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Improvement of the Mizusumashi System in an Electrical Devices Company: A Case of Transdisciplinary University-Business Cooperation

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Abstract. In the 1st year of the Master in Industrial Engineering and Management of the University of Minho (Portugal), teams of students develop semester-long UBC (University-Business Cooperation) projects involving four course units, according to the PBL (Project-Based Learning) methodology. This paper focuses on the project developed by a team of eight students in an electrical devices company, more specifically in the *mizusumashi* system (logistic train), responsible for supplying components to the assembly lines/cells, whose performance revealed some problems. The team carried out a detailed analysis/diagnosis of the current system, gathering data through surveys, interviews, and direct observations on the shopfloor. Several problems were identified, namely in the loading process of the *mizusumashi*, which takes place in the so-called dynamic warehouse (e.g., disorganization of components and picking inefficiencies), as well as in the routes travelled (e.g., imbalances and deficient/absent signaling). Cases of overloading the *mizusumashi* and problems in its physical structure were also revealed, with consequences at the ergonomic level. All this causes delays in the supply of components to the assembly lines/cells. To tackle these problems, the team developed and evaluated several improvement proposals, including modification of the routes signage (using visual management techniques), reorganization/ adjustment of the *mizusumashi* carriages, reorganization of the location of components in the dynamic warehouse, and introduction of an RFID (Radio Frequency IDentification) system to streamline the picking processes. These proposals are expected to eliminate *mizusumashi* overload and component-scanning times, decrease the number of transports and movements, reduce route delays, and reduce the risk of work-related musculoskeletal disorders (WMSD).

Keywords. Mizusumashi, visual management, ergonomics, warehouse management, RFID

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Introduction

In the 1st year of the Master in Industrial Engineering and Management of the University of Minho (Portugal), teams of students develop a semester-long UBC (University-Business Cooperation) project (Integrated Project in Industrial Engineering and Management III) involving other four course units (Ergonomics and Human Factors, Process Modelling and Analysis, Advanced Organization Production Systems, and Industrial Projects Management), according to the PBL (Project-Based Learning) methodology. This way, students are directly exposed to industry challenges and realities, and can apply theoretical knowledge to real-world problems, acquire industry-specific skills (as well as soft skills), and bridge the gap between academic life and industry. This project provides a transdisciplinary collaboration platform, allowing students to understand not only how different areas of study can be combined to solve complex real-world problems (interdisciplinarity), but also to see that the borders of curricular units end up being overcome (transdisciplinarity). In fact, by analyzing several case studies, [1] shows how PBL supports transdisciplinary engineering.

As the market demands an ever-increasing variety of products, companies are required to be highly responsive and, eventually, to customize products. However, to get “the right goods in the right quantity at the right time in the right place at the right price and in the right condition for the right customer." [2], it is unthinkable to have large inventories on the shop floor, mainly, but not only, because of the inherent costs. The adoption of Lean Thinking principles allows companies to improve their performance [3] and one of the key elements with major impact in that performance is the internal supply system. This is the context of the so-called *mizusumashi*, a cyclical transport system (logistic train), responsible for the material handling necessary to meet production needs [4], [5]. Although logistics trains offer many benefits for industry, implementing them requires precautions, and there is a need for continuous studies to improve and adapt the system to changing market demands.

This paper focuses on the project developed by a team of eight students in an electrical devices company, more specifically in two routes of the *mizusumashi* system, responsible for supplying components to the assembly lines/cells, whose performance revealed some problems. The main goal is to identify/analyze those problems and develop solutions that can improve company overall performance. Furthermore, this article aims to contribute to the body of knowledge of industrial engineering in general (more from a teaching/learning perspective), by presenting and analyzing a concrete example of University Business Cooperation (UBC), materialized through Project-Based Learning, with transdisciplinary features. In fact, a quick search on Scopus database revealed a gap due to the reduced number of publications addressing situations that involve UBC, PBL and transdisciplinary.

The paper is divided into 6 chapters. After this brief introduction, chapter 2 presents the adopted methods and chapter 3 the theoretical background. The diagnosis of the *mizusumashi* system is described in chapter 4 and the improvement proposals are developed in chapter 5. Chapter 6 is dedicated to the discussion of the results and the last chapter presents the conclusions.

1. Background

PBL is an active learning/teaching approach that may integrate academic knowledge with real-world business scenarios to solve interdisciplinary problems [6]. Lean thinking is a philosophy that prioritizes creating value while eliminating waste in organizations [3]. It focuses on continuous improvement, problem-solving, and process optimization. Lean methodology incorporates a comprehensive set of rigorous tools, without compromising the use of advanced statistics and mathematical tools, and a well-defined approach that can quickly produce significant results [3], [7]. According to [8], lean manufacturing is recognized worldwide as the main methodology for continuous improvement of production processes in organizations.

One transportation method used in lean methodology is the *mizusumashi*, which was first introduced by Toyota in 1955 and developed into a multi-stage delivery system in 1977. This method involves the "routing of a supply or delivery vehicle to make multiple pickups or drop-offs at different locations" [3]. Among the designated "seven deadly wastes" [9], two assume particular importance in this context: transport (unnecessary movement of parts in production) and movement (unnecessary movement of people). Also relevant in this project, is the visual management concept which aims to communicate information clearly and objectively to all workers, promoting transparency so that deviations can be identified early, and countermeasures taken [10]. Work standardization is an important factor for successful lean implementations [11]. It is "…a chronological process for defining the best practices and make sure that every worker can strictly follows them to bestow the value to the consumers" [12] that enhances the organization efficiency and reduces costs.

The ergonomic analysis of workplaces is of paramount importance in any context. Ergonomics is "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance" [13]. Work-related MusculoSkeletal Disorders (WMSD) are a major cause of occupational decline, with multifactorial causes including biomechanical, psychosocial, organizational, individual, and environmental factors [14]. An ergonomic analysis is critical in preventing WMSD, especially in industries with high ergonomic risks, such as the electrical industry, known for its technological innovation, global competition, and labor intensity [15], due to repetition, high load, awkward posture, and monotonous work [16].

In terms of inventory management systems, the RFID technology is increasingly being adopted by the companies [17] to wirelessly read tags, thus reducing the time spent to register products/containers [18]. There are three types of tags, but only passive transponders are recommended for this project, as they do not require an internal power source but only the electromagnetic field emitted by the antenna [19].

2. Methods

Project management methods are essential as they provide a systematic approach to achieving project objectives. These methods include a wide range of guidelines, tools, and techniques that can be utilized for project planning, execution, and monitoring. In this case, the Scrum methodology [20] was used, which focuses on teamwork, communication, and iterative progress toward defined goals. To ensure the development of hard and soft skills of all team members, each week a different member was designated as leader. The leader is responsible for providing guidance, support, and motivation to all members, and for ensuring that they clearly understand the project objectives, as well as their roles and responsibilities. To facilitate effective team communication, regular meetings were held to ensure everyone was updated on the progress of the project, discuss any issues or obstacles, and plan future tasks. Once a week, visits were made to the company as well as meetings with the project tutor and other teachers, for monitoring/guidance. All documentation was stored in the Teams software, also used by the team for videoconferencing. For frequent daily communications (e.g., clarifying simple doubts), Messenger was used. Data provided by the company was sent by email.

As for the project itself, the work involved *gemba* walks to clearly understand the production process and to show respect for the workers and their work (Business Process Modeling Notation, and Sequence Diagrams were used to process mapping). The cycle time of the workstations was measured, as well as important dimensions associated to the *mizusumashi* (e.g., dimensions/capacity of containers and carriage shelves). In addition, musculoskeletal risk assessment and identification of work problems were carried out using two diagnosis methods - the Nordic Musculoskeletal Questionnaire and the Ergonomic Workplace Analysis (EWA) – and two observational methods - Rapid Upper Limb Assessment (RULA) and Key Indicator Method (KIM). Moreover, interviews and brainstorming sessions were held with the leaders and two questionnaires were also given to the operators who work closely with the mizusumashi in order to find out the problems experienced at their workstations. The responses were then standardized, and evaluative criteria were established to conduct a comprehensive statistical descriptive analysis. This allowed the development of an Ishikawa diagram and the categorization of the level of urgency of intervention. All the information provided/collected was analyzed using Power BI and different ABC analyses were carried out to define and evaluate different levels of intervention priority and create a cost-benefit matrix.

3. System Diagnosis

Besides *gemba* walks, the data provided on the supply of *mizusumashi* carriages in the dynamic warehouse (available in the company logistics software) and on the supply of production (from the company ERP software), revealed situations of over-occupation and delays in the analysed routes indicated by the company (blue and black) (Table 1).

Table 1. Over-occupation and delays in the *mizusumashi* routes.

Routes	Over Occupation	Supply Time Above the Limit
Blue Route	7/152 routes - (4,61%)	58/152 routes - (38.16%)
Black Route	28/156 routes - (17.95%)	35/156 routes - (22.44%)

The data collected represented the total picking movements from the dynamic warehouse and production supply, characterized by number, picking batch, location, quantities supplied, date/time, route, and so on. This data was cleaned, treated, and restricted to the batches supplied on the shopfloor at the normal shift-labour (from 8 a.m. to 5 p.m.) - the critical schedule. Different ABC analyses were carried out: one general status evaluation (containing all picking movements) and one for each route, with different evaluations for both, by quantities delivered and by picked components (number of times each component was picked). With this, it was possible to define different levels of intervention priority which also allowed the evaluation of each route in terms of the necessary motion efficiency in the carriages supplying, considering the locations associated with each component in the dynamic warehouse. The next step was to analyse the *mizusumashi* carriages shelves supply method (i.e., dynamic warehouse - carriage), targeting the total area needed for the components in each of the routes (for one month; September 2022) and the time spent in the process. In parallel, over 3 months, weekly observations were made on the shopfloor, resulting in the identification of the following problems:

- Difficulty in identifying the different production lines and stations, due to the size and placement of identification plates.
- Paths of the various routes without clear signage, making it difficult to follow the correct directions.
- Wrong use of “STOP” signs which alert the operator to stop and supply.
- Poor location or absence of warning signs for the collection of empty containers from the lines.

Next the locations of all components picked in the referred month were studied. To make a consistent analysis, some parameters were set related to the maximum height at which the components should be located, and to the location in the dynamic warehouse where the high priority components should be. This analysis, along with meetings with the warehouse manager, revealed that many components were not in accordance with the defined parameters. Although a thorough investigation of the warehouse database has been carried out, it was imperative to observe and analyse the physical location (actual location of components and supply process), due to the more than likely existence of discrepancies. This allowed to conclude that:

- The reorganization of the dynamic warehouse is necessary (locations/ signalling).
- The turnover rate is not being used properly - 20 critical positions were detected.
- Ergonomic factors are likely to be at risk due to repetitive critical positions less than 25 cm from the ground.
- Obsolete components must be discarded.
- Codes never scanned must be reassessed.

In addition to all the technical analyses performed at this stage, it became crucial to understand what the workers themselves considered important to analyse in more depth. To determine the primary problems and requirements related to the supply process, two surveys were created and distributed among the workers responsible for the *mizusumashi* processes. The most referred problems were related to the identification of the components in the dynamic warehouse, difficulty in supplying the carriages (due to the empty containers coming from the shopfloor), identification of the position to be occupied in the carriage, number of human resources available, identification of “STOP” signs and stations to supply, and of components to be left at each station within that stop. There is some demotivation among workers as some of these issues are not new and, in their perception, there was no significant effort from the company to solve them.

4. Improvement Proposals

Proposals for the shopfloor signage were developed based on the visual management concept. Regarding the "STOP" signs for supply, it is suggested the use of LED warning lights (different colours for the different routes), with adjustable angles, instead of the current system. They must have a control panel so that the respective route light turns on at the right time. Concerning the signs for pickup locations, it is suggested to apply the same method, but using smaller LED warning lights.

To cope with the issues related to the *mizusumashi* itself, such as over-occupation, delays, and ergonomic risks, the following improvement proposals were suggested: (i)

- Proposal 1 - Remove part or all the internal flows[2] from the black route, transferring them to the blue route.
- Proposal 2 - Restructure the *mizusumashi*, reducing the maximum shelf height, to better fit the physical needs of the operators.

The first proposal involves designing a new carriage for the blue route, with 3 extra shelves (Figure 1), to accommodate the internal flows transferred from the black route.

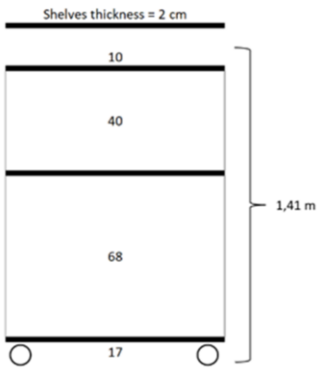

Figure 1. New carriage for the blue route (associated to proposal 1).

This proposal was designed having in mind two possible alternatives for internal flow management in the black route (Figure 2):

- Removing all the internal flows (Figure 2, upper chart), assuming that a new independent route will be created for this purpose.
- Removing part of the internal flows, such as IDP2 and IDP4 (2 and 4 pole pure differential circuit breakers) trays from the black route, considering only the area necessary for IDP4 Coils, MT (magneto-thermal circuit breaker), and MTC (magneto-thermal compact circuit breaker) trays (Figure 2, lower chart).

Evaluating the upper chart shows that while solving the over-occupation problem, an under-occupation problem is created, making the alternative unfeasible. The bottom chart alternative is better for balancing occupied and available areas, so it was chosen as a practical alternative.

[2] An internal flow is characterized as a component produced in one line and transported to another to undergo transformation, passing in a first instance through the warehouse.

The second proposal involves reducing the heights of the second carriage and of one of the shelves in the last carriage, to address the over height between shelves in the black route, having in mind the ergonomic study made.

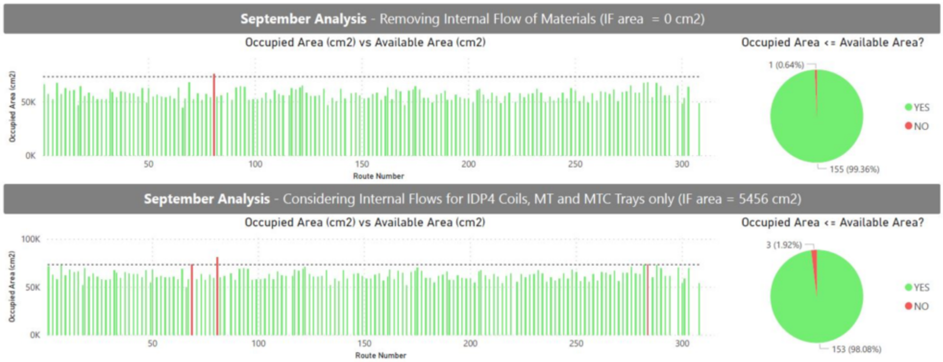

Figure 2. Alternatives for Internal Flows management.

Figure 3 illustrates the actual status and proposed repositioning of spaces through color-coded shelves with corresponding numbers indicating their height. Additionally, the creation of a new shelf resulting from the resizing can also be identified. This proposal should be tested as a pilot project to evaluate its effectiveness in preventing WMSD.

The third proposal is the implementation of RFID technology to eliminate the manual scanning of components. Tags with unique serial numbers should be added to all containers, allowing for automatic recording of inputs and outputs in a back-end software, thus improving the efficiency of the *mizusumashi*.

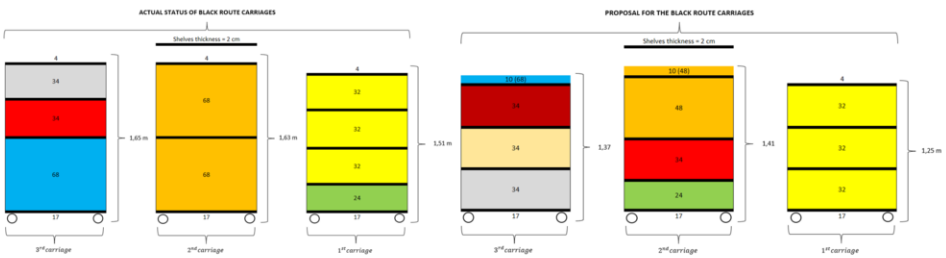

Figure 3. New carriages for the black route (associated to proposal 2).

The last proposal concerns the restructuring of the dynamic warehouse, which proved to be the most used place throughout the entire mizusumashi supply process, containing most of the components used in the analysed routes. This way, the team reorganized all the contents using the previous ABC analysis, placing the components close to the supply area according to their turnover rate, eliminating the deprecated components, and moving three high-turnover components from critical locations. The new organization of the dynamic warehouse can be seen in Figure 4.

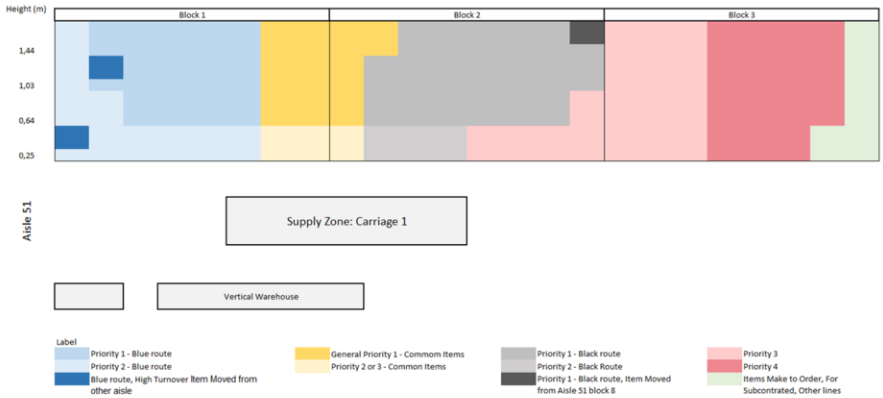

Figure 4. New organization of the dynamic warehouse.

5. Results Discussion

Regarding all the proposals on shop floor signage, the suggested measures will allow a better verification process for the workers thus avoiding non-compliance with the picking and supply processes, enhancing the *mizusumashi* efficiency, reducing workers pressure, and saving time in the shopfloor processes. Therefore, it is important to conduct a detailed analysis of the necessary time to supply the workstations and forecast the monetary gain of this implementation. To increase shopfloor efficiency, the proposed carriage improvements will not only enhance the quality of work for workers, but also address the issue of over-occupation of components in the black route and prevent WMSD caused by the current carriage dimensions. Therefore, it is important to apply these measures to promote a safe workplace, ensure the supply of all workstations and decrease the staff turnover in the dynamic warehouse. The implementation of RFID technology, will eliminate scanning times, allowing a saving of 2.3 s/container, resulting in a total time saving of 3.4 min/route. The associated costs for this operation in each route can be calculated using equation (1):

$$a = \frac{t_c}{3600} \times l \times r \tag{1}$$

Where t_c is time needed to scan a container, r the number of scanned containers, and l the labor cost per employee per hour. The cost of implementing an RFID system is considerable, so it is necessary to calculate the investment return in 3 years (company's requirement), which can be obtained using equation (2):

$$c = n \times d \times h \times k \times a \times (1 + i)^n \tag{2}$$

Where n is the number of years to retrieve the investment, d the number of days of work in a year, h the number of hours worked in a day, a the route current cost, k *the* route cost with RFID, and i the inflation rate. Considering all the above specifications, an investment cost of 38.118,16€[3] was obtained to implement this system. Thus, the

[3] This investment cost was achieved considering the average values in the Portuguese industry for each variable.

RFID scanning method cost in 3 years cannot be higher than this value, to make this affordable for the company. This proposal, together with the reorganization of the dynamic warehouse, will lead to reductions in movements, transports, workers fatigue as well as shorter supply times. Assuming that workers move at a speed of 1.5 m/s and one component is consumed in all routes, reallocating the supply area 6 meters closer can save 4 seconds per component and route. This corresponds to a total time savings of approximately 1.2 minutes per day for just one component and route. Given the large number of components supplied, the time savings can be quite significant.

6. Conclusion

Through the diagnosis phase, it was concluded that the main problems detected were related to the over-occupation of the *mizusumashi*, supply times (leading to delays), lack of visual management, and ergonomic issues. Therefore, as improvement solutions, it was suggested to implement visual management, an RFID system, redesign *mizusumashi* carriages, and to reorganize the dynamic warehouse. These solutions have the capacity to increase efficiency by reducing unnecessary movements and improving supply times (fewer delays). In addition, the relocation of components in the *mizusumashi*, moving the internal flows from the black route to the blue route (involving adding a new carriage to the blue route), allows the remaining racks to be balanced and avoids over-occupation. Lastly, the readjustment of the components on the black route allows the shelves to be lowered, thereby reducing the height of the carriages, which will make it possible to solve the ergonomic problems detected during the diagnosis phase.

This study contributed to the rationalization of the mizusumashi system using a combination of methods and tools developed in various course units. The use of RFID can save 2.3 s/container, i.e., 3.4 min/route. The reorganization of the dynamic warehouse foresees a saving of around 1.2 min/route per day for just one component, i.e., means a large impact considering the large number of components supplied.

This approach highlights the importance of transdisciplinarity in tackling complex challenges and emphasizes the value of integrating diverse perspectives to arrive at effective solutions. Interestingly, this project also revealed personal aspects of the workers, namely in terms of motivation and well-being at work. The workers' perception that something was being done to improve known problems (which had not yet been subject to a consistent improvement approach by the company) was encouraging for them. The successful and long-lasting implementation of any type of change in a production process depends a lot on the motivation and belief of the affected workers, i.e., those who will start to operate differently. In this project, the mizusumashi workers were directly involved in the development of the proposed solutions, but achieving this involvement was not an easy process and demanded from the authors a special sensitivity in the personal relationship with these workers, something that goes beyond the areas covered in industrial engineering courses. This involvement gave workers a sense of belonging in relation to the developed solutions, contributing to increasing the aforementioned motivation, belief, and well-being at work, and, consequently, to achieve the project's objectives.

In summary, this paper shows a concrete example of transdisciplinary engineering, achieved through University Business Cooperation centered on Project-Based Learning. The authors believe that the integrated association of these three approaches/concepts in a single project constitutes a valid contribution to the industrial engineering scientific and professional community.

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