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MODEL FOR ELIMINATING MOTION WASTE IN A MANUFACTURING COMPANY USING KPIS

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Purpose: The aim of this article was to develop and validate a model for identifying and eliminating motion waste in a selected production process using Lean Manufacturing principles. The paper also proposes a set of key performance indicators (KPIs) to support the measurement, monitoring, and continuous improvement of operational efficiency in a manufacturing environment.

Design/methodology/approach: The research objectives were achieved by analysing work organisation at two production workstations using a spaghetti diagram and a set of KPIs. The approach was based on the principles of Lean Manufacturing, focussing on identifying and eliminating motion waste.

Findings: A high level of motion waste was identified at both workstations. A lack of smooth workflow and excessive operator movement was observed. The proposed improvements will significantly reduce walking distances and improve work organisation.

Research limitations/implications: A limitation of the study is that it is restricted to two workstations within a single company, which may affect the generalisability of the results. Furthermore, the analysis focused primarily on motion waste, overlooking other forms of muda. Further research will aim to extend the analysis to other types of muda, other types of production processes, and workstations, and to conduct an in-depth analysis of the impact of the implemented improvements on work efficiency and ergonomics.

Practical implications: The results indicate that efficiency can be improved by reorganising the workstations. The use of KPIs plays a significant role, as they enable the ongoing measurement, monitoring, and evaluation of the effectiveness of the improvements being implemented. The proposed solutions, supported by the KPI system, can help reduce operating costs and increase production efficiency.

Social implications: Optimising traffic flow has a positive impact on ergonomics in the workplace, which can improve staff comfort and safety.

Originality/value: The value of this work lies in the integration of the spaghetti chart with KPIs in the analysis of waste in production. This study is aimed at Lean practitioners and production managers.

Keywords: Lean Manufacturing, workflow analysis, operational efficiency, process optimisation, production engineering.

Category of the paper: Research paper.

1. Introduction

The operation of modern manufacturing enterprises requires ensuring both high-quality products and efficient execution of processes under dynamically changing market conditions. At the same time, there is a growing need to reduce order fulfilment times (Muller et al., 2021). Consequently, the importance of proper work organisation and optimal use of available resources throughout the entire production process is increasing (Pietrewicz, 2019; Ostasz et al., 2020). This requires systematic improvement of operational procedures and a continuous search for opportunities to improve process efficiency. It requires monitoring and systematic improvement in operations execution, as well as the identification of opportunities to increase process efficiency (Ingaldi, Ulewicz, 2019; Czerwińska, Pacana, 2019).

One of the key factors reducing the operational efficiency of production processes is waste (Yamazaki et al., 2016). It is perceived as the unjustified use of resources or the performance of activities that do not contribute to the creation of added value. Despite its prevalence, waste is not always fully detected (Furugaki et al., 2007). This situation comes from the fact that it is sometimes treated as a natural part of a company's operations. As a result, some inefficiencies remain unidentified and are not subject to improvement measures. This limits the possibilities for systematic improvement of process efficiency and hinders their rational management (Szkudlarek, Zarzycka, 2011).

In the face of growing demands for operational efficiency, it is becoming increasingly important to identify activities that do not add value to production processes (Pacana, Czerwińska, 2019; Memari et al., 2024). The issue of waste in the industrial sector is the subject of management concepts focused on process improvement. Among these, the Lean Manufacturing approach stands out, which involves creating value from the customer's perspective while simultaneously eliminating activities that do not create this value (Melo et al., 2020; Zhang et al., 2018). In this context, the concept of 'muda' has been introduced, which refers to losses occurring within production processes (for example, inventory, overproduction, unnecessary processing, transport, waiting, defects, and inefficient movement) (Ulewicz, Kucęba, 2016; Ingaldi et al., 2018). Despite the widespread implementation of the Lean concept in manufacturing practice, its operationalisation is often difficult. This mainly concerns the identification and measurement of waste arising from operators' movements (Wolniak, 2013; Melo et al., 2020).

Motion waste refers to unnecessary movements by workers and inefficient manual tasks carried out within the workstation (Gajdzik, 2017). These activities do not add value to the product. Although individual movements may be considered insignificant, their accumulation results in measurable time losses. Unnecessary movements also lead to increased worker fatigue and reduced productivity (Mika, 2025). Motion waste is often the result of a failure to optimise the layout of workstations. Inadequate organisation of the workspace also plays a significant role, as does the lack of standardisation of the operations carried out. In industrial practice, this means that a significant proportion of an employee's activities do not lead to value creation, but are a consequence of organisational imperfections in the process (Piekowski, 2021).

Effective identification of motion waste requires an analysis of the actual flow of the process. It is important to identify and analyse in detail the tasks performed by operators. This approach enables an understanding of the true scale of the problem. It also helps identify the areas with the greatest potential for improvement (Doliska-Dawson et al., 2015). In this regard, tools for visualising workflow play an important role, including spaghetti diagrams and process flow maps (Michlowicz, Witoniowski, 2011). These tools are used to map the actual routes of movement of workers and materials within the production environment (Bajic et al., 2024). Their use aids in identifying unnecessary movements, backtracking, excessively long transport routes, and intersecting paths. The use of this group of tools supports the analysis of workstation organisation and the assessment of their ergonomics, which is crucial in the context of reducing the number of inefficient movements (Pilch, Baron-Puda, 2024).

The analyses of motion waste are complemented by quantitative performance assessment methods, particularly key performance indicators (KPIs), which translate observed phenomena into measurable parameters (Czerwińska et al., 2025; Borsos et al., 2016). Their use facilitates an objective assessment of the scale of waste and enables a comparison of alternative ways of organising work both within the production line (for example, the layout of workstations, the organisation of production cells, the flow of materials), as well as at individual workstations (for example, the sequence of operations, the arrangement of tools and materials within the work area) (Sujová et al., 2023). Integration of qualitative and quantitative approaches within motion waste enables not only a more accurate diagnosis of the problem but also an assessment of the effectiveness of the improvement measures implemented (Pacana, Czerwińska, 2025; Pacana et al., 2022).

The literature indicates that research is being conducted into the reduction of the 3Ms (Muda, Mura, Muri) through improved layouts and ergonomic interventions in the Lean implementation process (Melo et al., 2020), as well as the integration of ergonomics into the Lean concepts of Muda, Muri, and Mura (Umar et al., 2024). Research is also being conducted that focusses on the identification and analysis of waste (muda) in the context of Lean Management and Industry 4.0, with a particular emphasis on its new form, 'digital waste'. Inefficient data use has been shown to constitute a significant source of loss, negatively impacting the efficiency of production processes and the quality of decision-making (Alieva, Haartman, 2020). Companies are implementing methods to eliminate motion muda, e.g., the Glenday sieve method to identify areas requiring value stream mapping and those of excessive complexity that do not create added value (Ulewicz et al., 2016). However, despite the interest in the issue of waste in the literature, there is a noticeable lack of structured approaches aimed at the comprehensive identification and elimination of motion waste.

There is a clear lack of integration between flow visualisation tools, such as spaghetti diagrams, and key performance indicator systems. This limits the ability to quantitatively assess the effects of improvement measures and makes it difficult to compare them.

Consequently, it is appropriate to focus research on developing an approach that enables the identification, analysis, and reduction of motion waste in production processes. In this regard, the aim of this article was to develop and validate a model for identifying and eliminating motion waste in a selected production process using Lean Manufacturing principles. The paper also proposes a set of key performance indicators (KPIs) to support the measurement, control, and continuous improvement of operational efficiency in a manufacturing environment.

2. Method

Modern industrial enterprises focus on eliminating waste that negatively impacts process efficiency. One of the key areas of waste in Lean Manufacturing is the inefficient movement of operators and materials.

The procedure adopted within the developed model comprises a structured set of actions that enable the identification of waste sources and their quantitative assessment using KPIs. The adopted approach is characterised by a systematic nature aimed at supporting improvement activities within the production environment. The following stages of the procedure have been identified:

1. Specifying the objective and scope of the study
   The definition of the study objective should be based on a precise definition of the research problem within the analysed process, as well as on identifying the intended outcome of the analysis. Next, the scope of the study must be defined, that is, a selection must be made of the process, the production line or the workstations, taking into account criteria relevant to the objective of the study, such as the nature and complexity of the process, the level of losses, or the potential for improvement.
2. Characteristics of the process and production stations
   The process description should include a description of its structure, including the definition of inputs, the sequence of technological operations, and the process outputs. At this stage, the workstations to be included in the analysis are also identified, and their role within the production flow is determined. The aim of this stage is to gain a full understanding of the system under analysis prior to performing the loss analysis.

3. Development of a Spaghetti Diagram
   On the basis of observations of the actual process flow, a spaghetti diagram is created, illustrating the actual routes taken by operators and materials. The diagram helps identify inefficient movement patterns (ie, backtracking, loops, and intersecting flow paths).
4. Identification and classification of movements
   The movements identified within the Spaghetti diagram are classified according to their impact on value creation. Three categories are distinguished: value-adding (VA) movements, necessary but non-value-adding (NNVA) movements, and non-value-adding (NVA) movements. This stage is carried out to identify activities that constitute waste in the process or the workstation under investigation.
5. Quantification of movement (KPI)
   Identified movements within a process or workstation are converted into measurable performance indicators. Quantification allows for an objective assessment of the scale of waste and enables a comparison of different work organisation options, workstation layouts, and process flows before and after the implementation of improvement measures.
6. Identification of sources of MUDA in movement
   This stage involves analysing the root causes of movement waste. On the basis of the results of the analysis, the root causes of the phenomenon under investigation are identified. These may result from a lack of standardisation of operations, suboptimal workstation layout, inadequate organisation of the workspace, or ergonomic mismatches.
7. Development of improvement measures
   At this stage, measures are formulated aimed at reducing or eliminating the identified losses, i.e. movements that do not add value to the process.
8. Defining the future state
   This stage involves designing the operation of the target process, taking into account the proposed improvement measures. Improvements focus on simplifying the workflow, reducing distances, and eliminating unnecessary movements of operators and materials.

This structured methodology organises the activities involved in analysing and reducing waste of movement within the production area. It enables a systematic progression from defining how the process is carried out, through identifying inefficiencies and quantifying them, to developing and implementing improvement measures.

3. Results

The study was carried out at a company specialising in the manufacture of external wooden doors, internal panel doors and hybrid twin doors. The company is located in south-eastern Poland. The study was carried out in the third quarter of 2025.

The main focus of the research was the analysis and evaluation of the stile door production process to identify areas requiring a reduction in motion waste. The scope of the research was limited to a single production line, characterised by the most complex manufacturing process within the company. The production process for frame doors consisted of 32 operations, which, due to the technological process, were divided into primary, auxiliary and support manufacturing processes. The breakdown of the processes is as follows:

- core manufacturing processes (directly forming the product): cutting MDF boards, producing door frame components, mouldings, trim strips, quarter-round mouldings, edge banding, milling holes for fittings and seals, fitting hardware, milling base stiles, double-sided edge banding, milling of crossbars, drilling of holes, tenoning, insertion of dowels, machining of vertical stiles, trimming, milling of the top rebate, application of Touchwood film, drilling of holes for dowels, hinges and locks, assembly, pressing, fitting of fittings;
- auxiliary processes (supporting production but not directly adding value): purchasing raw materials and semifinished products, collecting raw materials and semi-finished products from the warehouse, transport to the production department, selection of components (crossbars, vertical stiles, glass), arrangement on transport racks;
- support processes (inspection, logistics, dispatch preparation): in-process inspection, final inspection, quality control, packing, labelling, transport to the finished goods warehouse, storage.

During the study, activities were carried out to gather the data required to perform a comprehensive analysis of motion waste.

A spaghetti diagram was drawn based on observations of employees performing tasks at individual workstations on the door stile production line. The distances covered by the workers were marked and numbered. Due to the large number of workstations and industrial confidentiality, Figure 1 shows only a section of the stile door production line diagram, illustrating the spaghetti diagram for the operations carried out at workstations 5 and 6.

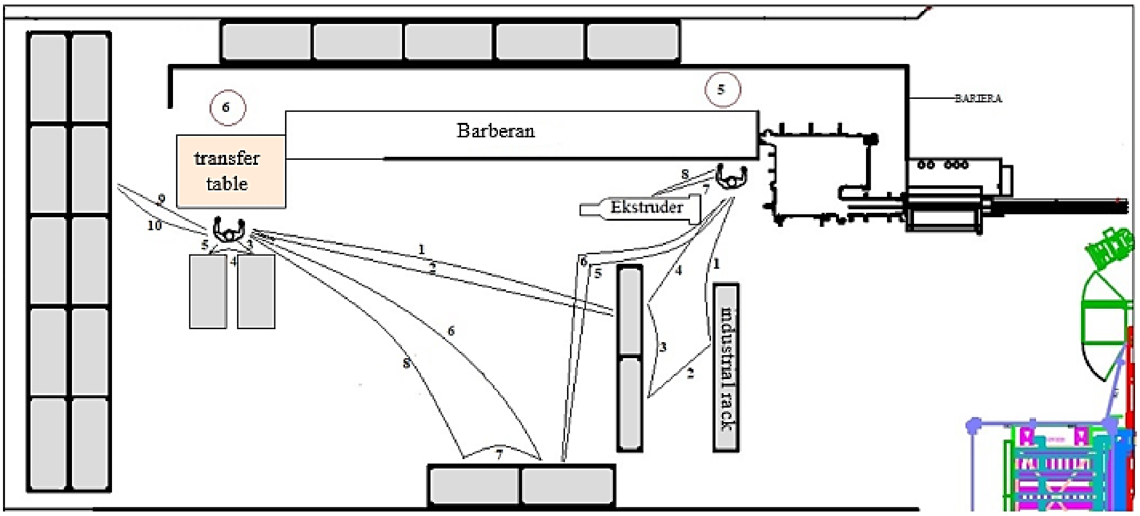

Figure 1. Spaghetti chart for the planing and edging station.

Source: own work.

Based on an analysis of the spaghetti diagram (Figure 1), a motion tracking table (Table 1) was compiled, taking into account the actual movement patterns of the operators and materials at workstations 5 and 6. The data collected form the basis for further analysis of motion waste and for determining process efficiency indicators.

Tabela 2.
Traffic monitoring – stations 5 and 6

Track number	Number of repetitions	Distance [m]	Time [s]	Added value	Movement category
Station 5					
1	1	5	6	No	NNVA
2		2.5	4	No	NNVA
3		2.5	4	No	NVA
4		4.6	6	No	NVA
5		9.0	10	No	NNVA
6		9.0	10	No	NVA
7		1.9	3	Yes	VA
8		1.9	3	Yes	VA
Station 6					
1	1	7.0	9	No	NNVA
2		7.0	9	No	NNVA
3		0.5	1	No	NVA
4		0.5	1	No	NVA
5		0.5	1	No	NVA
6		7.0	9	No	NNVA
7		1.5	3	No	NNVA
8		1.5	3	No	NNVA
9		3.25	5	No	NVA
10		3.25	5	No	NVA

The spaghetti diagram (Figure 1) and the motion log data for workstations 5 and 6 indicate a significant amount of motion waste, resulting mainly from the suboptimal layout of workstations and the repeated movement of operators and materials. Within workstation 5, there is considerable variation in path lengths, indicating a lack of standardisation in the sequence of operations and a chaotic nature of the flow. In contrast, workstation 6 is characterised by repetitive and relatively long routes, which indicates systemic losses associated with transport. Within both workstations, there is a lack of smooth, linear material flow, which contributes to an increase in the proportion of activities that do not add value throughout the production cycle.

To monitor the efficiency of operations on the workstations, an appropriate set of KPIs relating to motion waste has been proposed. The KPIs and their characteristics are presented in Table 2.

Tabela 3.
Analysis of KPIs related to traffic wastage for workstations 5 and 6

KPI	Definition / method of measurement	Interpretation	Purpose	KPI achieved for the position:	
				5	6
Total length of the operator path [m]	Total distance covered by the operator during the cycle	A high value indicates an inefficient workstation layout and excessive movement	Minimisation	36.4	37.5
Number of movements per cycle [pcs/cycle]	Number of movements between workstations (e.g. rack–extruder–table)	A high number indicates a scattered workflow and a lack of continuity	Reducing the number of transitions	8	10
Proportion of movement time [%]	Time spent on movement and auxiliary actions / total time taken	A high proportion indicates a predominance of non-value-adding activities	< 20-30%	~38	~40
Unnecessary movement index [%]	Proportion of unnecessary movements (e.g., backtracking, reaching again)	It points to a lack of standardisation and poor tool placement	Elimination	~38	~25
Number of material contact points [pcs]	Number of times an item is picked up and put down during the task	The more contacts there are, the more time wasted and the risk of damage	Minimisation	5-6	4-5
Ergonomic index (forced movements) [forced movements/cycle]	Number of bends, turns, and reaches outside the comfort zone	High values indicate operator overload and a risk of errors	Limiting forced movements	~ 9	~ 8
Linear flow index [%]	Proportion of movements in a single direction (without turning back)	A low level indicates chaotic workflow and the need to reorganise the workstation	Maximisation (unidirectional flow)	~ 50	~ 55

Based on the KPI values obtained (Table 3), it can be seen that both workstations exhibit a high level of motion waste, as evidenced by the considerable length of the operator's walking routes and the high proportion of time spent moving. A significant proportion of the work carried out in the workstations under analysis does not add value; rather, it is the result of inefficient workstation organisation.

At workstation 5, the motion muda is chaotic and non-standard (high variability of routes and a high proportion of unnecessary movements). In contrast, at workstation 6, muda resulting from repetitive, long movement routes predominates, indicating a problem with the layout of workstations. At both workstations, there is a lack of smooth linear flow, as well as an excessive number of movements and staging areas, which exacerbates losses. The KPI values clearly indicate that motion muda is a key problem and requires the implementation of optimisation measures to shorten routes and streamline material flow.

To address the issue of wasted movement at workstation 5, the following measures were proposed:

- standardisation of the operator's workflow (defining the optimal sequence of tasks),
- implementation of the 5S principles (organisation and assigning designated locations for materials and tools),
- equipping the workstation with a multi-tiered rack for storing parts (strips, clamps),
- relocating the tool rack (ensuring that the rack is positioned as close as possible to and in a convenient location relative to the workstation),
- reducing the number of storage points (reducing the number of operator movements).

However, to eliminate wasted movement at the busiest workstation – workstation 6 – the following was proposed:

- bringing cooperating workstations closer together, including the shelving unit with spare parts (elimination of unnecessary transport distances),
- reducing intermediate transport (direct handover of components between operations).

Proposals for improvements to the workstations analysed (5 and 6) are presented in the form of visualisations of the solutions (Figure 2).

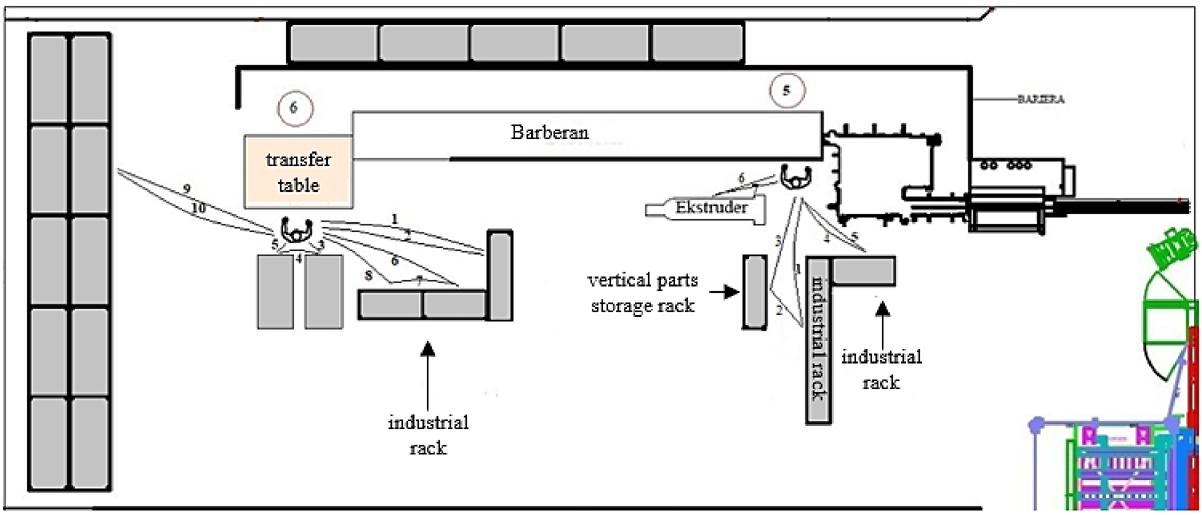

Figure 2. Spaghetti chart for the planing and edging station: suggestions for improvement.

Source: own work.

Following the relocation and refit of workstation 5 in accordance with the proposed layout (Figure 2), the length of the movement path will be reduced from 36.4 m to approximately 18 m. It is not possible to relocate the tool rack because the extruder is permanently fixed to the floor. In the case of workstation 6, following the implementation of the proposed improvements, involving the transfer of parts stock to the designated location, motion waste will be reduced to approximately 13 m. At the same time, the elimination of paths 9 and 10 (3.25 m), leading to storage racks, is not possible due to their permanent attachment to the floor.

The proposed improvement measures focus on two main issues: streamlining the workflow (station 5) and reducing transport distances (station 6). Their implementation leads to a significant reduction in motion waste and, additionally, to improved work ergonomics and increased efficiency of the production process.

4. Summary

Given the growing pressure to improve the efficiency of production processes, identifying and eliminating motion waste has become crucial. The aim of this article was to develop and validate a model for identifying and eliminating motion waste in a selected production process using Lean Manufacturing principles. The paper also proposes a set of key performance indicators (KPIs) to support the measurement, control, and continuous improvement of operational efficiency in a manufacturing environment.

As part of the research carried out, an analysis of work organisation was carried out at selected workstations using a spaghetti diagram, which helped identify the actual movement patterns of operators and materials within the workstation and to pinpoint areas generating motion waste. The analyses were supplemented by the use of appropriately selected KPIs. This approach enabled a quantitative assessment of the scale of the identified problem, movement inefficiency. Based on the results obtained, improvement measures were proposed for the analysed workstations. The proposed solutions focused on reducing distances, reducing unnecessary movements, and streamlining material flow. Their implementation confirms the practical usefulness of the Lean concept in the analysed process.

The model for eliminating motion waste presented in this study may be useful for Lean Manufacturing specialists, process engineers, and production managers responsible for organising efficient workstations and operational improvement. The research findings form the basis for further research aimed at extending the analysis to other types of muda, other types of production processes and workstations, and an in-depth analysis of the impact of the implemented improvements on work efficiency and ergonomics.

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