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A study of the connection between lean manufacturing and ergonomics

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Abstract: If an organization implements lean manufacturing without concurrently considering ergonomic requirements, the anticipated outcome, such as increased production productivity, may not be realized. Several authors have emphasized the significant potential for synergies resulting from the successful integration of lean manufacturing and ergonomics. The objective of this paper is to exemplify the application of lean manufacturing tools in enhancing the productivity of casting aluminium alloys while incorporating ergonomic considerations. The results of the assessment of working positions through the CERAA application before intervention indicate a potential risk of increased physical strain on operator. Utilizing a hybrid research design, we conducted a singular case study that delves into the industrial implementation of a robotic cell in the production line for manufacturing battery covers for electric/hybrid vehicles. The results of the assessment of working positions after the implementation of robotic technology do not indicate a potential risk of increased physical load on the operator. This case study demonstrates the integration of ergonomics and lean manufacturing principles in practice.

1 Introduction

The findings of numerous research studies [1-3] indicate that the implementation of lean manufacturing significantly amplifies the perceived workload among employees. One contributing factor is the elimination of non-value-adding activities in the work process, as part of efforts to reduce waste. This elimination can result in heightened constraints associated with task execution, coupled with a reduction in workload variability. Consequently, the outcome often involves monotonous work characterized by repetitive manual tasks, a prevalence of identical work assignments, or labour at a forced pace with limited breaks and rest opportunities. Such conditions not only adversely impact work performance but also detrimentally affect the health of individuals engaged in the work process.

It becomes evident that implementing lean manufacturing in an organization without simultaneous consideration of ergonomic requirements may thwart the expected outcome of increased production productivity. While lean manufacturing and ergonomics may appear initially to have conflicting objectives, this is not entirely accurate. Consider the shared goal of eliminating one fundamental type of waste: unnecessary movements. Unnecessary movements contribute to increased employee fatigue, potentially leading to diminished product quality and prolonged production times. Consequently, initiatives that contribute to reducing unnecessary movements can be viewed as mutually beneficial from both lean production and ergonomics perspectives.

2 Literature review

Various authors underscore the substantial potential for synergies resulting from the successful integration of lean manufacturing and ergonomics in this context. Nunes [4] proposed a methodological framework for integrating Lean Six Sigma (LSS) and ergonomics. Alsaffar and Ketan [5] proposed a diagnostic expert system in the form of a software tool that was developed in the Visual Basic 6 environment. The software tool is based on the idea of combining methods aimed at identifying and reducing lost time and ergonomic risks related to the biomechanical and postural requirements of work activities. Brito et al. [6] highlighted the possibility of reducing machine retyping time while improving working conditions from an ergonomics perspective. The case study was carried out in a tap manufacturing plant where a high rate of absenteeism and complaints from employees related to excessive strain on the limbs was noted. By applying the SMED (acronym for term Single Minute Exchange of Die) method, the retyping time was reduced by 46 percent and at the same time the risk of damage to the support and locomotion system was reduced to an acceptable level through the REBA (acronym for term Rapid Entire Body Assessment) method. Jarebrant et al. [7] extended the traditional lean manufacturing VSM (acronym for term Value Stream Mapping) tool to include an ergonomic dimension, resulting in the new ErgoVSM tool. The ErgoVSM tool is based on visualization and dialogue to support the process from mapping the current state to the creation of a future state value stream, including a list of actions needed to achieve it. The ergonomic assessment considers the following areas: working postures, muscle strength, variability of physical load and resting ability. Arce et al. [8] further extended the ErgoVSM method to assess mental workload. The assessment of mental workload is carried out through the subjective response of the employee using the NASA TLX method. Botti et al. [1] developed a linear mathematical model that can be used to determine the optimal placement of manual and automated jobs in a hybrid assembly line. The optimization criteria are based on the reduction of work-in-process quantity and total cost, taking into account at the same time, in the case of manual jobs, the risk of health damage due to high-frequency repetitive activities in manual handling through the OCRA (acronym for term Occupational Repetitive Actions) evaluation method. Oliveira et al. [9] demonstrated the synergistic effect of lean manufacturing and ergonomics through the example of material flow optimization in order to increase labour productivity and improve working conditions. By modifying the original logistics processes, they were able to reduce by 94 percent the walking distance that operators have to cover in order to secure the necessary material between the warehouse and the workplace. Yusuff and Abdullah [10] conducted an ergonomic analysis based on observation and evaluation of non-value adding work movements. They used movement time studies, a standardized Nordic questionnaire, and the RULA method (an acronym for term Rapid Upper Limb Assessment) in their evaluation. Based on the results of the analysis, ergonomic interventions were designed to eliminate or reduce unnecessary movements as much as possible. The results of the study confirmed that an inappropriate combination of work positions and work movements not only increases the risk of cumulative trauma disorder, but also decreases the productivity and efficiency of the employee. Colim et al. [11] analyzed the synergism of integrating lean manufacturing principles and ergonomics through the implementation of a collaborative robotic assembly workstation. The evaluation of the workplace before and after the implementation of the robotic technology was carried out by determining various key performance indicators using a time study and direct observation. The subjects of the ergonomic analysis were 40 work positions during assembly operations. Three methods were used to evaluate the workstations: the RULA, the RSI (acronym for term Revised Strain Index) and the KIM (acronym for term Key Indicator Method). In addition, operators' attitudes towards the introduction of the robot in the assembly workplace were investigated by means of questionnaires. The aforementioned multi-method approach demonstrated that the implementation of a collaborative robotic assembly workstation achieved: a reduction in production times, an improvement in working conditions and an increase in personal well-being at work from the operators' point of view. Pekarcikova et al. [12] and Spirkova et al. [13] focused on the application of simulation tools in creation of the casting process model and simulation of technological operations on the workplace of casting processing. They optimized the workplace layout in terms of ergonomics by using the virtual reality system or Tecnomatix Jack software module and Microsoft Kinect.

Aim of the paper is to demonstrate the use of lean manufacturing tools in increasing the productivity of casting aluminum alloys while taking into account ergonomic requirements.

3 Methods of ergonomic assessment

Similarly, as Colim et al. [11] we adopted a hybrid research design and conducted a single case study. This case study explores an industrial implementation of a robotic cell in production line for the production of battery covers for electric/hybrid vehicles, integrating ergonomics and lean manufacturing principles. We assessed the workplace before and after the implementation of robotic technology and measured different indicators through a time study and direct observation. Originally, the operator manually transferred the castings from the transport basket to the storage basket for heat treatment (Figure 1). Subsequently, after heat treatment and cooling of the castings, operator again manually handled them from the storage basket to the transport basket. After intervention, operator just lifts the castings from the transport basket to the conveyor and the robot arm then places the castings in the storage basket.

Value stream mapping method was used to identify non-value tasks. Basket load/unload task was considered as non-value adding task but necessary so this task cannot be eliminated, just reduced as much as possible.

Ergonomic assessment was performed using following methods:

• CERAA (acronym for Ceit Ergonomic Analysis Application) module Evaluation of working postures and dimensional requirements and module Assessment of manual handling,

• Key Indicator Method for assessing physical workloads with respect to manual lifting, holding and carrying of loads (KIM-LHC),

• Rapid Entire Body Assessment (REBA).

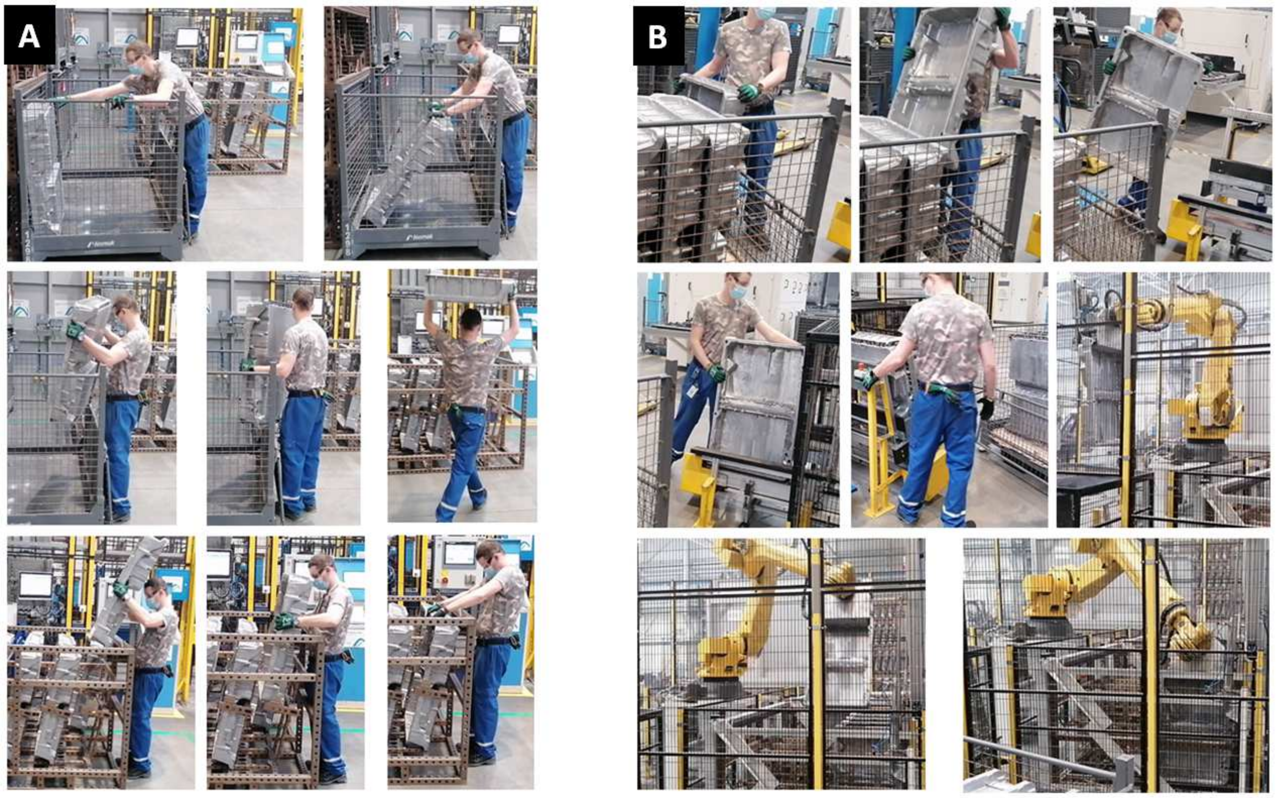

Figure 1 Manual handling of castings: A – before intervention, B – after intervention [14]

4 Results and discussion

Comparison of the workplace before and after the implementation of robotic technology is presented in Table 1.

Table 1 Comparison of the workplace before and after the implementation of robotic technology

Indicator	Before intervention	After intervention
Production lead time	3618 seconds	3587 seconds
Number of operators	2	1
KIM-LHC score Physical loads	101.5 points High intensity of load	49 points Intensity of load is slightly increased
REBA score Task – casting carrying Task – placing the cast in the basket	8 points High risk 8 points High risk	4 points Medium risk - -
CERAA Working postures Maximal full shift weight of the load	Limit exceeded Limit exceeded	Limit not exceeded Limit not exceeded

The results of the assessment of working positions through the CERAA application before intervention indicate a potential risk of increased physical strain on operator (Figure 2). During the evaluation of the trunk

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forward bend, it was found that the cumulative duration of the unacceptable working position (trunk forward bend > 60°) for the entire shift is 11.44 minutes.

Figure 2 Working postures evaluation in CERAA before intervention [14]

During the head tilt assessment, it was found that the cumulative duration of the unacceptable working position (head tilt > 40°) for the entire shift is 29.33 minutes. During the evaluation of upper limb flexion, it was found that the cumulative duration of an unacceptable working position (limb flexion > 60°) for the entire shift is 24.5 minutes. The total working time in the work shift in individual unacceptable work positions thus exceeds the permitted 30 minutes. When evaluating the maximum full shift weight of the load, it was found that the indicative weight value is observed only in the case of operators in the age category of 18 to 29 years. In the remaining age categories, the maximum full shift weight is exceeded by 8.4% (30-39 years), by 30% (40-49 years), and by 56% (50-60 years).

The results of the assessment of working positions after the implementation of robotic technology do not indicate a potential risk of increased physical load on the operator. During the evaluation of the trunk forward bend, it was found that the cumulative duration of the unacceptable working position (trunk forward bend > 60°) for the entire shift is 2.86 minutes. When evaluating head rotation, it was found that the cumulative duration of an unacceptable working position (head tilt > 15°) for the entire shift is 18.33 minutes. During the assessment of upper limb flexion, it was found that the cumulative duration of an unacceptable working position (upper limb flexion > 60°) for the entire shift is 7.33 minutes. Thus, the total time of work in a work shift in individual unacceptable work positions does not exceed the permitted 30 minutes. During the evaluation of the trunk forward bend, it was found that the cumulative duration of the conditionally acceptable working position (trunk forward bend: 40°- 60°) for the entire shift is 2.2 minutes. When evaluating head tilt, it was found that the cumulative duration of a conditionally acceptable working position (head tilt: 25°- 40°) for the entire shift is 11 minutes. During the assessment of upper limb flexion, it was found that the cumulative duration of a conditionally acceptable working position (upper limb flexion: 40°- 60°) for the entire shift is 14.67 minutes. The total working time in a work shift in individual conditionally acceptable work positions does not exceed the permitted 160 minutes.

5 Conclusions

The findings of this study clearly demonstrate that integrating robotic technology into production processes can significantly reduce the physical workload and ergonomic risks for workers while simultaneously enhancing productivity and operational efficiency. Specifically, the implementation of a robotic cell for handling castings led to a marked reduction in the time workers spent in ergonomically risky positions, as evidenced by improved scores in assessments like KIM-LHC (from 101,5 to 49 points) and REBA (from 8 to 4 points) [15-20]. Following the intervention, the intensity of physical load was reduced, and work postures that previously exceeded recommended limits were brought into acceptable ranges. Thus, the total time of work in a work shift in individual unacceptable work positions does not exceed the permitted 30 minutes and the total working time in a work shift in individual conditionally acceptable work positions does not exceed the permitted 160 minutes. The reduction in time spent handling castings manually and the minimization of monotonous manual tasks not only improved working conditions but also boosted overall productivity.

An important aspect of this study is the confirmation of the synergistic effect of integrating lean manufacturing and ergonomics. Lean manufacturing, which emphasizes eliminating unnecessary movements and waste, need not conflict with ergonomic principles; rather, it can complement them effectively. By removing non-value-adding tasks and optimizing working conditions, both worker well-being and production quality can be improved, with shorter production times as a result.

This study highlights that incorporating ergonomic requirements when implementing lean manufacturing is essential for achieving comprehensive improvements in both performance and employee satisfaction. By doing so, companies can avoid unintended negative impacts on workers' health while supporting long-term sustainability and competitiveness in production processes.

The integration of robotic technologies with an emphasis on ergonomics presents a crucial approach to modernizing production lines, particularly in the context of increasing productivity and improving working conditions. This approach is essential not only for improving operational efficiency but also for safeguarding the health and well-being of employees.

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