TRANSPORT EFFICIENCY STRATEGIES IN ASSEMBLY WORKPLACE: A CASE STUDY

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Resume
In this article, improvements in assembly workplace layouts in an industrial context are investigated to enhance productivity and efficiency. The installation of the Cleaner M300 device is focused on, existing layout challenges are identified, and targeted improvements are proposed. Data collection, analysis, and real-world experimentation are employed to evaluate current workplace conditions and potential enhancements, including material flow dynamics and transport cart utilization. Proposed solutions are aimed at streamlining assembly processes, minimizing material transportation time, and boosting operational efficiency. The effectiveness of these improvements is validated through qualitative feedback from workers and supervisors. The importance of improving workplace design to enhance manufacturing operations, increase productivity, and improve transport efficiency is underscored by the study.

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1 Introduction

Efficient workplace design is crucial for maximizing productivity and improving operational performance in various industries, particularly in manufacturing environments [1-3]. The layout of assembly workplaces significantly influences workflow efficiency, material handling, and overall productivity [4-6]. This scientific article is focused on the comprehensive evaluation and proposed enhancements of assembly workplace layouts within an industrial context.

A thorough analysis of the current state of a selected workplace is entailed by the study, with a specific focus on the installation of the Cleaner M300 device.

Through meticulous examination, existing layout challenges and inefficiencies are identified, providing the groundwork for targeted improvement measures.

The proposed solutions aim to streamline assembly processes, minimize material transportation time, and enhance the overall ergonomic design of the workplace. Key aspects of the proposed measures include a detailed overview of the current workplace layout and strategies for reducing the number of transport carts required for efficient operations [7-10].

Specific subtopics outlined in subsequent sections, such as the current and proposed layout of the assembly workplace, and the reduction in the number of transport carts with material, are explored in this study to offer valuable insights and actionable recommendations for improving assembly workplace layouts and enhancing operational efficiency.

A combination of data analysis, software utilization, and real-world experimentation is employed in this research to provide practical solutions for enhancing workplace productivity and performance. [11-13].

2 Material and methods

This section presents an outline of the methodology employed in workplace design aimed at enhancing transportation, workplace layout, material flows, and productivity augmentation. The study employed a blend of data collection, analysis, software utilization, and real-world data obtained from an industrial entity.

The current state of the workplace and subsequent proposals for their enhancement were determined through material flow analysis using the assessments delineated in the third section and the fourth case study.

The company for the investigation was selected due to its alignment with the research goals and feasibility of collaboration. Data acquisition encompassed the compilation of data concerning the current workplace arrangement and manufacturing procedures via onsite observations, interviews, and document scrutiny.

The AutoCAD and Delmia software packages were employed for evaluating the existing conditions and suggesting remedies. Those aided in generating visual representations of the workplace and production system, as well as assessing various solution alternatives. Data visualization was utilized for result interpretation and trend identification.

The investigation yielded a notable decrease in transportation duration, underscoring the efficacy of the recommended layout enhancements. Substantive input from employees and supervisors offered insightful perspectives on the usability and feasibility of the novel layout proposals.

In essence, the significance of refining workplace design to improve material flows and elevate operational efficiency, particularly concerning transportation, is underscored by the study.

3 Case study

The primary aim of this investigation was to suggest enhancements to the configuration of the working environment. The arrangement of the workplace has been addressed within the chosen organization, which specializes in the manufacturing of components.

The sub-objectives of the case study include:

- Research the company from the manufacturing sector and examine the range of activities and services provided by the company.
- Analyze the current state of the selected company, in which the case study is being implemented, in the field of production system deployment.
- Examine the layout of the equipment assembly workplace.
- Analyze transportation and transport of material within the production system.

A production process encompasses a series of orchestrated activities involving human resources, production facilities, and physical operations, necessitating one or more forms of inputs to yield an output of value to the consumer. Such activities involve the conversion of raw materials into a finished product or the fulfillment of a customer service request [14-16].

To optimize the operational efficiency of the production system, particular facets of the production process were scrutinized in this investigation, with a specific focus on the flow of production and layout within the company. The objective was to enhance the transformation of inputs into valuable outputs for the clientele. Considering that customers typically have restricted insight into the realization of these outputs, their paramount interest lies in the end product or service [17-20].

3.1 Revealing the analyzed firm: comprehensive company overview

The establishment located in Slovakia, established in December 1995, sustains an employee count of approximately 270 individuals. Its primary objective entails the fabrication and processing of comprehensive systems for the global semiconductor and electrotechnical sectors. Its product portfolio encompasses solar energy resources and the assembly of machinery for solar cell manufacturing. The engineering division has spearheaded numerous projects upon the request of client enterprises, inclusive of developmental initiatives and structural designs tailored for the electrical industry. The organization has delineated objectives for each division annually, with the overarching aim of attaining a preeminent stance within the energy-solar industry domain by delivering high-caliber output at a competitive pricing tier. Presently, the focus of the company lies in the production and assembly of diverse equipment varieties tailored for both the electrotechnical sector and the burgeoning energy solar market.

In Figure 1, one can see selected production equipment that is manufactured by the company. The M 600 Cleaner device is used to clean or maintain certain components or parts in the production process. The Cleanroom 10’000 device is designed to protect sensitive processes and products from contamination from the environment. A wafer sorter is a device used in semiconductor manufacturing to sort and arrange silicon wafers, also called “wafers”, according to specified criteria.

3.2 Description of the investigated selected device

The configuration of the assembly environment dedicated to fabricating the Cleaner M 300 apparatus is endeavored to be enhanced by the research. This device can be seen in Figure 2. This semi-automated device is integral to the “wet” process, specifically designed for cleansing wafer transport enclosures utilized in board carrier manipulation. Board carriers serve as conduits for silicon boards (wafers), fundamental components in semiconductor manufacturing employed across diverse electronic sectors, including computer

Figure 1 *Crafted precision: Company's cutting-edge production equipment*

Figure 2 *Visual Representation of Engineered Machinery Cleaner M 300*

technology, consumer electronics, telecommunications, and automotive industries, among others.

The transportation of this material necessitates a highly pristine and dust-free environment. The company's apparatus undergoes a rigorous cleaning process utilizing pressurized deionized water, coupled with rotational motion and subsequent drying, ensuring the thorough cleansing of transport containers, rendering them impeccably prepared for the conveyance of compatible materials. These devices are fabricated to exacting standards of quality, representing some of the most widely utilized and distinctive machinery within this domain.

The intricately structured device comprises numerous components, necessitating its categorization into five primary segments, specifically:

- Structural Component,
- Electrical and Propulsion Components,
- Process Component,
- Pneumatic and Water Components,
- Complete Encasement.

3.3 Description of the selected workplace: comprehensive overview

Presently, the majority of products encompass intricate mechatronic apparatuses, such as the Cleaner M300 device. Consequently, the assembly process encompasses not only mechanical component integration, but the interconnection of electrical, hydraulic, or pneumatic circuits, as well. The equipment is incorporated into piece (small-batch) production, characterized by a diverse range of products, each manufactured in quantities ranging from 1 to 50 pieces (e.g., Cleaner M204, Wafer sorter M20, Reticle stocker M1990). The assembly process adheres to stationary assembly principles, characterized by:

- Assembly conducted at a single location by one or more workers,
- Adherence to established assembly protocols with predefined time constraints (time standards), dictating the sequence of assembly operations.

The primary advantage of this assembly approach lies in its adaptability to changes in the production schedule. The mounting system for the Cleaner M300 is classified as a nest mounting system, distinguished by its solitary or partially isolated placement from other nests. Installation of this equipment typically involves 2 or 3 highly skilled workers, responsible for overseeing all aspects of the work. Worker roles are specialized in two professions: electrical assembly and mechanical assembly.

The cumulative assembly duration amounted to 588 hours, delineated across various stages. Foundry and welding operations accounted for 207 hours, while electrical assembly required 168 hours. Mechanical and pneumatic assembly tasks consumed 201 hours, with an additional 27 hours dedicated to IBN (In-Bonded Inspection) inspection and testing procedures.

Figure 3 illustrates the layout of the assembly facility within the company premises using the AutoCAD software.

Figure 3 provides an overview of the complete configuration of the production system, with a focused depiction delineated within the green circumscription, offering detailed elucidation of the assembly workspace dedicated to the Cleaner M 300 apparatus, inclusive of comprehensive annotations regarding its constituent devices. The assembly workplace, as can be seen explained in the lower part of the picture, contains the device Cleaner M300, assembly table, side table, cart with material, small cart with material, trash and chair.

4 Proposal for assembly workplace layout improvement

In the process of design, it is imperative to consider all facets comprehensively to mitigate the time losses, diminish the risk of material degradation during the transportation, and curtail material costs. Consequently, two prospective configurations for the workplace layout have been proposed.

In response to the requirements, the following principles, governing material flow and workplace arrangement in assembly have been delineated:

- Proximity of the warehouse to the assembly, workplace is essential,
- Assembly workstations should be configured to minimize material transit distances and prevent crossflow,
- For mobile assembly setups, ensuring the timely supply of input materials to workstations and facilitating inter-operational transport is paramount,
- Concluding operations such as inspection, testing, surface treatment, packaging, and shipping should follow the final assembly operation,
- The improved layout of mounting points is contingent upon factors including the type, complexity, and dimensions of assembled products and the seriality and repeatability of the production processes,
- Spatial arrangement considerations may commence concerning a catalog of standard assembly locations, which addresses mounting site allocation, access to assembly units, equipment handling, and worker positioning.

Additionally, an ergonomic approach is integral to the design of manual assembly workstations:

- Tools should be organized based on the sequence of assembly tasks,
- Tools and aids should be stored according to their frequency of use and weight,
- Storage of tools should be so oriented to accommodate right or left-handed workers,
- Dedicated fixed locations should be designated for the storage of tools and aids,
- Tools and aids should consistently be stored within the worker's reach zone.

4.1 Proposal of measures leading to an improved layout of the assembly workplace

This section provides a detailed decription of both the existing and proposed arrangements of the Cleaner M300 assembly workspace. Subsequently, an alternative approach, aimed at minimizing the quantity of material

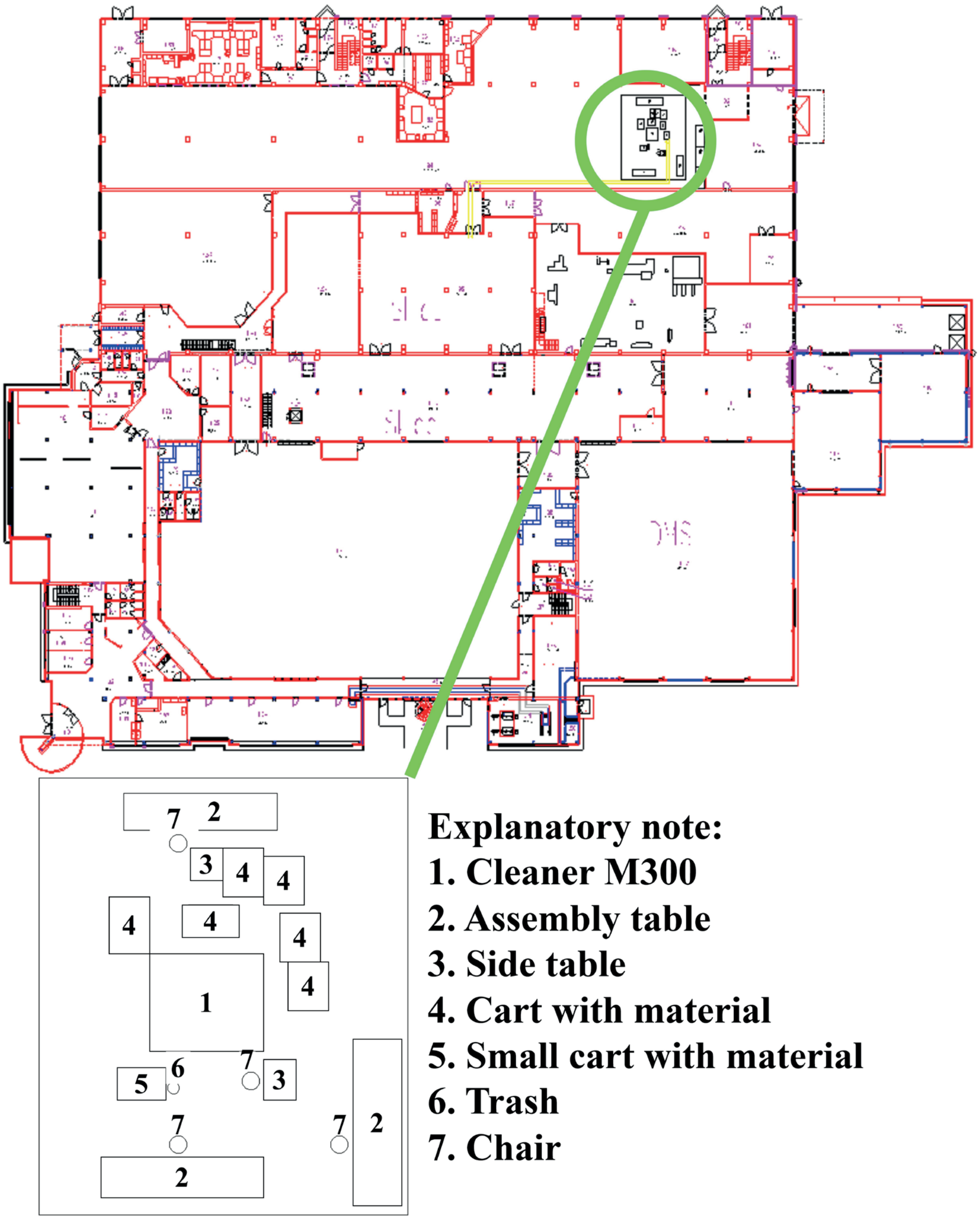

Figure 3 *Graphic representation of the workplace layout*

transport carts, is delineated, including an analysis of both the current status and the proposed design.

In the process of layout design, it is imperative to consider spatial dimensions meticulously to ensure optimal placement of the workplace. This entails providing adequate distances between assembly tables, equipment, and material carts to facilitate efficient workflow. Material transport carts are utilized for the conveyance of materials and constitute integral components in material flow management.

4.1.1 Current layout of the workplace for the installation of the Cleaner M300 device

The layout of the assembly workplace is currently placed in an inappropriate way, which results in:

- Difficult access to the used material (carts are lined up tightly),
- Inappropriate arrangement of pre-assembly parts,
- The carts are located at an inappropriate distance from the equipment, which forces the employee to move away from the assembly workplace and thus leads to time losses that could have been used more efficiently for work on the given operation,
- Improper arrangement of carts with material results in limited movement of workers around the equipment,
- There is material at the workplace that is not necessary for assembly in the current state of development of the device.

Figure 4 shows the current layout of the workplace.

The design of the workplace also took into account the storage and subsequent inspection of

Figure 4 *Current layout of the assembly workplace*

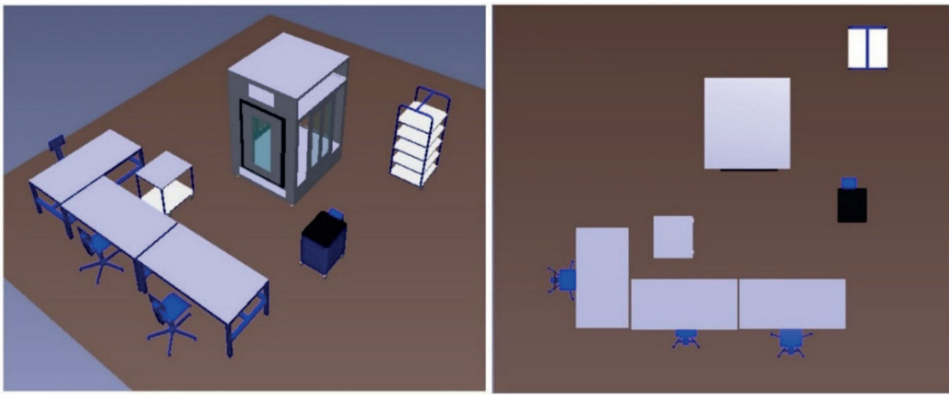

Figure 5 *The first variant of the L-shaped arrangement of assembly trolleys*

the Cleaner M300 device. These two aspects were not of much importance, since the warehouse and control have well-defined areas that are conveniently located.

Particular attention was paid to the arrangement of the assembly workplace itself. The dimensional arrangement according to the catalog of typical mounting points was taken into account. Important is the used space, which will be created in this design by rearrangement. In this way, the free capacity would be created for the assembly of a second device of the same type, which would increase production. By suitably organizing the workplace, the accident rate at the workplace would be reduced and sufficient spaces will be created for the movement of the worker around the equipment. Appropriate arrangement of the tools and used material according to the principles of ergonomic design would facilitate and speed up the assembly of the device, thereby reducing the overall assembly time.

4.1.2 Design layout of the workplace for installation of the cleaner M300 device

Upon thorough review of pertinent documentation, regarding layout alternatives and appropriate workplace dimensions, two layout variants were proposed for the company.

The first proposed variant entails an L-shaped configuration of assembly trolleys, occupying minimal space and arranged around the device at an appropriate distance. This setup features two carts - a supplementary cart and a smaller cart housing materials - both maneuvering around the device without designated fixed locations. The number of material carts has been reduced from six to either one or two, contingent upon the requirements of the assembly operator. The first variant can be seen in Figure 5.

In the second variant, assembly tables were arranged in a U-shaped configuration, with the intervening spaces filled by mobile carts (auxiliary cart, small cart with material). This positioning ensures unimpeded movement for workers around the equipment, thereby enhancing workplace safety. Through the reduction of material carts and consequent space savings, additional room was made available for the installation of another Cleaner M300 device. The second variant can be seen in Figure 6.

Upon presentation of the proposals to the company, it was assessed that the optimal arrangement for the new layout would be the first variant. This decision was reached based on the rationale that the small mobile carts, being in constant motion around the facility, do not require dedicated permanent space. Consequently, the allocation of space for them in the second variant unnecessarily occupies valuable space that could be utilized more efficiently. Therefore, the first variant

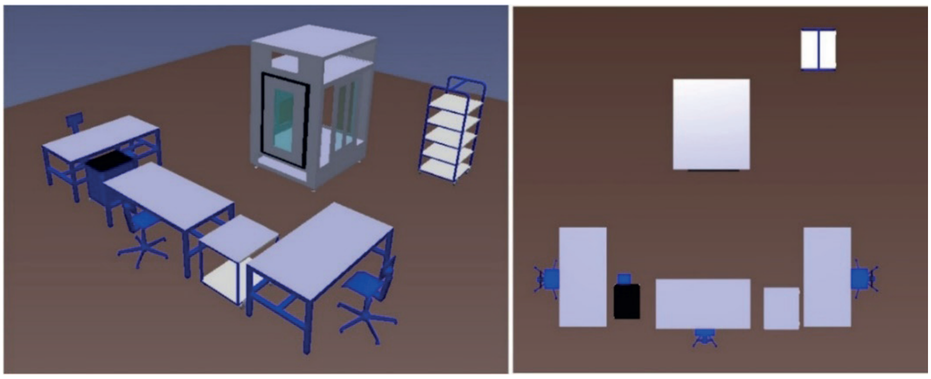

Figure 6 *The second variant of the U-shaped arrangement of assembly trolleys*

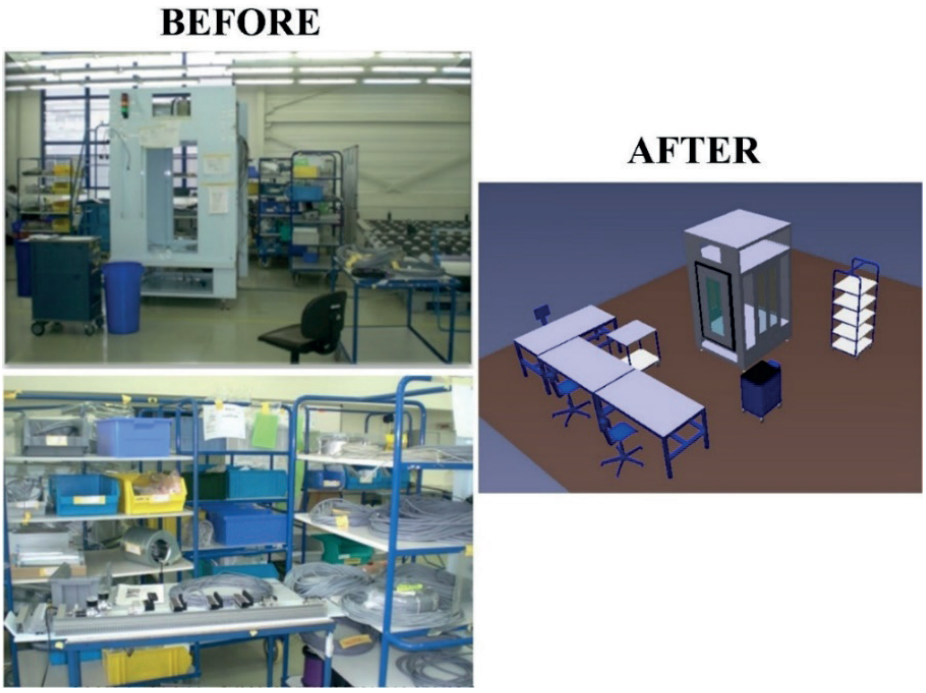

Figure 7 *View of the workplace before the new layout and after processing the design of the new layout*

stands as an enhanced solution and recommendation for the company.

4.2 Reduction in the number of transport carts with material

The basic task of material handling is the temporal and spatial connection of the production process and material consumption. It was decided to reduce the number of carts, which will reduce the area of the entire assembly workplace and thus create space for the assembly of a second device of the same type, increase the quality of the material, and shorten the time of transporting the material and the time of the overall assembly of the Cleaner M300 device. View of the workplace before the new layout and after processing the design of the new layout can be seen in Figure 7.

4.2.1 The current state of transport trucks with material

Presently, a defined sequence of individual operations is lacking, necessitating the simultaneous movement of 6 material carts from the warehouse to the workplace by the worker. Additional carts are consistently in stock, as carts for other equipment are also being retrieved. The worker is obliged to seek out suitable carts for assembly, resulting in time losses that could otherwise be allocated to the assembly process on the designated equipment.

Currently, during the initial phase of assembly, the worker transports 6 material carts to the device, consuming approximately 15 minutes. The carts, being relatively heavy, necessitate careful transportation, requiring approximately 2.5 minutes per cart to traverse the 100-meter distance from the warehouse to the

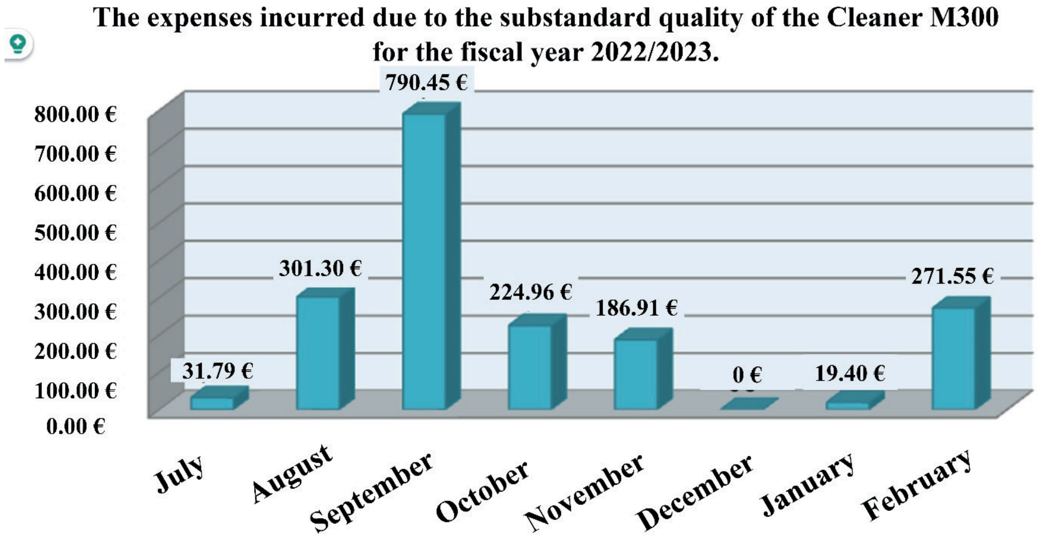

Figure 8 *Figure of costs for the poor quality of the Cleaner M300 device*

workplace. Following the completion of equipment assembly, the carts must be returned to the warehouse, a process taking approximately 9 minutes. Notably, this duration is shorter since the carts being empty, allowing for the transportation of two carts simultaneously. The cumulative time for transporting material carts to and from the warehouse totals 24 minutes. Most of the worker's time is spent selecting a suitable cart from the warehouse, a duration included in the cart transportation time. Six carts are present at the workplace, constraining the movement of the worker or workers currently engaged in assembling the respective component. Furthermore, these carts occupy valuable workspace.

Material retrieval occurs at the initiation of Cleaner M300 assembly, requiring 0.25 hours, and after assembly, when carts are returned to the warehouse, necessitating 0.15 hours.

The materials required for assembling the polished parts of the device (carousels) must remain undamaged and flawless throughout the transportation. Damage to the materials often arises due to prolonged stationary positioning and frequent manipulation around them, or when materials intended for other operations are extracted from the cart. Given the considerable expense associated with these materials, any damage incurred leads to significant losses, subsequently elevating costs and compromising quality. Moreover, the necessity to replace the damaged materials further exacerbates time and cost burdens.

The company provided data related to the cost of poor quality. Figure 8 shows the current state of the costs of poor quality. The fluctuations shown in Figure 8 were caused by the changing volume of production in individual months. Figure 8 demonstrates a notable fluctuation in the cost of poor quality across the examined months. Specifically, in July, the cost was €31.79. This figure escalated significantly in August, reaching €301.30. The highest cost was recorded in September, amounting to €790.45. In October, the cost decreased to €224.96, followed by a further reduction to €186.91 in November. Remarkably, December exhibited optimal conditions with no cost of poor quality reported, amounting to €0. The cost in January was €19.40, which then increased to €271.55 in February.

4.2.2 The design state of transport trucks with material

By implementing an appropriate technological procedure, it is feasible to reduce the number of original 6 trolleys to 1-2 trolleys.

With the assistance of the company's personnel, we conducted an in-depth examination of the entire procedure, which was previously established but lacked a specified sequence. The procedure underwent meticulous analysis, inclusive of individual operation times, leading to the development of a new material-picking technological procedure with the requisite sequence. Subsequently, it was segmented into four main groups based on material retrieval from the warehouse. The picking procedure was ultimately partitioned into a technological framework, utilized for designing an enhanced layout in DELMIA Process Engineer. By implementing the new picking procedure, material carts would be selected based on the component of the equipment being assembled, enabling employees to select a cart labeled with the appropriate number (1 to 4) without wasting time searching for a suitable cart.

This approach ensures that the material required for assembly at any given moment consistently arrives at the workplace, thereby reducing the truck transport time and the time spent selecting suitable trucks. Whereas the original technological procedure involved

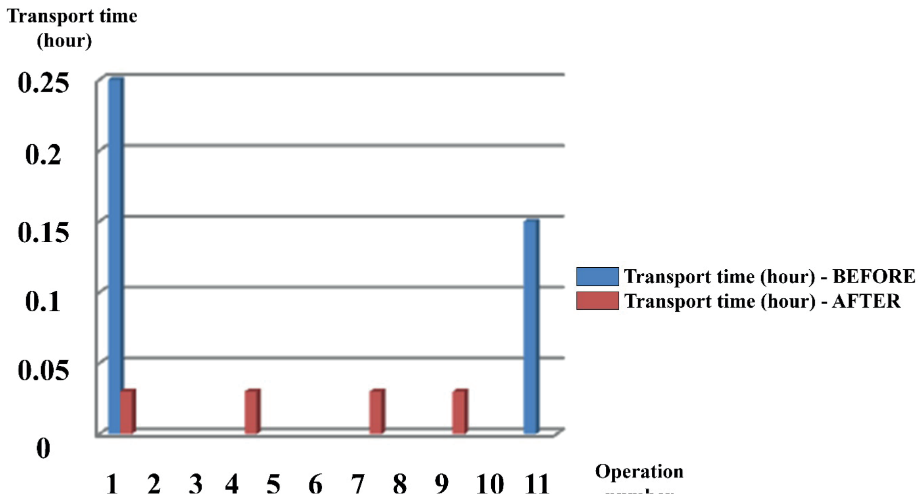

***Figure 9** Comparison of material transport before and after the modification of the technological procedure*

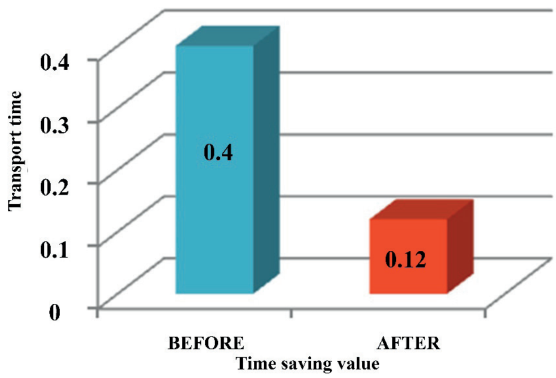

***Figure 10** Representation of time savings for material transport*

the simultaneous retrieval of all the carts by the employee, the modified approach involved carts being retrieved one at a time and prepared in the warehouse for the employee according to numerical order. Consequently, the employee retrieves a single cart without the need for a search, reducing retrieval time from 2.5 minutes to 1.8 minutes. Upon completing the installation of relevant materials on the device, the employee returns with an empty cart to the warehouse and immediately retrieves another pre-prepared cart. This process repeats until the final assembly of the device.

This method reduced material transport time by up to 70% and a 6% decrease in total assembly time, while reducing the transportation time for a single truck by 25%. The distribution of individual cart transport and the color-coded cart picking can be observed in Table 1.

In Figure 9, is shown the comparison of a material transport before and after the modification of the technological procedure, distinguished by colors. Before the creation of the new picking procedure, the material was transported at the beginning of the assembly of the device, which took 0.25 hours (15 minutes), and at the end of the assembly with a time of 0.15 hours (9 minutes), which together makes up a time of 0.40 hours (24 minutes).

After the introduction of the new procedure, the transportation of the material was divided 4 times, while the cart with the material was brought to the workplace only when the material was mounted on the equipment at that moment. The possible time saving is calculated for one cart from the original 2.5 minutes to 1.8 minutes, where 0.7 minutes were saved.

Figure 10 illustrates the reduction in material transportation time from the warehouse to the workplace, where the time was decreased from the original 0.40 hours (24 minutes) to 0.12 hours (7.2 minutes), resulting in a savings of 0.28 hours (16.8 minutes).

Thanks to the new picking procedure, it is possible to mitigate the material degradation, particularly for polished parts. The material cart will only be dispatched from the warehouse to the workplace when the specific part is being assembled on the device.

Figure 11 illustrates the costs associated with poor quality for February 2023, amounting to € 271.55, with € 200 attributed to the cost of damaged polished material. This damage occurred due to prolonged storage in one location and constant manipulation, or when the material was removed from the cart for other operations.

Therefore, cost savings can be achieved if the cart is prepared for the job site when the relevant part is

Table 1 Modified technological procedure for assembling the device with new transport times

Operation number	Description of the operation	Transport - current state (h)	Transport - design state (h)	Type of trolley for design state
1	Bringing the supporting part	0.25	0.03	Trolley
2	Preparation of electric plate			
3	Installation of electric plate			
4	Preparation of pneumatic plate		0.03	Trolley
5	Installation of a pneumatic plate			
6	Installation of moving parts of the door			
7	Assembly of the chemical part		0.03	Trolley
8	Installation of water nozzles and heating elements			
9	Pre-assembly of polished parts		0.03	Trolley
10	Installation of polished parts			
11	Carousel and door installation	0.15		
12	Casing assembly			
	Total transport time	0.40 h = 24 min	0.12 h = 7.2 min	

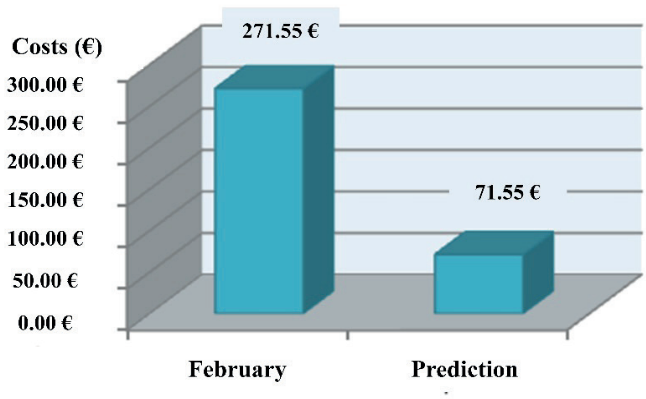

***Figure 11** Cost of poor quality for February and estimated cost savings*

promptly mounted on the equipment. The estimated cost savings amount to approximately € 200, leading to a reduction in material costs by 73.65 %.

5 Conclusion

In conclusion, the layout of the Cleaner M300 assembly workplace is endeavored to be enhanced through a meticulous analysis of its current state. Comprehensive documentation was meticulously prepared to facilitate the design of improved variants. To facilitate comprehension, the assembly workplace was succinctly depicted using the AutoCAD graphics program, subsequently integrated into the broader company layout. This integration allowed for a gradual examination of problematic areas within the workplace, which served as the focal point of this case study. Identified issues encompassed challenging material access, suboptimal arrangement of pre-assembly tables, improper cart positioning about equipment, restricted worker mobility, surplus material accumulation, and protracted material transport times.

Moreover, this study introduces partial digitization of the company, leveraging Delmia software to craft visualizations of proposed solutions. In response to identified challenges, various strategies were proposed. These include adopting improved methods for material storage to mitigate damage risks, expanding space around the assembly workplace to enhance safety, optimizing cart placement to streamline assembly processes, and rationalizing material distribution to minimize worker movement.

A key proposal involves reducing the number of material carts from six to one or two, affording several advantages. This reduction optimizes space utilization, potentially accommodating additional equipment while curbing material damage and associated costs. Additionally, it promises to expedite material transportation, thereby augmenting overall efficiency.

Anticipated benefits of these interventions encompass diminished material damage and costs, heightened workplace safety, reduced spatial requirements for assembly, shorter transport durations, heightened productivity, and enhanced operational efficiency. Through meticulous analysis and strategic proposals, the Cleaner M300 assembly workplace is endeavored to be improved, offering a pathway to enhanced performance and resource utilization within the company's operational framework.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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