five times less time. Our proposals regarding ergonomic improvements conform with similar studies which have been carried out by other authors (Mirka et al., 2002). They determined that 'productivity benefits which could be drawn from these interventions were also found, but it is felt that the productivity improvements may only be a fraction of those that may result from the long-term utilisation of such interventions by skilled workers attempting to maximise their productivity'. Those ergonomic intervention measures which have been proposed in the study could be effective when it comes to ensuring a reduction of work-related muscular-skeletal diseases (WRMSD) which are related to the work of employees, which is something that has also been suggested by the authors of other studies (Marras et al., 2000; Karsh et al., 2001). The participation of those employees who were involved in the study on ergonomic improvements in the sawing and packing processes promoted ergonomic solutions, which conforms to studies on solutions for ergonomic intervention in relation to employee participation and the continuous introduction of ergonomic solutions in order to decrease incidents of WRMSD (van Eerd et al., 2010; Cantley et al., 2014). In the studies, it is emphasised that the systematic control of ergonomic risks is part of the system of occupational health and safety at work. At the same time, the authors indicate that participants in ergonomic improvements should be knowledgeable, experienced, and trained in ergonomics.

### Results from the FMEA method

For the analysis of the potential effectiveness of ergonomic solutions in woodworking operations, the FMEA method was applied and the danger levels involved in and the priority levels for these faults were determined in the sawing and packing processes.

Ergonomic solutions were considered in relation to the installation of a new automated line for sawing the logs, and acquiring new ergonomic hoists in packaging operations.

FMEA, using the computer program, XFMEA, proved the potential effectiveness of ergonomic intervention in the sawing and packing processes. Errors made by the equipment were analysed, along with ergonomic risks and the production process. The FMEA analysis results are summarised in Tables 4 and 5.

**Table 4.** Risk Priority Figure before and after potential ergonomic solutions being put into place in packing operations

| Processes and faults (errors) | | RPF before ergonomic solutions | | | | Potential RPF after ergonomic solutions | | | |
|---|---|---|---|---|---|---|---|---|---|
| Process | Likely kind of fault | Severity | Probability | Detection | RPF | Severity | Probability | Detection | RPF |
| Packing operations | Equipment: | | | | | | | | |
| | Sorting errors | 9 | 9 | 8 | 648 | 6 | 5 | 4 | 120 |
| | Packing errors | 9 | 8 | 8 | 576 | 8 | 4 | 3 | 96 |
| | Other faults | 8 | 9 | 8 | 576 | 6 | 5 | 4 | 120 |
| | Ergonomics risks: | | | | | | | | |
| | Muscles fatigue | 9 | 9 | 8 | 576 | 7 | 6 | 5 | 210 |
| | Manual handling | 9 | 9 | 7 | 392 | 6 | 5 | 5 | 150 |
| | Other faults | 9 | 6 | 8 | 216 | 5 | 6 | 5 | 150 |
| | Human factor errors | | | | | | | | |
| | Skills, competences | 8 | 8 | 8 | 512 | 8 | 8 | 8 | 512 |
| | Fatigue | 9 | 9 | 7 | 567 | 5 | 5 | 4 | 100 |
| | Other faults | 9 | 6 | 8 | 432 | 5 | 6 | 4 | 120 |
| | Production errors: | | | | | | | | |
| | Scratch faults | 9 | 9 | 8 | 648 | 7 | 5 | 6 | 210 |
| | Design defects | 8 | 9 | 8 | 576 | 7 | 5 | 5 | 175 |
| | Other faults | 8 | 9 | 8 | 576 | 6 | 7 | 4 | 168 |
| Total RPF | | | | | 6,758 | Total RPF | | | 2,131 |

The FMEA analysis showed that the main errors in packing operations are related to machinery and lifting equipment, as well as to ergonomics and errors involving the human factor. Equipment errors were connected to sorting and packing defects (the RPF was above a score of 500), as well as scratches and design defects which appeared due to inappropriate lifting and moving of the loads (the RPF was above a score of 500). Hence ergonomics risks were analysed along with the main errors which were associated with muscle fatigue and manual handling as well as awkward postures and repetitive movements. These risks influence errors which involve the human factor such as attention, skills, competences, and fatigue levels. Skills and competences depend upon each individual operator and will remain the same even after potential improvements have been carried out. Additional training could improve skills for these employees after ergonomic solutions have been implemented in terms of packing operations (specifically involving automated lifting equipment).

Similarly, the FMEA analysis was applied to sawing operations and the following main errors were found: technology (machinery), ergonomics, the human factor, and production errors. Production and equipment errors (with an RPF above 600) could be significantly minimised if potential improvements could be implemented in terms of a new automated line for sawing the logs (the RPF could be decreased to 150). Similarly, as for packing operations, sawing operations could also see a decrease in ergonomics and errors which involve the human factor. Skills and competences will remain at the same level even after the introduction of an automated sawing line, but could be improved if training were to be provided to employees. A summary of RPF scores before and after potential ergonomic solutions are implemented is shown in Table 5.

**Table 5.** Risk Priority Figure before and after potential ergonomic solutions

| Processes | TOTAL RISK PRIORITY FIGURE (RPF) | |
|---|---|---|
| | RPF before ergonomic solutions | Potential RPF after ergonomic solutions |
| Packing operations | 6,758 | 2,131 |
| Sawing operations | 9,364 | 2,081 |

The total initial risk priority figure (RPF) was determined which, in the business which was being studied, was: an RPF of 6,758 (packing operations) and 9,364 (sawing operations). This RPF was very high and showed that urgent improvements are needed in terms of work organisation and risk prevention. The potential RPF evaluation suggests that after ergonomic solutions have been implemented and a modernisation of technology has been carried out, ergonomic risks could be reduced: an RPF of 2,131 (packing operations) and 2,268 (sawing operations). This shows that improvements are needed through the introduction of ergonomic solutions which will help to reduce errors in work in terms of the equipment as well as preventing a physical overload by at least three to four times. There is a reason to consider that, together with the introduction of preventive measures, the volume of production and product quality will also increase.

Several authors have successfully applied the FMEA method. For example, the risk priority level was calculated for the failure mode in a manufacturing business and the FMEA has been proposed as a decision-making support tool (Franceschini & Galetto, 2001). The researchers analysed the potential failure modes in manufacturing and chose the greatest failure risk as one that would be the target of improvements. This corresponds to the investigation by the authors which discovered that the risk priority figure can be significantly decreased if the ergonomic solutions are implemented.

**Economic calculation analysis of potential ergonomics solutions**

Potential economic calculations have been calculated for ergonomic solutions in sawing and packing operations. Financial indices were compared before and after any potential improvement to sawing and packing processes.

The calculation summary for ergonomic solutions in a woodworking business is shown in Table 6.

**Table 6.** Calculation summary for potential ergonomic solutions

| Total losses | Before ergonomic solutions | Potential after ergonomic solutions |
|---|---|---|
| | 79,000 EUR | 22,800 EUR |
| Potential effectiveness after ergonomic solutions | | |
| annual economic effectiveness or advantage | absolute effectiveness of investments | period of investment payoff |
| 63,000 EUR | 0.78 | 1.28 years |

The economic calculation analysis which was carried out in terms of potential ergonomic solutions was made possible by being allowed access to the financial data of the business which was the subject of the study. The results indicate that, after ergonomic solutions have been implemented in sawing and packing operations, annual production rates could increase by 43%. When taking into account potential profits and the expenses being incurred for maintenance and ergonomic solutions (covering maintenance staff, equipment servicing, the acquisition of spare parts, etc), the annual economic effectiveness was determined as being a figure which could reach as high as 63,000 EUR. The calculated absolute economic effect of investments, EA = 0.78, shows that investments in ergonomic solutions will be effective. The period of investment payoff, T, is calculated as being comparatively short, almost a single, with $T = (1/EA) = 1/0.78 = 1.28$ years.

Analysis proves that investments into the improvement of ergonomics in relation to the automation of production process retains human resources and is economically favourable when it comes to ensuring the sustainable development of the business in question.

## CONCLUSIONS

Employees in a woodworking company are subjected to heavy levels of manual work, a high physical load, and repeated and frequent movements of the arms and body, as well as awkward work postures. These can all serve to cause rapid tiredness and a lack of attention, which may result in errors in production process and defective production.

An analysis of the effectiveness of ergonomic solutions shows that any business that has introduced ergonomic solutions and has modernised its production process technology can decrease not only the risk of physical overload at work, but can also decrease error types and their consequences, improve the monitoring of the process, and also the quality of the finished products.

Ergonomic solutions in combination with other improvements in woodworking production processes all have a positive effect on productivity levels and are likely to have financial benefits for a business, including a decrease in WRMSD, the promotion of satisfaction in its employees, and an improvement in the company’s image.

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