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Contribution to the synergies between ergonomics and lean management for industrial performance: a simulation-based approach

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Abstract

Maintaining an equilibrium between employee well-being and economic sustainability is essential in modern industrial environments. "Lean sustainability" encourages an operational excellence strategy that is human-centred and increases efficiency through waste reduction and resource optimization. This article addresses worker ergonomic concerns while identifying bottlenecks and optimizing resources in manufacturing processes using lean principles. The research, which uses the waste sorting process as a case study, aims to find a balance between ergonomics and lean management by using a simulation-based methodology. It provides recommendations for improving operator well-being and overall efficiency.

Keywords: Performance; Ergonomics; Digital Twin; Flow Simulation; Value Stream Mapping (VSM); Lean Management; Multi-scale Approach; Virtual Reality (VR)

1. Introduction

Lean sustainability is defined in the view of integrating environmental and social considerations into traditional lean manufacturing practices [1]. More precisely, social factors include, improving workplace place conditions and workers' safety and well-being among others. However, the interdependent connection between ergonomics and lean management principles becomes evident as a vital link in tackling the operational inefficiencies that are common in manufacturing facilities and businesses. Lean principles and ergonomic factors must be carefully balanced to achieve operational efficiency without compromising worker health and safety. Much research [2,3] states that most of the time, ergonomic factors are often ignored when implementing lean concepts. This combination of ergonomic factors with lean principles helps to guarantee optimal operational efficiency while making sure that the welfare of workers is safe [4]. The fields of smart manufacturing and Industry 4.0 have brought tools such as simulation software, AI, sensors, digital twins, virtual reality, and augmented reality that could help understand the connections between ergonomics and lean management [5]. Although still in its initial stages, incorporating these technologies shows promise for enhancing the sustainability and efficiency of industrial processes. Therefore, after a comprehensive literature review, it appears that today there is a research gap in properly combining lean principles with ergonomic factors. The purpose of this study is to contribute to filling the gap in the integration of lean principles with ergonomic factors supported by digital technologies.

The goal of this research is then to support the process to achieve optimal operational efficiency while employee well-being is not compromised. This study seeks to discuss how enterprises use lean management principles and their possible outcomes. This combined approach that this study makes, plans to maximise the outcome of both productivity and the well-being of the workforce.

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To achieve the above-mentioned goal, we propose a framework based on a simulation approach using digital technologies. Through a meticulous, phased methodological process, a versatile framework applicable to future users is developed. This framework is then applied in a case study examining the optimization of waste separation stations in garbage sorting facilities. The case study explores how integrating ergonomic factors with lean management principles could enhance these stations' efficiency and effectiveness. In the rest of the paper, workplace ergonomics and lean management principles are introduced in sections 2 and 3, respectively. Section 4 discusses the role of digital technologies in the combination of ergonomics and lean. Our proposed methodology is presented in section 5 followed by, a case study in section 6. The results are discussed in section 7, discussion and finally section 8 concludes the paper and outlines future work.

2. Workplace ergonomics

The race for productivity and quality led to a tremendous evolution in mass production and lean systems resulting in the emergence of ergonomics [6]. Work-related chronic health issues are becoming more common [7]. Fundamentally, ergonomics seeks to design workspaces that accommodate employees' physical and mental constraints and abilities, improving comfort, security, and output.

Workplace ergonomics are important for more reasons than just personal health; they also have wider organizational benefits that have a big impact on total output and efficiency. Businesses can lower absenteeism by emphasizing ergonomics since employees are less likely to get sick or have accidents that need time off [8]. Additionally, a workplace that adheres to ergonomic principles raises employee morale and happiness [8]. Employees who perceive that their welfare is esteemed are more likely to be involved, driven, and dedicated to their jobs. Ergonomic interventions, such as well-made workstations and tools, can decrease errors and improve task precision. This results in improved client satisfaction and the company's reputation through higher-quality goods and services [9]. In the long term, investment in ergonomic implementation in an organization will affect positively the organization and it will reinforce the long-term stability of the organization as well [7].

The first step in implementing ergonomics in the workplace is to conduct a thorough task analysis, which involves watching and documenting the tasks that employees complete, the positions they take, and the forces they apply. Once ergonomists have a clear understanding of the specific requirements of each job, they can identify potential risk factors for discomfort and injury. A method that is often followed in assessing ergonomics is the Rapid Entire Body Assessment (REBA) method [10]. The next stop of the process is the assessment of the organization to identify the instances where ergonomic implementation could be applied. It could include operations such as redesigning, and reassigning of tools and equipment that are used. This can involve modifying the height and angle of work surfaces, making sure that materials and tools that are often used are accessible, and creating products that reduce the need for uncomfortable hand postures or unnecessary force [11]. Another lesser addressed factor when implementing ergonomics factors is the training and educating of the employees. This ensures that the executed ergonomics implements are in practice at all times. Additionally, encouraging a culture of ergonomics at work motivates staff members to actively participate in preserving their health and safety, which results in a more engaged and effective workforce.

3. Lean management

Lean management could be defined as a methodological approach that increases the productivity of an organization while reducing waste. It also makes sure that the customer needs are met appropriately as well. Lean management concepts were first implemented in the Toyota Production System (TPS) in the middle of the 20th century, and since then, they have spread throughout other industries globally [10]. Five fundamental ideas summarise the core principles of lean management: mapping the value stream, defining value from the customer's perspective, producing flow, producing pull, and striving for perfection [12].

The development of technology throughout the world has impacted its entirety. This also has impacted the principles of lean in a positive manner as well. The use of digital technologies has helped lean management to make the process of decision-making much more precise and faster.

However, it is also important that lean management establishes continuous improvement within the company. It fosters a sense of empowerment and engagement by encouraging staff members at all levels to share ideas and take responsibility for their work processes [13]. To put it simply, lean management offers a thorough framework for attaining long-term success and operational excellence in the fast-paced business world of today.

To achieve higher operational efficiency over a long period and have a social responsibility within the workplace, the principles of lean management could be combined with sustainable practices as explained by [1]. The triple bottom line which states that the company’s performance should be evaluated not just by economic factors but with a combination of economic, environmental, and social goals, is also emphasized by lean sustainability [14]. Lean sustainability explains that the company must provide value to each of the stakeholders. These include customers, managers, employees and also the environment. To achieve this, lean sustainability extends the concepts of lean management, which include waste reduction, continuous improvement, and value stream mapping, to take into account resource conservation, pollution prevention, and worker and community well-being. The main feature of lean sustainability could be mentioned as the implementation of lean concepts with a long-term goal in mind [15] which has been highlighted in many studies as a major aspect. In the end, lean sustainability offers a comprehensive framework for attaining both sustainability and excellence, guaranteeing that corporate expansion is in line with the values of social justice and environmental preservation.

4. Digital technologies to integrate lean and ergonomics

The fields of smart manufacturing and Industry 4.0 have brought tools such as simulation software, sensors, digital twins, virtual reality, and augmented reality to help understand the connections between ergonomics and lean management [5]. Workers of a site can get overwhelmed with data, if there was an attempt made to make processes more complicated by adding more data. Further investigation into these aspects is necessary to ensure proper management of mental demands alongside operational and physical improvements [16]. Research trends show that only a small number of publications in consideration use a simulation-based methodology to investigate the relationship between ergonomics and lean management which could arise due to several key aspects. The limited application of this methodology can be attributed to the complexity of modelling human behaviour [17], the multifaceted nature of ergonomics, challenges in validation [5] and the resource-intensive nature of developing realistic simulation environments. Although still in its initial stages, incorporating these technologies shows promise for enhancing the sustainability and efficiency of industrial processes.

To overcome such problems, the currently existing solutions include software such as FlexSim for discrete event simulation. It allows to model, analyse and optimize different workflows in a system. By visualizing these it allows us to make data-driven decisions, and test different scenarios without disturbing the actual process.

CAPTIV by TEA Ergo is a specialized tool used to record and analyze movement, posture, and physical strain during jobs. It is used to gather ergonomic data. Critical ergonomic data, such as awkward postures, repetitive motion, or excessive pressures exerted by workers during their operations, can be gathered with the aid of CAPTIV. CAPTIV software allows to analysis of such collected data.

5. Proposed research methodological approach

To combine ergonomics and lean management aspects, a multi-step procedure is proposed that incorporates ergonomic data and digital modelling to optimise processes while taking sustainability and ergonomic considerations into account. There are two key streams to the process: creating a digital simulation model and gathering ergonomic data as shown in the Fig. 1.

Creating a digital replica of the facility's real operational system is the first step in the procedure. As a virtual depiction of the work processes, this model aids in the analysis and visualisation of the dynamics of the existing workflow as well as the identification of inefficiencies.

The digital model is validated once it is built to make sure it faithfully depicts the real-world system. Validation is the process of verifying that the model acts realistically and is suitable for use in further optimisation stages by contrasting the simulation results with the facility's actual operations.

Following data collection, the research focuses on finding key ergonomic data, i.e., regions where workers are more vulnerable to strain injuries. This information is essential for enhancing the workflow and design of the workstation.

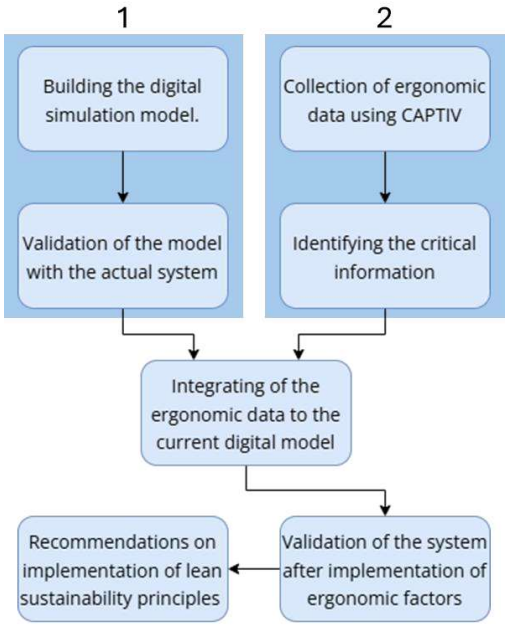


Fig. 1. Proposed framework to combine lean and ergonomics factors.

The next stage is to integrate the ergonomic data into the digital simulation model after the data has been gathered and the model has been validated. This results in a comprehensive system that takes ergonomics and operational efficiency into account, enabling the testing of various scenarios through simulation.

After integration, the system is validated once more; this time, the effectiveness of the suggested ergonomic enhancements inside the digital model is evaluated. This stage guarantees that any modifications or suggestions based on ergonomic data will improve operations without endangering the health of the workforce.

The goal of a theoretical model that unifies ergonomics with lean management concepts is to systematically and formally integrate human well-being with operational efficiency. Researchers and practitioners can use this model as a framework to optimise processes without compromising worker health and safety.

One of the biggest limitations of the model is the dependency of the simulation model on historical data. This could limit the responsiveness of the model. Although the model allows for customisation, if it is not sufficiently adapted to organisational or industry contexts, there is a risk of overgeneralisation, which could result in ineffective interventions. Furthermore, the completeness and quality of the data used have a significant impact on the model's accuracy and dependability. Incomplete or inaccurate data can produce deceptive results that jeopardise the process of making decisions.

The validity of the model could depend on many factors. The accuracy of the data has a significant impact on the model's accuracy. Consequently, it's critical to ensure that the data being used is reliable. The model's parameters and data inputs should be regularly reviewed and modified to account for any significant operational changes or adjustments to ergonomic requirements. When this model is designed, care must be taken to ensure that the opinions of various system users and

stakeholders are taken into account. As a result, managers, staff members, and other specialists are also quite important. To adapt processes repeatedly to feedback and changing circumstances, a continuous improvement mechanism ought to be incorporated into the model.

The model's indications emphasise how important the validity of the model is. A few of the model's metrics include the content variance at various stations, worker utilisation rates, and the throughput by various stations. The effectiveness of ergonomic modifications is evaluated using ergonomic health indicators, such as worker fatigue levels, the frequency and severity of musculoskeletal problems, and ergonomic risk assessments. Consideration is given to employee satisfaction levels, which operate as oblique indicators of how successfully ergonomic analysis balances worker well-being with operational advances. Frequent cost-benefit analyses serve as a guide for estimating the financial effects of changes that are put into place and assessing the return on investment in terms of lower costs associated with inefficiencies and medical expenditures.

6. Case study

Waste sorting facilities serve as key components of municipal waste management systems, where different types of waste are sorted, recycled and disposed of in an environmentally friendly way. In this plant, waste is collected, sorted, compressed into bulks and transported outside the facility. However, these facilities often face challenges such as inefficient workflow processes, excessive stock accumulation, difficult working conditions, and ergonomic strain on workers due to the repetitive nature of sorting tasks.

Throughout the case, the company in consideration will be hereafter referred to as ABC for confidentiality reasons, while the waste sorting facility in consideration will be referred to as X. The processes of the waste management plant start by receiving the waste material into the plant. These are sorted using both manual and mechanical sorting methods. This sorting separates the different types of waste such as plastics, paper, cardboard, wood and metals. Then the recyclable materials are processed to prepare them for dispatch. Transportation inside the plant is done through material handling equipment such as forklifts. The plant requires to be lean and reduce inefficiencies in the processes thus resulting in reduced stock, increasing the rates of recycling, lowering the impact on the environment and taking a step towards a more sustainable waste management system.

The optimization of waste separation plants becomes critical for ensuring the efficient processing of incoming waste streams while minimizing operational bottlenecks. Often, companies are required to increase profits, have more operational efficiency, and increase the quality of their products and services. In the case of ABC company as well, they are also required to have these requirements. Through lean management problems like quality improvement, reduction of the costs etc. could be addressed. However, this often leads to the simple and simplistic solution of increasing the pace of work to the detriment of working conditions and increasing the risk of Musculoskeletal Disorders due to high work rates. ABC employs people in vocational rehabilitation. The reduction in working conditions will therefore inevitably lead to difficulties in recruiting employees, which in the medium term will reduce production at the plant. ABC's main problem is therefore to simultaneously increase production and improve ergonomics.

To improve the efficiency of its X waste sorting facility, ABC initiated a comprehensive investigation. This effort was driven by the need to increase material recovery rates, boost sorting capacity, and implement ergonomic solutions to reduce operator strain and support long-term staff retention. The project also aimed to prepare the facility for future market changes and technological advancements.

7. Results and discussion

This section discusses the data from the case study of ABC's X waste sorting facility and an evaluation of the results. To obtain these results the proposed methodology integrating the Lean management principles and ergonomics was applied (see section 5). First, a study based on the lean management tools of value stream mapping and material flow analysis to define key performance indicators. A simulation model was implemented to formalize the process dynamics and identify the impact of the whole materials flow on the system performance. Second, the critical workstation including manual operations was studied from the perspective of ergonomics, using the CAPTIV system. Analysis of different KPIs was done which supports the decision-making process of the company ABC. This shows the results of the integration of lean and ergonomics in a digital simulation by identifying the difficulties faced as well as the benefits that can be achieved.

Seven types of waste were identified from the qualitative observations. This is done using a value stream mapping of the facility. At ABC's X waste sorting facility, they are overproduction, inventory, unnecessary transport, extra processing, duality defects, waiting, and information flow.

Fig. 2. Using TEA Ergo's activity analysis software to map the movements of the workers

TEA's CAPTIV sensors were used to perform ergonomic analysis of the manual sorting station workers, as shown in Fig. 2. Using the technology of TEA Ergo, all the actions performed by manual sorters were identified. The postural constraints are mostly located at the back of the body due to bending. During this analysis, repetitive movements by the workers were identified. This can be identified as a KPI for the ergonomics analysis.

Based on the information gathered, the third phase aims to

comprehend how ergonomics are affected by lean process optimisations and vice versa. This requires overlaying in the simulation lean improvements (like shortened task durations) with ergonomic limitations (like minimising difficult postures). A variety of lean tactics are simulated, and any possible ergonomic effects could be assessed. To make sure that the results from the lean implementation will not affect the ergonomics considerations, the effect on the ergonomics will be assessed for each of the suggested lean implementations. For example, cutting down on process time shouldn't result in more repetitious work that puts people at risk for harm. Based on static data inputs, the simulation output produces reports that illustrate how lean improvements impact worker health measures and overall system efficiency.

There are some occasions where both lean and ergonomics complement each other. For example, through the ergonomics analysis of the processes, it was identified that there is a bottleneck in the manual sorting on the floor. This led to the analysis of the postures, resulting in improving the postures. Although the goal of this ergonomics analysis was not to improve efficacy but to improve efficiency, it resulted in an improvement in the well-being of the workers as well. This illustrates an example of an instance where lean-focused improvements could result in ergonomic benefits ultimately resulting in increased productivity along with worker health.

Integration of lean and ergonomics resulted in highlighting the areas of improvement for the sorting facility. They are, ensuring the continuous supply of materials, avoiding processing small cardboard and developing platforms for manual sorting.

The integration of lean and ergonomics lead the team to propose several improvement scenarios. Different types of platforms were suggested for the development of platforms, each with unique advantages. These platforms could be configured in different orientations to obtain the maximum results. Four configurations were considered to be implemented as shown in Fig. 3. They are:

- simple chain on the ground (solution 1)
- double chain on the ground (solution 2)
- single chain on the platform (solution 3)
- double chain on the platform (solution 4)

Fig. 3. Different orientations of the four proposed solutions.

These configurations could be simulated on a digital model to identify their efficiencies as shown in Fig. 4.

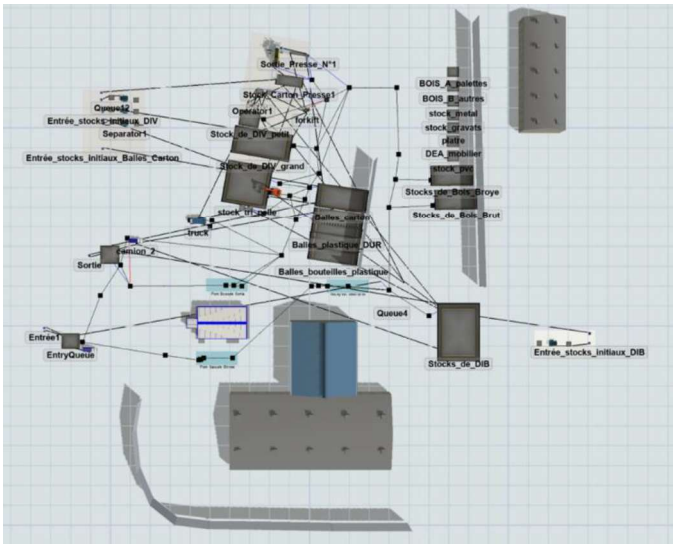


Fig. 4. The simulation model of the ABC waste sorting facility using FlexSim

Table 1. Comparison of throughput by operators resulted from simulations

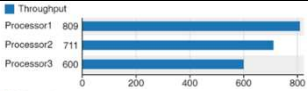
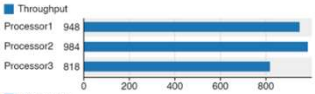
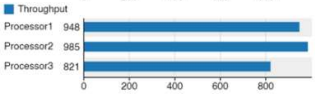
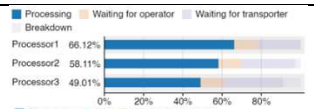
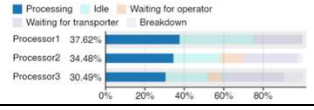
	Throughput by operators
Existing Solution	
Solution 1 - Simple Chain on the Ground	
Solution 2 - Double Chain on the Ground	

Table 2. Comparison of the occupancy rate of operators resulted from simulations

	Occupancy rates of operators
Existing Solution	
Solution 1 - Simple Chain on the Ground	
Solution 2 - Double Chain on the Ground	

To obtain these results shown in Table 1 and Table 2, the proposed methodology integrating the Lean management principles and ergonomics was applied (see section 5). First, a study based on the lean management tools of value stream mapping and material flow analysis to define key performance indicators. A simulation model was implemented to formalize the process dynamics and identify the impact of the whole materials flow on the system performance. Second, the critical workstation including manual operations was studied from the perspective of ergonomics, using the CAPTIV System.

The outcomes of the simulation point to several significant advancements and difficulties. Operator throughput increased

significantly with both systems, with solution 1 achieving a 29.71% improvement and solution 2 demonstrating a 29.90% rise. Nevertheless, table 2 shows that the operator idle time has increased, mainly due to waiting times for forklift trucks that have to push waste to make it available to operators, so there is still room for improvement. Therefore, this comparison shows that one of the improvements that can be made to the site is the addition of another forklift. The advantage of having this type of digital model is that this suggestion of the addition of another forklift could be easily implemented in the digital model and see how much it would improve the actual system. The reduction in stock levels in incoming waste is further evidence of the improvement in stock management. However, the Overall Equipment Effectiveness of the number 1 cardboard press remains very low. The main cause identified is forklift waiting, which suggests that there is still room for improvement.

8. Conclusion and future work

This study has shown how relevant it is to combine ergonomics with lean management to improve workplace productivity while enhancing worker well-being. Results show that these strategies work well together to increase ergonomic safety and productivity. This interaction, however, has not been thoroughly explored in the present research, indicating a crucial topic for further investigation and improvement.

FlexSim was used to create a sophisticated digital model that worked well, particularly for process simulation and refinement before physical deployment. Future developments should concentrate on integrating thorough human factor analyses, transforming qualitative ergonomic data into digital modelling-ready formats for use in FlexSim modelling, and employing virtual reality technologies to evaluate ergonomic data with the workforce directly. Increasing the model's ability to apply lean concepts more broadly will create new opportunities for more thorough testing and application in a variety of industries.

Additionally, the model should be updated frequently to reflect user feedback from practical implementations to remain relevant as technology progresses. By guaranteeing the model's scalability, accuracy, and usefulness, these improvements will promote data-driven decision-making and further the industry-wide adoption of lean and ergonomic methods.

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