Lean implementation case study for manual order picking and packing in warehousing operations

Abstract

Purpose: This study analyses the application of lean thinking in warehousing operations' picking and packing processes.

Methodology: The research design used is a conceptual framework based on the literature for lean practitioners' guidance.

Findings: The results of the empirical study reveal an increase in efficiency of 30% in picking and packing operations when analysing and decreasing the non-value-added processesin the case study.

Originality: Our study overcomes the lack of a structured framework for lean manual order picking and packing and evaluates the potential of a set of lean and process analysis tools to increase the efficiency of order picking and packing.

Limitations: The proposed framework has not been implemented in a wide range of operations. The findings are limited due to the focused feature of the case study. Additional cost-benefit analysis can be investigated.

Practical implications: This study can guide warehousing logistics practitioners toward achieving excellence in manual picking and packing operations through lean thinking implementation.

Keywords: lean; order picking; order packing; manual process; warehouse; framework

Article classification: Research paper

1.Introduction

In the last few decades, lean management has been widely applied in the business world. The lean concept targets increasing the value added, that is, what customers are paying, while reducing the non-value added (Haddud and Khare, 2020). Accordingly, lean focuses on analysing operations and reducing unnecessary activities to eliminate waste (Minovski *et al.*, 2018). The lean philosophy originated from industry, specifically the Toyota Production System. Since then, it has been brought to service applications such as logistics (Gutierrez-Gutierrez *et al.*, 2016).

In manual systems, the time taken by workers to move between locations is unpredictable (Fang and An, 2020). Therefore, one of the main problems logistics stakeholders encounter in this area is increasing the order preparation efficiency despite the diversity of order processing activities. Order picking and packaging processes are crucial for warehousing operations and directly impact the supply chains' downstream flow. Despite digital transformation and automated systems, order picking is still extensively operated manually (Fang and An, 2020). This is due to the high investments required by automated systems, their interruption risk, and the flexibility of manual order preparation processes (Vanheusden *et al.*, 2020).

Increasing the efficiency of manual order picking is worth researching since order picking is both cost- and time-consuming (Rasmi *et al.*, 2022). It has been argued that order picking generates most warehouse costs (Van Gils *et al.*, 2018). Kostrzewski (2020) reported that order-picking costs might vary from 55% to 70% of the total warehouse costs, based on previous studies. In the United States, for instance, order picking accounts for over 50% of the annual $150 billion spent in warehouse operations (Wu *et al.*, 2016). Its requirement of human involvement makes it a highly laborious activity in many warehouses (Ardjmand *et al.*, 2021).

Despite the fact that the interest in lean logistics, one of the main gaps in current literature is that studies so far have failed to consider the lean potential in manual order picking. Previous manual order picking studies have focused on balancing workload (Vanheusden et al., 2020). The authors introduced the operational workload balancing problem of order picking by presenting a mathematical model for the order picking planning problem. Rijal *et al.* (2021) focused on the order picker scheduling problem and presented two formulations: a branch-and-price algorithm and a meta-heuristic. The authors' findings reveal near-optimal solutions at 80% shorter computation times. However, to the best of our knowledge, no previous studies have focused on lean implementation for manual order picking and packing. Therefore, our motivation is stimulated by the need to support the current research on improving manual order picking efficiency. Our study seeks to advance lean thinking in logistics order processing, particularly with regard to the waste that could be associated with unnecessary activities involving human labour. Hence, the main research questions (RQs) addressed in our study are:

- (RQ1): *How can LM be effectively implemented to improve order picking and to pack warehousing processes?*

- (RQ2)*: What are the practical implications of implementing LM to improve order picking and packing warehousing processes?*

To address the RQs, this paper contributes to the literature on lean by presenting a case study and proposing a framework for lean manual order picking processes. The main practical contribution aimed at here is to illustrate the application of lean to increase order picking and packing efficiencies. Lean methods are suitable for increasing the efficiency of order picking and packing due to the waste noted in these processes (Åberg, 2019; Pipatprapa, 2019). We build on the work of Mostafa *et al*. (2013) regarding the lean manufacturing framework literature. The main advantage of the framework is its ability to provide focus on the objective to be achieved with clear structures and guidelines (Dora and Gellynck, 2015). To validate the framework, a case study has been conducted on the manual picking and packing operations in the warehouse of an international industrial aeronautics manufacturer. The case study approach is one of the most powerful approaches to investigation in real-life contexts (Ebneyamini and Sadeghi Moghadam, 2018). It enables an explicit perception of the conditions under which a particular phenomenon occurs and hence tends to be more accurate (Mariotto*et al*., 2014). A rapidly developing industry was chosen for this study, as this industry tends to be prominent in supply chain activities (Gutierrez-Gutierrez *et al*., 2016).

The main contribution of this study is the implementation of lean tools in manual order picking and packing. On a practical level, the implications of this study can be beneficial for warehouse engineers and managers. Our lean implementation approach can be adopted to reduce waste produced across human activities in such systems. Further, this study can benefit third-party logistics (TPLs), which are companies that specialised in providing logistics services. Theoretically, this study contributes to the body of knowledge of lean logistics services by explaining how various lean tools can be used in the diagnostics and analysis of warehouse manual order picking and packing systems. The remainder of this paper is structured as follows. Section 2 presents the theoretical background and literature review. Section 3 outlines the research design and methodology. Section 4 describes the research design and methodology in detail. Section 4 presents the case study. Section 5 discusses the results. Finally, Section 6 concludes with theoretical and practical implications and future research pathways.

2. Theoretical background and literature review

The order picking is a vital component of the warehousing processes. Shah (2023) explained its relation to the other processes in warehouse process control department. In a forward reserve model, the author illustrated with a VSM analysis how picking process is mapped along with restocking and shipping processes.

We performed a systematic literature review following prisma protocol by using lean and warehousing and picking keywords in Scopus database. Appendix 3 outlines the PRISMA protocol. It has been observed that the concept is of lean warehousing is an relatively a new topic since the first publication was in 2004 but the literature started tackling this issue in a boarder scope starting from 2015. It is worth mentioning that this topic has been covered in a number of countries. Appendices 1 and 2 showcase the number of publications per year and the number of publications per country.

2.1 Background on lean in manual versus automated processes

As this paper focuses on implementing lean in manual processes, it is essential to review the literature concerning lean in both manual and automated systems. Specifically, Industry 4.0 represents the latest trend in automation and data interchange within organizations (Sony et al., 2020). Åberg (2019) indicated that during the 2000s, the literature suggested that lean and Industry 4.0 were in opposing camps, whereas more recent studies propose that Industry 4.0 naturally evolves from lean principles. In contrast to manual processes, Chiarini (2015) highlighted significant enhancements in machinery due to TQM and Lean tools. Other researchers have noted that TPM serves as an effective Lean tool for automated machinery. Moreover, the author contended that automated processes contain waste related to labor motions, delays, and transportation.

In today's business environment, it is increasingly essential for all commercial companies to adhere to the principles and methodologies of Industry 4.0. This compliance is vital for maintaining competitiveness and achieving advanced capabilities, particularly in relation to technology (Salvato *et al*. 2022). Software solutions, such as cloud-based Business Process Management (BPM) applications, can transform traditional manual processes into digitally-enabled, automated workflows. This transformation supports an organization's overall digital transformation strategy (Kunduru 2023). Such automation software plays a crucial role in streamlining repetitive and time-consuming tasks by replacing manual processes with automated systems (Ajiga *et al*. 2024).

2.2 Warehousing operations and order picking/packing waste

Order picking is a typical example of a warehousing process, defined as the process of retrieving products from storage locations in response to a specific customer request (Dukic and Oluic, 2007). As we focus on manual processes in our study, reviewing the order picking methods reveals several systems. Different waste materials result from order picking and packing processes. Åberg (2019) explored packing waste in a case study. He grouped them into six waste types, including:

- Travelling to collect boxes as movement waste
- Stored boxes as inventory waste
- Excessive bubble wrap as over-processing waste
- Waiting for consignment notes as waiting waste
- Carrying heavy packages as unnecessary motion waste
- Incorrect article/quality picked as correction of mistakes waste

Similarly, Pipatprapa (2019) argued that travelling, searching, returning, and waiting times are key wastes in order picking. Huber (2014) emphasised the walking time waste, especially for manual picking systems.

2.3 Lean methods for order picking and packing

Lean order picking and packing has become a critical research area. Pipatprapa (2019) studied the use of QR codes on mobile platforms to improve order picking in lean factory warehouses, finding that quick scanners and smartphone 3D sensors reduce waste and walking time. However, this study did not examine the packing process. To fill this gap, Aberg (2019) analyzed waste and root causes in packing processes through a case study, focusing primarily on order packing, while also considering order picking. The study did not assess the efficiency of manual processes; rather, it investigated the feasibility of redesigning packing processes with warehouse automation. Cajner et al. (2022) applied a bi-objective Assignment Model for Lean Order Picking, while Kong (2007) developed a lean-based order picking system that demonstrated efficient labor times. Lin (2010) created models to predict picking times and employed simulation for comparison. Other studies have integrated RFID, pick-to-light, and augmented reality to enhance these processes, but none have provided a structured lean framework.

2.4 Previous frameworks for lean warehousing

Several applications are revealed after reviewing the previous frameworks for lean warehousing, as outlined in Table I. Dixit *et al*. (2020) suggested a framework that redesigns the existing layout facilitated by a new assignment policy. Shah and Khanzode (2017) presented a model pointing to adopting lean thinking for designing a storage allocation strategy. The main purpose here is to reduce wasted space in the forward buffer. Harun *et al*. (2019) explored the relationship between 5S and value stream mapping (VSM) implementation tools, while Raghuram and Mahesh (2021) developed a lean warehouse framework that considers multiple objectives, such as storage and material handling. Nonetheless, the studies above fail to use the potential of various lean and problem-solving tools in the proposed frameworks. In addition, despite some research considering picking and packing processes, it is not the main scope of the studies.

[Insert Table I here]

2.5 Research gaps

Research on the Scopus database was done on 6 February 2023 within the article title, abstract, and keywords framework. The search string used was: “lean” AND “picking” AND “packing”. Two papers were found as a result: Srisuk and Tippayawong (2020); Shah and Khanzode (2016). The main difference between our research questions and Srisuk and Tippayawong (2020) work is that their main objective was to apply lean tools to decrease time and complication in the raw material picking process and to discuss the issue of the techniques of general manufacturing firms. Shah and Khanzode’s (2016) full paper was not available to us, but after screening the abstract, it was observed that the main difference between our study and their work is that they consider the forward-reserve scenario of a distribution warehouse. The authors here evaluate the performance trade-offs from the lean context in order to reduce storage waste.

Researchers have discussed lean adoption in various areas covering a broader scope of order picking, packing and warehousing. Table II illustrates a comparative analysis of the current literature. The research gap revealed is twofold:

[Insert Table II here]

- Limited structured and detailed frameworks for manual order picking and packing. There is a gap between the research issue of lean applications and the practice of order picking and packing processes. This gap is worth filling since conceptual frameworks constitute a gulf between explaining the research issue and the practice of investigating that issue (Leshem and Trafford, 2007).

- Previous research fails to investigate the potential of several lean and problem-solving tools such as CTQ, Spaghetti, 5 whys, and functional analysis to assess and decrease the waste in order picking and packing processes.

Hence, we aim in this study to fill these gaps by investigating a conceptual framework while integrating a holistic set of lean and problem-solving techniques.

3. Research design and methodology

3.1 Research design

A grounded theory approach is crucial to building the logic of a research design (Edmondson and McManus, 2007). Figure 1 presents the research design adopted in this study. A lean framework for order picking and packing processes is developed based on the lean manufacturing implementation framework (Mostafa et al., 2013). The framework is designed by using lean and problem-solving tools. This study is exploratory and uses the framework to support a case study. The case study research methodology mainly involves investigating real-life phenomena (Ridder, 2017). Voss *et al.* (2002) affirm that a case study methodology is a description of a phenomenon, past or present, based on multiple sources of evidence.

Hence, the real-life phenomena of processes and waste issues in picking and packing processes have been investigated in the logistics platform of a manufacturer. Seuring (2008) points out the relevance of adopting a case study methodology for understanding phenomena in areas about the supply chain field.

[Insert Figure 1 here]

3.2 Single case study

The case study is proven to be a very useful method for challenging theoretical assumptions (Antony *et al.*, 2018). The single-case approach supports readers in understanding the phenomena under study by detailing the analysis in a single organisation, event, or location (Li *et al.*, 2019). Therefore, generalities derived from a single-case study could be limited. However, documenting the case about the literature enriches the existing knowledge for researchers' and practitioners' communities (Antony *et al.*, 2011). Furthermore, despite multiple-case studies being more robust and single-case studies in some cases not being generalisable (Gijo *et al.*, 2019; Welsh and Lyons, 2001), the single detailed case study has been accepted and considered as a valid research methodology in academic research (Antony *et al.*, 2018; Woodside, 2010). The internal validity of the suggested improvement was gauged by discussing the "why" cause-effect relationships of the waste findings with the team.

3.3 Lean framework

We build our research framework based on Mostafa *et al*. (2013). The main reason behind the choice of this framework is its general structure of a lean implementation. This framework takes into account a tutorial stage for lean practitioners' guidance. Accordingly, we adapted the framework steps on the order picking and packing processes by shedding light on the required analysis to be held to investigate order picking and packing waste. Figure 2 shows our suggested framework.

[Insert Figure 2 here]

Tooling this framework may take various forms. The lean expert can pick the suitable tool to be used concerning the process features and the analysis to be performed. It is pertinent to highlight that the sequence between the framework steps is not always linear. Return cycles could be predicted in certain application cases. These iterations might occur in various forms. For instance, identifying missing collected data when processing analysis, calculation errors, or implementation issues may lead to reprocessing previous steps. The first step aims to conceptualise the problem. Step 2 implements the lean and problem-solving tools to investigate wastes. Step 3 evaluates the former implementations. Finally, step 4 documents and standardises the improvements achieved.

4. Case description

We used a single case study in this paper to answer both research questions. This method is adequate for answering the research questions under investigation. According to Voss *et al.* (2002), the case method enables the questions of "why," "what," and "how" to be answered with a global understanding of the complexity and the nature of the phenomenon. Mariotto *et al.* (2014) argued that the single-case study had been commonly used in various areas as a source of knowledge. The authors stated that this could be as a source of vicarious experience, a sample of what can happen, or an example to follow. The single-case study is an example of similar order picking and packing processes to decrease waste. Specifically, we are following the system-driven theoretical path associated with the theoretical paths guiding a case study (Løkke and Sørensen, 2014). According to the authors, there is a matching theory-testing research design using several theories to examine the system from various angles, that is, triangulation. We used various lean manufacturing methods and tested their application for manual order picking and packing in warehousing operations.

4.1 Data collection

For this study, the order preparation leader of the case company site assisted as the main contact for operational data collection. The methods engineer and the logistics manager also served to identify the right processes and the key employees to collaborate with for a better understanding of the processes. Both primary and secondary resources are used in this research. Secondary research comprises reviewing the types of order picking methods to categorise the company processes according to methods in the existing literature. Primary data include observations, timing measurements, and interviews with the team members to understand operational processes.

4.2 Framework implementation and results

4.2.1. Conceptual phase

Figure 3 outlines the functional analysis to define the scope of the picking and packing lean project. A failure mode effect analysis (FMEA) is performed to assess the risks associated with lean transformation, as outlined in Appendix 5. Identifying project risk management is crucial to prevent eventual failures, and FMEA is one of the techniques used for this purpose (Toljaga-Nikolić *et al*., 2018). Accordingly, the eventual risks are addressed and rated. Finally, a set of actions are outlined and considered to mitigate the aforementioned risks' impact proactively.

[Insert Figure 3 here]

In a lean approach, improvement actions eliminate non-value-added (NVA) actions and increase the overall rate of value-added (VA) actions. To proceed with this analysis, we first address the VA and NVA from a customer perspective and then map the order preparation processes in line with the defined value. The objective of the Critical To Quality (CTQ) diagram is to dissect the " 'customer's needs into requirements, which must be compared with the characteristics to be evaluated (Table III). It is a matter of listening to the customer's voice: any expressed requirement is a VA action, and any other order preparation activity is an NVA action.

[Insert Table III here]

4.2.2 Implementation design phase

We commence by mapping the processes to visuals of the main interactions between sub-processes and the associated inputs and outputs. We then examine the VA and NVA operations.

- *Process mapping*

Requests for customer orders are mainly related to finished products (FP). However, given the diversity of the industrial activities of the manufacturing firm, they can express their needs even on primary parts (PP) and sub-assemblies (SA), which will therefore be the subject of orders. Orders are sent out every day from the headquarters toward the end of the second shift, to be dispatched according to the delivery date of the next day, and processed thereafter.

To describe the physical flows of the process, we have drawn the SIPOC diagram consisting of Supplier, Input, Process, Output, and Customer (Figure 4). Products go through pre-shipment control, particularly before arriving at the order preparation, in the Control Before Shipment (CBS) zone. If an anomaly is detected during preparation, it is declared and must be returned to the supplier. Otherwise, it is directed to the shipping area. Orders are sent there to the headquarters site for assembly or directly to end customers.

[Insert Figure 4 here]

To dissect the stages of the preparation process, the SADT diagram (Structured Analysis and Design Technique) is drawn for each type of product (Figure 5) for the A0 level, and an extended micro-mapping is described in Figure 6 for the A1 level. There are two types of commands. First is the sampling lists; these orders are requested by end customers and contain their references marked as per their request. Second is inter-site requests; these present the orders intended for logistics platforms, which are then redirected to other platforms.

[Insert Figure 5 here]

[Insert Figure 6 here]

Once the co-leader assigns the order to the warehouse clerk, the latter initiates the mission order via the ERP. It manages the internal stock and keeps the traceability of all stock movements. The warehouse clerk has information on the locations containing the order packages that they must pick up, which are managed by the FIFO (First In, First Out) system. Depending on the current work organisation, each warehouse clerk prepares a single order described in the SADT micro-mapping diagram.

When the load increases, the instruction is communicated to the warehouse clerks to carry out five orders at a time. In this case, the operations of picking, double system control, and the printing of labels are carried out for the five orders simultaneously. This method of organisation gives rise to feedback and mixtures of parts and labels. The ultimate goal of order picking activities is to personalise customer orders to meet their needs in terms of time and quality, knowing that the orders are not predictable. Being the back end of the supply chain, the orders preparation function is a critical step in the product lifecycle, as every mistake made is detrimental to the corporate image.

- *Value-added analysis*

Once the customer needs are defined, we can describe the processes adding value. The purpose of the red/green flowchart is to analyse a process's flow and visually present the value added (Table IV); green stands for VA, while red stands for NVA. Based on the mapped processes of order preparation, we can conclude that green operations are articulated through four processes: picking, the printing of packing receipts and attached order files, piece counting, and packaging/labelling.

[Insert Table IV here]

Red operations comprise handling multiple packages between the trolleys and distribution in the rows of the CBS according to families, compliance control, and double counting control, which is compulsory when order quantity exceeds 250 units.

- *Process analysis*

We examine the quantification of the value added to understand the root waste causes among order picking and preparation operations.

- *Gemba walk*

A series of field Gemba walks were considered to identify the most time-consuming operations using the instantaneous observation method. The Gemba walk entails visiting the actual worksite, known as the "Gemba," to observe processes in real-time. This helps managers and team members identify waste and inefficiencies (Zvidzayi 2021). By interacting with the workforce and understanding their challenges, organizations can streamline operations and foster a culture of continuous improvement and collaboration.This method determines the distribution of activities for a given resource without resorting to continuous observation (permanent timing). The number of observations making it possible to have a representative engagement rate with the desired precision depends on the actual engagement rate and the precision obtained. We consider the following parameters:

N: Total number of Gemba walks to be implemented

P: Percentage of desired commitment, which has been set at 90%

S: The desired accuracy rate, which has been set at 5%

Thus, the total number of walks (1) is defined as:

$$N = (4 * (1-P)) / (S^2 * P) = 178 \text{ walks} \qquad (1)$$

In each Gemba walk, it was necessary to observe all the warehouse clerks using the observations sheet. Due to time constraints, 85 observations were made, spread over two shifts and three days. Figure 7 illustrates the results of the observations in terms of the percentage of times observed per operation.

[Insert Figure 7 here]

It has been noted that the movements of warehouse clerks are a major source of waste, hence the interest in performing an in-depth analysis at this level. In this effort, we produced a cause tree (Figure 8) on the causes of clerks' movements.

[Insert Figure 8]

This method consists of asking the question "why?" five times to delve deeper into the analysis of a problem, and every answer given will become a new problem to be solved. Subsequently, we opted for separating the types of trips according to the distances of movements. Thus, the fact that the warehouse clerk moves within his perimeter to the printer, welder, or scale does not influence his efficiency as long as he moves to the storage rows or the CBS. The same is observed for counting, labelling, and control operations; this results in the idea of making categories into product families and having the same preparation phases, which share the same characteristics.

- *Categorisation with data mining*

A first distribution was made in relation to the location of the storage rows. The prepared orders are stored in the orders preparations area (FP) or the warehouse (PP). The third type is managed between the production workstations and the warehouse: these are accessories consumed in production and managed as work in progress within production lines. Thus, according to the First In Forst Out (FIFO) system, the ERP system generates the location in the warehouse or production area when an order relates to an accessory. Subsequently, an analysis was conducted based on the history of one year, divided into three quarters, to take into account any possible peak load and fluctuation in demand. This load was stable for the year after; however, the accessories and the primary parts saw a slight increase. The significant difficulty at this stage is that the zone codes have changed during the year due to actions to improve the store's management, which required analysis before and after each change.

Second, the families of products were classified according to the labelling method. At this level, it was necessary to consider all the internal and external transfers that influence the packaging methods. The activity of order preparation is recent within the firm. After its initiation, the transfers of the production preparation load to the order preparation take place in instalments, as some parts remain in the switching process.

Finally, the last classification criterion is the counting mode. The process comprises three modes.

- Counting with the small scale: Concerns about counting accessories that are very small-sized products. This is a delicate operation, especially for very thin parts. In the same way, use a filter in relation to the families and sub-families that use this counting mode.
- Counting with the big scale: Used for parts larger than the previous ones, particularly for inserts, when the order quantities exceed 50 units. The process involves weighing a sample of the product specified by the manufacturer; the scale deduces the unit weight from it and then uses it for counting the following units placed on the bulk scale support.
- Manual counting: Inserts are counted manually and packed in packages separated by partitions and for bulky sub-assemblies, which must be arranged on well-defined floors. At this stage, we encountered some difficulties in separating the sub-families that belong to different counting methods, especially since the designation of the computer zone codes is not based on precise rules and due to the great diversity of products. For some references, it was necessary to physically search in the packages to identify the product and its method of counting. To build our classification tree (Figure 9), we chose three segmentation variables to ensure a divergence separation of the tree and to formalise the final classes.

[Insert Figure 9 here]

Each node constitutes an arbitration of possible future segmentations according to the characteristics of each zone. For example, orders for primary parts managed in stores are counted using the three counting modes. We tried to analyse a load of each mode to separate them, but given the intense fluctuation in customer demand, it turns out that the variable is random. Hence the segmentation of this branch stops at this level. In contrast, the products stored in the orders preparation area that only require the packaging label are numerous and cover all three counting methods.

- *Movements and control analysis*

The picking movement is the most time-consuming operation, given the layout distances and the demand frequency. To quantify these movements, we used the spaghetti diagram, which is a tool used to provide a clear vision of the physical flow of individuals. Appendices 6, 7, and 8 illustrate the movements in the order preparation area, the global warehouse zone, and the travels between the production cells. This visualisation is used to identify redundant flows and recurring crossings and measure the distance each product or person takes. Subsequently, a study was carried out to determine the families of products whose accessories used are the most in-demand, using Pareto analysis. The movements in this zone are easily discriminated by multiplying the distances travelled in each journey by the corresponding family's rotation frequency. The next operation to be analysed comprises the three control points during the logistics order preparation.

First, we analyse the compliance check which is carried out for each package collected to avoid service errors at the picking level. The second control consists of double counting. Ensuring rigour in the personalisation of the order is essential to ensure a better quality of service for its customers. In this context, a double counting check is carried out for each order that exceeds 250 pieces.The final operation covered is database control, which is carried out using a web application called the “double system control” database. With the main objective of avoiding the errors of service of the orders, this control consists in scanning the number of the order and scanning the order printed on the packing ticket of the parcel to ensure the correspondence between these two elements. Knowing that this beeping is done by order, we analysed the number of orders edited in the prepared commands per day. We timed the time spent beeping an order to arrive at the overall duration of this control per day, estimated at 1.5 h.

- *Handling analysis and final synthesis*

We noticed that the packages go through several handling operations during the order preparation between the trolleys and the workstations. Two types of trolleys are used: the warehouse clerks do the picking with trolley (1), handle the packages toward the workstations, and once the preparation is completed, they handle them toward trolley (1) for a second time to handle them a third time in the trolley (2). There is one cart on each side of the order preparation zone, shared by the warehouse clerks who work in this area, who all move together to take it to the CBS once it is full. Then, they distribute the packages according to product families in the storage columns of the CBS, awaiting control.

We measured the time spent in these operations to estimate the waste, especially since trips are frequent. According to the observations during the accompaniment of the warehouse clerks during the accomplishment of their tasks, we noticed that the last stage of the trolley (1) is very rarely used by the warehouse clerks, especially as long as the orders are prepared individually and if the order does not contain many packages. As a result, warehouse clerks opt to use the highest shelves, so there is no storage space, and pick travel is frequent. Table V synthesises the observations made while analysing the points and the time wasted.

[Insert Table V here]

The total daily NVA operations take 38 hours of working time for all warehouse clerks over the two operating shifts in the firm. In this phase, the initial performances of the order picking and preparation processes were assessed at the beginning of the project. This will enable prioritising improvements to be done and calculating how such improvements will contribute to reducing waste. Historical order analysis showed a high variation in quantity, the required movement for picking, and packaging. As a result, the focus was put on eliminating the root causes of NVA on a warehouse operations basis, not on an order type or customer basis.

- *Lean improvement*

- *Lean control points*

The control of the green bag, which takes 5 hours a day, was done to ensure the conformity of the part. Recently, the control of the double system control database with the double beeping was inaugurated to avoid errors occurring at the command level. Therefore, the two controls play the same role and filter the same errors.

For the double counting, it has been noticed that the check does not filter out many of the deviations. To reduce the time spent on this check, we analysed the recording, containing the history of the orders checked during one month. Of 648 orders checked, 30 were found to contain quantity discrepancies. Given the diversity of products, in terms of part size and counting method, it turns out that PP2 presents 83% of erroneous orders. The same analysis was redone for two months, proving the findings. A first reflection leads us to restrict this control for critical families. However, the quality risk of customer returns arises. The objectives and quality indicators are defined within the logistics department in terms of the part per million (PPM) defect rate. Thus, we will keep the filter based on the amount of deviation and change the control threshold.

To do this, we conducted a two-dimensional analysis of orders with quantity deviations, which shows the quantities of the deviations as a function of the sizes of the associated orders, by projecting analysis results into a two-dimensional space using the point cloud. Finally, it was proposed to move the threshold from 250 pieces to 1,000 pieces, which will present a huge gain in terms of efficiency while maintaining the quality of order preparation already achieved. To ensure better change management, it was proposed to carry out this action in two stages: follow up on customer returns in the phase of going from 250 to 500 parts, and after two months, go to the proposed final threshold of 1,000 pieces.

- *Kaizen layout and trolleys*

To optimise picking movements, it has been proposed to combine the picking of several orders in the same zone code simultaneously. Thus, the warehouse clerks will move once for the rows of an area code and collect as many orders as possible related to this family.

To minimise the movements of warehouse clerks between the computers, welders, and printers, as well as the multiple unnecessary handling of the packages between the trolleys and the tables, we proposed to design W2P stations, one of the important concepts of the lean approach. This concept is based on assigning one position to a warehouse clerk to work on a product: one workstation, one product, and one person. This makes the flow more fluid and provides a better yield in terms of quality, as packages or labels are not mixed. To execute this, the workstations were relocated. The layout was redesigned, so all the needed materials for order preparation are arranged in the same workstation to achieve the W2P's work design. This new work organisation will provide separate flows with dedicated workstations. Such a mass-picking organisation causes a quality risk in terms of mixing packages that do not belong to the same order.

Given the diversity of the orders, in terms of the number of packages as well as the sizes and shapes of the packages, the walls can be slid flexibly from end to end so that a shelf can contain one to three separate orders and an order containing several packages can be placed on the highest shelf. Knowing that 120 daily orders are for quantities ≤10 pieces, this trolley can handle up to 10 orders at a time without the risk of mixing. We carried out a test with a warehouse clerk by picking nine orders individually, and in the second configuration of picking nine orders simultaneously, we found that the travel time was optimised by 50%.

To optimise the distances covered by warehouse clerks for the picking to storage areas, it was proposed to install a workstation at the centre of the store to prepare primary parts and accessories orders. The obtained optimisation of this action is 1 hour per day.

The total simulated gained time per action category is presented in Figure 10, while the total improvement ratios are outlined in Figure 11. These mid-term actions are a roadmap for continuously improving logistics order picking and preparation processes. However, the most important contribution of this case study is a structured framework for lean logistics operations. Homogenous group work with frontline workers via Gemba walks, and field observation leads to exploring the main waste improvement areas and a collaborative vision to reorganise the workplace through kaizen logistics.

[Insert Figure 10 here]

[Insert Figure 11 here]

While analysing and identifying improvements, the focus was on quick win actions, which could be implemented with less effort and minimum investment. These improvements were discussed with the team leader, front-line workers, and engineering team. Such brainstorming and focus group discussions ensure better feasibility and applicability of the improvement actions. The last two phases were not finalised in the firm due to the project's time constraints. Some quick actions were implemented; however, the mid-term actions were planned for execution by the firm team.

5. Discussion

In theory, lean enables pull-system-based processes (Singh, 2019). We adopt the lean approach in this study since organising the manual picking and packing processes in a lean way has the potential to increase efficiency. This study is in line with previous studies on order picking, such as Moeller (2011). The author stated that an appropriate sequencing of picking lines is pivotal to reaching high efficiency since travel time constitutes a considerable part of the picking process. In addition, using lean tools for process waste assessment found that labelling and controlling processes is the most time-consuming. This is a significant issue for manual order preparation. Accurate controls of order preparations should be held before shipping. This supports the need to avoid picking errors, as Schwerdtfeger and Klinker (2008) stated since it creates high customer follow-up costs.

In correlation with the literature, our results show significant evidence that movements are one of the most laborious and time-consuming processes, supporting previous studies. Our study emphasises the statements of Burinskiene *et al*. (2018), noting that unnecessary movements are one of the warehouse wastes. Our suggestion regarding improving the lean warehouse layout implementation joins arguments by Baby *et al*. (2018), which state that changing the layout can generally eliminate movement waste. Similarly, Karásek (2013) argued that travel time is an increasing function of travel distance. The author emphasises that researchers' interest has been stimulated in investigating warehouse travelling for picking since it is the most time-consuming part of the process. Furthermore, it has been found that packaging is a lengthy process. This enhances the previous statements of Hellström *et al*. (2007), who report that the label application time is one of the important issues in packaging operations.

Regarding the literature on over-processing waste in the warehouse, our findings about controlling waste in the picking and packing processes support former studies. Here we relate to the literature on lean warehouse management. Risdayanti *et al*. (2021) identified the waste in the receiving process. They depicted extra processing when the checking process is repeated on scanning activities. The authors analysed the extra processing waste causes, and among the stated causes, they pointed out the high volume of items to be checked. This applies to our study since the products under processing are very small, and some references are weighted in bulk instead of manual counting. In addition, they outlined repeated checking as an extra processing cause. Our study also supports this cause, as we found that double counting for a specific type of order does not reveal any inconsistency.

6. Conclusion

This study presents an integrated framework for manual order picking and packing based on lean thinking while using problem-solving tools in a lean approach. The case study shows that three main actions can significantly improve the logistics operations efficiency for order preparation. First is the kaizen controls, where the voice of the customer for logistics orders should be well defined. Controls that do not reveal any errors or that might be substituted with automated ones should be cancelled. Second is the Kaizen layout, where the movement of the clerk is the waste that consumes most of the operational time. This fact has been diagnosed by spaghetti and demand analysis. Root causes have been addressed, quantified, and classified. As a result, lean work organisation, layout, and W2P workstations can be accurate for NVA reduction. Finally, the logistics operations should be smooth and in line with unpredicted orders. Dynamic trolleys were designed to enhance the process flexibility in picking and preparation.

CTQ was a good and simple method, addressing the order preparation processes in line with customer needs and expectations. SIPOC was an efficient mapping tool for capturing the different interactions between processes. Further, the SADT, which is mostly used for industrial purposes, has been analysed for mapping the processes. It is promising that the logistics benchmarking of this tool provides an appropriate vision of the operations correlations, inputs, and outputs.

6.1 Theoretical implications

The main research gap in the literature that we aim to fill is that there have been limited efforts to incorporate lean frameworks into manual order picking and packing processes in warehousing operations. This research gap is worth researching for the following reasons. First is because warehouses cannot always automate their processes due to costs (Åberg, 2019). Second, that order picking operations significantly impact the system efficiency since they are reiterated for each order (Yener and Yazgan, 2019). Third is that process focus is one of the drivers for lean management (Yadav *et al*., 2019). In manual processes, processes need high focus, since work standardisation is one of the challenges in lean implementation (Abu *et al*., 2019). To overcome the limitations of the existing frameworks, the study has proposed a structured methodology to improve the picking and packing process efficiency.

In light of the literature, our study complements the previous works of Pipatprapa (2019), Åberg (2019), and Huber (2014) for waste analysis in order picking and packing systems. The main contribution of this study is the project-based framework that provides a conceptual framework based on Mostafa *et al*. (2013) for lean manual order picking and packing processes. A set of analysis phases have been described to depict the process mapping, waste identification, and measurement, along with the improvement plans.

6.2 Practical implications

In a broader context, professionals engaged in the logistics sector, along with engineers and managers dedicated to advancing continuous improvement and operational excellence, can derive invaluable insights from our research. By leveraging the conceptual framework we present, organizations have the opportunity to implement strategies that, while straightforward, are profoundly impactful in driving enhancements across their operational processes. Central to this approach is the adoption of a customer-centric philosophy, ensuring that every activity undertaken is deliberately aligned with the goal of delivering significant added value to the end user. It is crucial for practitioners within manufacturing organizations to conduct a thorough and critical evaluation of the various lean tools at their disposal. This could be applied not only to picking processes but to packing as well. This selection process should be approached with careful consideration of the organization's unique internal processes and cultural dynamics, setting the stage for the seamless integration of lean practices in sourcing processes as well.

Organizations looking to enhance their sustainable performance should start by adopting lean principles, which focus on reducing waste and improving efficiency (Kovilage 2021). Once these improvements are in place, they can move toward implementing green practices to further promote environmental sustainability. Servitization in manufacturing is also crucial for sustainability. This transition shifts firms from selling just products to offering Product-Service Systems (PSS), which add value through associated services (Hao et al. 2021). This approach not only extends the product life cycle and reduces waste but also encourages a circular economy. By embracing servitization, manufacturers can align with consumer demands for more sustainable solutions while contributing to a healthier environment

6.3 Limitations and future research scope

Generalizability is one of the limitations of the paper as findings is based on a single-case study approach. Kennedy (1979) stated that single-case studies had been adopted as an alternative to group comparison studies. However, they argued that their main drawback is a lack of a generally accepted rule for deriving causation and generalisation inferences. Similarly, Voss *et al.* (2002) emphasised that greater depth is the advantage of single cases but argued that it limits the generalizability of conclusions as per the biases such as exaggerating data and misjudging the representativeness of a single event. However, this limitation can be overcome by following a multi-case study approach or by conducting a comparative case analysis using secondary cases from the literature.

Case studies are often criticized for their findings not being easily applicable to broader populations, especially when compared to results from large-sample, quantitative research methods. This limitation arises because case studies typically focus on a specific or unique context and involve a limited number of participants. As a result, the conclusions drawn may not be extendable to other settings or groups. While case studies can provide in-depth insights and a comprehensive understanding of particular situations, their findings may not accurately represent trends or patterns that would be observed in a more diverse or larger sample.

Whereas the integrated framework proposed and applied has an excellent outcome in this case study, there are some limitations to be considered in future research projects. First, achieving six sigma analysis is considered to be a restriction. Considering the combination of lean with six sigma, this study can encourage academics to explore the potential of six sigma to reduce quality variation issues, such as reference picking and order quantity, using the six sigma statistical customer-focused tools. Rather than trying to minimise the Non Value Added (NVA), future studies must encourage breakthrough ideas regarding the industrial 4.0 barriers correlated to lean logistics operations management, especially in light of the post-COVID-19 era (Fares and Lloret, 2022; Fares *et al*., 2022, Fares and Lloret 2023). A lean analysis of intrinsic and extrinsic factors of lean management of order picking and preparation would be a promising research area (Chauhan *et al*., 2020). In this context, future works can investigate the enablers of industry 4.0 in lean logistics implementation (Raj *et al*., 2020) and potentially benchmark with other operational processes such as omnichannel in fast-fashion retail (Fares et al. 2023).

References

Åberg, H. (2019). “Layout redesign and automation for a lean packing process in a distribution center”, unpublished manuscript, master thesis, Lund University. Available at: https://lup.lub.lu.se/luur/ accessed on (August 8th, 2022)

Abu, F., Gholami, H., Mat Saman, M.Z., Zakuan, N., and Streimikiene, D. (2019), "The implementation of lean manufacturing in the furniture industry: a review and analysis on the motives, barriers, challenges, and the applications", *Journal of Cleaner Production*, Vol. 234, pp. 660–680. DOI: https://doi.org/10.1016/j.jclepro.2019.06.279

Ajiga, D., Okeleke, P. A., Folorunsho, S. O., & Ezeigweneme, C. (2024). 'The role of software automation in improving industrial operations and efficiency' . *International Journal of Engineering Research Updates* 07(01), 022–035

Ali, S. S., & Kaur, R. (2021), "Effectiveness of corporate social responsibility (CSR) in implementation of social sustainability in warehousing of developing countries: A hybrid approach", *Journal of Cleaner Production*, Vol. 324, p. 129154. DOI: https://doi.org/10.1016/j.jclepro.2021.129154

Alkhoraif, A. (2018). "Lean Implementation in small and medium enterprises: Literature review", *Operations Research Perspectives*, Vol. 6, pp. 100089. DOI: https://doi:10.1016/j.orp.2018.100089.

Antony, J., Ghadge, A., Ashby, S.A., and Cudney, E.A. (2018),"" ""Lean Six Sigma journey in a UK higher education institute: a case study"""""", *International Journal of Quality & Reliability Management*, Vol. 35 No. 2, pp. 510–526. DOI: https://doi.org/10.1108/IJQRM-01-2017-0005

Antony, J., Gijo, E. V., and Childe, S. J. (2012), "Case study in Six Sigma methodology: manufacturing quality improvement and guidance for managers", *Production Planning & Control*, Vol. 23 No. 8, pp 624–640. DOI: http://dx.doi.org/10.1080/09537287.2011.576404

Aomar, R. A., Alshwailat, A., & Alfarraj, A. (2020), "A simulation-aided lean application to an automated production line", Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, August 10–14, 2020.

Ardjmand, E., Singh, M., Shakeri, H., Tavasoli, A., and Young II, W. A. (2021), "Mitigating the risk of infection spread in manual order picking operations: A multi-objective approach", *Applied Soft Computing*, Vol. 100, pp. 106953. DOI: https://doi.org/10.1016/j.asoc.2020.106953

Baby, B., Prasanth, N., and Jebadurai, D. S. (2018), "Implementation of Lean principles to improve the operations of a sales warehouse in the manufacturing industry". Industrial Engineering, Vol. 9, pp. 46–54 DOI: https://doi.org/10.14716/ijtech.v9i1.1161

Bonilla-Ramirez, K. A., Marcos-Palacios, P., Quiroz-Flores, J. C., Ramos-Palomino, E. D., & Alvarez-Merino, J. C. (2019, December). Implementation of lean warehousing to reduce the level of returns in a distribution company. In 2019 IEEE International

Conference on Industrial Engineering and Engineering Management (IEEM) (pp. 886-890). IEEE.

Burinskiene, A., Lorenc, A., and Lerher, T. (2018). “A simulation study for the sustainability and reduction of waste in warehouse logistics”, International Journal of Simulation Modelling, Vol. 17, pp. 485–497. DOI: https://doi.org/10.2507/IJSIMM17(3)446

Cajner, H., Butlewski, M., Opetuk, T., & Đukić, G. (2022). Bi-objective Assignment Model for Lean Order Picking in a Warehouse. Tehnički vjesnik, 29(1), 293-300.

Cagliano, A., Grimaldi, S., & Schenone, M. (2018). Proposing a new framework for lean warehousing: first experimental validations. XXII Summer School"" Franceso Turco""-Industrial Systems Engineering, 156-163.

Cajner, H., Butlewski, M., Opetuk, T., and Đukić, G. (2022), “Bi-objective assignment model for lean order picking in a warehouse”, *Tehnički vjesnik,* Vol. 29, pp. 293–300. DOI: https://doi.org/10.17559/TV-20201002103433

Chiarini, A. (2015). Effect of ISO 9001 non-conformity process on cost of poor quality in capital-intensive sectors. International Journal of Quality & Reliability Management, 32(2), 144-155

Chauhan, C., Singh, A., and Luthra, S. (2020). “Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy”. *Journal of Cleaner Production,* Vol. 285, pp. 124809. DOI: https://doi.org/10.1016/j.jclepro.2020.124809

Chiarini, A. (2015), “Improvement of OEE performance using a Lean Six Sigma approach: an Italian manufacturing case study”, *International Journal of Productivity and Quality Management*, Vol. 16 No. 4, p. 416. doi:10.1504/ijpqm.2015.072414

Cheng, C.Y., and Chang, P.Y. (2012). “Implementation of the Lean Six Sigma framework in non-profit organisations: A case study”, *Total Quality Management & Business Excellence*, Vol. 23, pp. 431–447. DOI: https://doi.org/10.1080/14783363.2012.663880

De Koster, R., Le-Duc, T., and Roodbergen, K.J. (2007), “Design and control of warehouse order picking: A literature review”. *European Journal of Operational Research*, Vol. 182, pp. 481–501. DOI: https://doi:10.1016/j.ejor.2006.07.009

De Vries, J., de Koster, M.B.M., and Stam, D. (2015), “Aligning order picking methods, incentive systems, and regulatory focus to increase performance”, *SSRN Electronic Journal*, Vol. 25, pp. 1363–1376. DOI: https://doi:10.2139/ssrn.2630169

Dixit, A., Shah, B., and Sonwaney, V. (2020), “Picking improvement of an FMCG warehouse: a lean perspective”, *International Journal of Logistics Economics and Globalisation*, Vol. 8, pp. 243–271. DOI: https://doi:10.1504/ijleg.2020.109613

Dora, M., and Gellynck, X. (2015), “House of lean for food processing SMEs”, *Trends in Food Science & Technology,* Vol. 44, pp. 272–281. https://doi:10.1016/j.tifs.2015.03.008

Dukic, G., & Oluic, C. (2007), “Order-picking methods: improving order-picking efficiency”. *International Journal of Logistics Systems and Management,* Vol. 3, p. 451. DOI: https://doi:10.1504/ijlsm.2007.013214

Ebneyamini, S., and Sadeghi Moghadam, M.R. (2018), “Toward developing a framework for conducting case study research”, *International Journal of Qualitative Methods*, Vol. 17, p. 1609406918817954. DOI: https://doi.org/10.1177/1609406918817954

Edmondson, A.C., and McManus, S.E. (2007), “Methodological fit in management field research”, *Academy of Management Review*, Vol. 32, pp. 1246–1264. DOI: https://doi.org/10.5465/amr.2007.26586086

Fang, W., and An, Z. (2020), “A scalable wearable AR system for manual order picking based on warehouse floor-related navigation”, *The International Journal of Advanced Manufacturing Technology,* Vol. 109, pp. 2023–2037. DOI: https://doi.org/10.1007/s00170-020-05771-3

E.V., G., Antony, J., and Sunder M.V. (2019),”” ““Application of Lean Six Sigma in IT support services – a case study”””””, The TQM Journal, Vol. 31 No. 3, pp. 417–435. https://doi.org/10.1108/TQM-11-2018-0168

Faccio, M., Gamberi, M., Bortolini, M., & Pilati, F. (2018). Macro and micro-logistic aspects in defining the parts-feeding policy in mixed-model assembly systems. International Journal of Services and Operations Management, 31(4), 433-462.

Fares N., Lloret J.(2023) “Barriers to supply chain performance measurement during disruptions such as the COVID-19 pandemic”. International Journal of Quality & Reliability Management. Vol. ahead-of-print No. ahead-of-print

Fares N., Lloret J., Kumar V., Frederico G. (2023) “Factors Affecting Omnichannel Buying Online and Return in Store: Evidence From Fast-Fashion Retail”. Journal of Enterprise Information Management. Vol. ahead-of-print No. ahead-of-print

Fares, N. and Lloret J. (2022), “An integrated SWOT-AHP-fuzzy TOPSIS approach for maturity management following the COVID-19 outbreak: lessons learned from fast fashion”. *Journal of Global Operations and Strategic Sourcing* ahead-of-print. DOI: https://doi.org/10.1108/JGOSS-09-2021-0072

Fares N., Lloret J., Kumar V., Frederico, G., Kumar A., and Garza-Reyes J. (2022), “Enablers of post-COVID-19 customer demand resilience: Evidence from fast-fashion MSMEs”, *Benchmarking: an International Journal,* ahead-of-print. DOI: https://doi.org/10.1108/BIJ-11-2021-0693

Figueroa-Rivera E. , Bautista-Gonzales A. ,Quiroz-Flores J. Increased productivity of storage and picking processes in a mass-consumption warehouse applying Lean Warehousing tools: A Research in Peru. 20th LACCEI International Multi-Conference for Engineering, Education, and Technology, Florida- USA, July 18 - 22, 2022.

Garberoglio, C., and Chalakkal, D.K. (2022), “Manufacturing warehouse analysis by lean production methodologies” (Doctoral dissertation, Politecnico di Torino).

Gomes, B. E., Pereira, M. T., Oliveira, M., & Ferreira, F. A. (2022). Continuous Improvement of Logistics Processes in a Production Line of Electric Buses Chassis. In Innovations in Mechanical Engineering II (pp. 250-258). Cham: Springer International Publishing.

Gutierrez-Gutierrez, L., de Leeuw, S. and Dubbers, R. (2016),“” ““Logistics services and Lean Six Sigma implementation: a case study”””””, *International Journal of Lean Six Sigma*, Vol. 7 No. 3, pp. 324–342. https://doi.org/10.1108/IJLSS-05-2015-0019

Haddud, A. and Khare, A. (2020),” “““Digitalising supply chains potential benefits and impact on lean operations”””””, *International Journal of Lean Six Sigma*, Vol. 11 No. 4, pp. 731–765. https://doi.org/10.1108/IJLSS-03-2019-0026

Harun, M.F., Habidin, N.F., and Latip, N.A.M. (2019), “5S lean tool, value stream mapping and warehouse performance: Conceptual framework”, *International Journal of Supply Chain Management*, Vol. 8 No. 3, pp. 605–608.

Haekal, J. (2021), “Application of lean six sigma approach to reduce worker fatigue in racking areas using DMAIC, VSM, FMEA and ProModel simulation methods in sub logistic companies: A case study of Indonesia”, *International Journal of Engineering Research and Advanced Technology* (E-ISSN 2454-6135), Vol. 10, pp. 1–11.

Hao, Z., Liu, C., & Goh, M. (2021). Determining the effects of lean production and servitization of manufacturing on sustainable performance. Sustainable Production and Consumption, 25, 374-389.

Heaslip, G., Mangan, J., and Lalwani, C. (2008), “Modelling a humanitarian supply chain using the Structured Analysis and Design Technique (SADT)”, Logistics Research Network (LRN).

Hellström, D., and Saghir, M. (2007), “Packaging and logistics interactions in retail supply chains”, *Packaging Technology and Science: An International Journal*, Vol. 20, pp. 197–216. DOI: https://doi.org/10.1002/pts.754

Huber, C. (2014), Throughput analysis of manual order picking systems with congestion consideration (Vol. 76). KIT Scientific publishing.

Isidro, M., Susaya, A., Viacava, G., & Namay, W. (2021). Warehouse Management Model Under the Lean Warehousing Philosophy to Reduce Product Returns in the Marketer. In Advances in Manufacturing, Production Management and Process Control: Proceedings of the AHFE 2021 Virtual Conferences on Human Aspects of Advanced Manufacturing, Advanced Production Management and Process Control, and Additive Manufacturing, Modeling Systems and 3D Prototyping, July 25-29, 2021, USA (pp. 446-454). Springer International Publishing.

Karásek, J. (2013), “An overview of warehouse optimisation”, International journal of advances in telecommunications, electrotechnics, signals and systems, Vol. 2, pp. 111–117.

Kennedy, M.M. (1979), “Generalising from single case studies”, *Evaluation Quarterly*, Vol. 3 No. 4, pp. 661–678. doi:10.1177/0193841x7900300409

Kłodawski, M., Jacyna, M., Lewczuk, K., and Wasiak, M. (2017), “The issues of selection warehouse process strategies”, *Procedia Engineering*, Vol. 187, pp. 451–457. DOI: https://doi:10.1016/j.proeng.2017.04.399

Kong, C. (2007), “Design and management of a lean order picking system”, Unpublished doctoral dissertation, Ohio University.

Kong, C., & Masel, D. (2008). Methods for design and management of a fast-pick area in a warehouse. In IIE Annual Conference. Proceedings (p. 1367). Institute of Industrial and Systems Engineers (IISE).

Kostrzewski, M. (2020), “Sensitivity analysis of selected parameters in the order picking process simulation model, with randomly generated orders”. *Entropy*, Vol. 22, p. 423. DOI: https://doi.org/10.3390/e22040423

Kovilage, M. P. (2021). “Influence of lean–green practices on organizational sustainable performance”. *Journal of Asian Business and Economic Studies*, 28(2), 121-142.

Kunduru, A. R. (2023). “Cloud BPM Application (Appian) Robotic Process Automation Capabilities”. *Asian Journal of Research in Computer Science*, 16(3), 267-280.

Leshem, S., and Trafford, V. (2007), “Overlooking the conceptual framework”, *Innovations in Education and Teaching International*, Vol. 44, pp. 93–105. DOI: https://doi.org/10.1080/14703290601081407

Li, N., Laux, C.M., and Antony, J. (2019),”” ““How to use lean Six Sigma methodology to improve service process in higher education: A case study”””””, *International Journal of Lean Six Sigma*, Vol. 10 No. 4, pp. 883–908. DOI: https://doi.org/10.1108/IJLSS-11-2018-0133

Lin, C. J. (2010). “Developing design rules for a lean order picking system” Unpublished doctoral dissertation, Ohio University.

Liviu, I., Ana-Maria, T., and Emil, C. (2009), “Warehouse performance measurement—A case study”, *Annals of Faculty of Economics*, Vol. 4 No. 1, pp. 307–312.

Løkke, A. K., and Sørensen, P.D. (2014), “Theory testing using case studies”, *Electronic Journal of Business Research Methods*, Vol. 12 No. 1, pp. 66–74.

Lupeanu, M.E., Brooks, H., Rennie, A.E., and Hill, D. (2013), “Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions”, *University Politechnica of Bucharest Scientific Bulletin Mechanical Engineering Series D*, Vol. 75 No. 1, pp. 141–60.

Mariotto, F.L., Zanni, P.P., & Moraes, G.H.S. (2014), "What is the use of a single-case study in management research?". *Revista de Administração de Empresas,* Vol. 54, pp. 358–369. https://doi.org/10.1590/S0034-759020140402

Martins, R., Pereira, M.T., Ferreira, L.P., Sá, J.C., and Silva, F.J.G. (2020), "Warehouse operations logistics improvement in a cork stopper factory", *Procedia Manufacturing,* Vol. 51, pp. 1723–1729. DOI: https://doi.org/10.1016/j.promfg.2020.10.240

Mičieta, B., Howaniec, H., Biňasová, V., Kasajová, M., and Fusko, M. (2021), "Increasing lean six sigma approach to reduce worker fatigue in racking areas using Gemba Walk", *European Research Studies Journal,* Vol 24 No. 4.

Minovski, R., Jovanoski, B., and Galevski, P. (2021),"" ""Lean implementation and implications: experiences from Macedonia""""", *International Journal of Lean Six Sigma,* Vol. 12 No. 1, pp. 78–97. https://doi.org/10.1108/IJLSS-10-2016-0057

Moeller, K. (2011), "Increasing warehouse order picking performance by sequence optimisation", Procedia-Social and Behavioral Sciences, Vol. 20, pp. 177–185. DOI: https://doi.org/10.1016/j.sbspro.2011.08.023

Oey, E., & Nofrimurti, M. (2018). Lean implementation in traditional distributor warehouse-A case study in an FMCG company in Indonesia. International Journal of Process Management and Benchmarking, 8(1), 1-15.

Palšaitis, R., Čižiūnienė, K., and Vaičiūtė, K. (2017), "Improvement of Warehouse Operations Management by Considering Competencies of Human Resources". *Procedia Engineering,* Vol. 187, pp. 604–613. DOI: https://doi:10.1016/j.proeng.2017.04.420

Pattanaik, L.N., and Sharma, B.P. (2008), "Implementing lean manufacturing with cellular layout: a case study", *The International Journal of Advanced Manufacturing Technology,* Vol. 42 No. 7–8, pp. 772–779. doi:10.1007/s00170-008-1629-8

Pipatprapa, A. (2019), "QR Code on mobile platform for improving order picking process of lean factory warehouse". *International Journal of Innovation, Management and* Technology, Vol. 10, pp. 56–60. DOI: https://doi.org/10.18178/ijimt.2019.10.1.836

Prasetyawan, Y., Simanjuntak, A. K., Rifqy, N., & Auliya, L. (2020, July). Implementation of lean warehousing to improve warehouse performance of plastic packaging company. In IOP Conference Series: Materials Science and Engineering (Vol. 852, No. 1, p. 012101). IOP Publishing.

Raghuram, P. and Arjunan, M.K. (2022),"" ""Design framework for a lean warehouse—a case study-based approach""""", *International Journal of Productivity and Performance Management,* Vol. 71, No. 6, pp. 2410–2431. https://doi.org/10.1108/IJPPM-12-2020-0668

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A.B.L., and Rajak, S. (2020), "Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An intercountry comparative perspective", *International Journal of Production Economics*, Vol. 224, p. 107546. DOI: https://doi.org/10.1016/j.ijpe.2019.107546

Rasmi, S.A.B., Wang, Y., and Charkhgard, H. (2022), "Wave order picking under the mixed-shelves storage strategy: A solution method and advantages". *Computers & Operations Research*, Vol. 137, p. 105556. DOI: https://doi.org/10.1016/j.cor.2021.105556

Ridder, H.G. (2017). "The theory contribution of case study research designs", *Business Research*, Vol. 10, pp. 281–305. DOI: https://doi.org/10.1007/s40685-017-0045-z

Rijal, A., Bijvank, M., Goel, A., & de Koster, R. (2021), "Workforce scheduling with order-picking assignments in distribution facilities". *Transportation Science*, Vol. 55, pp. 725–746. DOI: https://doi.org/10.1287/trsc.2020.1029

Risdayanti, A., Nuruzzahri, M.R., Rizaldy, W., & Prasidi, A. (2021), "Lean warehouse approach to minimise the waste in the receiving process in warehouse finished goods of PT. Emudah fulfillmen Indonesia". *Advances in Transportation and Logistics Research*, Vol. 4, pp. 1163–1179. DOI: https://doi.org/10.25292/atlr.v4i0.472

Rungruengkultorn, P., and Boonsiri, S. (2022), "Warehouse processes improvement using lean six sigma and RFID technology2, International Journal of Mathematics and Computer Science, Vol. 17 No. 3, pp. 1175–1186.

Salvato, R., Marra, G., Scardamaglia, P., Di Gironimo, G., Marzullo, D., & Mozzillo, R. (2022). "Design and integration of automation systems with manual operation: small and medium enterprises issues". In *Design Tools and Methods in Industrial Engineering II: Proceedings of the Second International Conference on Design Tools and Methods in Industrial Engineering*, ADM 2021, September 9–10, 2021, Rome, Italy (pp. 298-307). Springer International Publishing.

Sanchez, N. Y. E., Santos, P. Y. S., Lastra, G. E. M., Flores, J. C. Q., & Merino, J. C. A. (2021, March). Implementation of Lean and Logistics Principles to Reduce Non-conformities of a Warehouse in the Metalworking Industry. In 2021 10th International Conference on Industrial Technology and Management (ICITM) (pp. 89-93). IEEE.

Schwämmle, A. (2022), "Implementation of a Kaizen organisation in an existing retail warehouse", In *Project Management in Logistics and Supply Chain Management: Practical Guide with Examples From Industry, Trade and Services* (pp. 311–322). Wiesbaden: Springer Fachmedien Wiesbaden.

Schwerdtfeger, B., and Klinker, G. (2008), "Supporting order picking with augmented reality". In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (pp. 91–94). IEEE.

Senderska, K., Mareš, A., and Václav, Š. (2017), "Spaghetti diagram application for workers' movement analysis", UPB Scientific Bulletin, Series D: Mechanical Engineering, Vol. 79 No. 1, 139–150.

Serna-Ampuero, M. A., Arias-Navarro, M., & Quiroz-Flores, J. C. (2022, September). Inventory Management Model under the Lean Warehousing Approach to Reduce the Rate of Returns in SME Distributors. In Proceedings of the 8th International Conference on Industrial and Business Engineering (pp. 103-108).

Seuring, S.A. (2008),“” ““Assessing the rigor of case study research in supply chain management”””””, *Supply Chain Management*, Vol. 13 No. 2, pp. 128–137. https://doi.org/10.1108/13598540810860967

Shah, B., and Khanzode, V. (2016), “Design and assessment of lean handling buffers in forward-reserve model”, Proceedings of the International Conference on Industrial Engineering and Operations Management, March 8–10, 2016, pp. 314.

Shah, B. (2023). What should be lean buffer threshold for the forward-reserve warehouse?. International Journal of Productivity and Performance Management, 72(2), 361-387.

Shah, B., and Khanzode, V. (2017), “Storage allocation framework for designing lean buffers in forward-reserve model: a test case”, *International Journal of Retail & Distribution Management*, Vol. 45, pp. 90–118. DOI: https://doi.org/10.1108/ijrdm-07-2016-0112

Singh, J. (2019),“The lean prescription for non-traditional adult learners”, *Quality Assurance in Education*, Vol. 27 No. 3, pp. 347–359. DOI: https://doi.org/10.1108/QAE-09-2018-0100

Sony, M. and Naik, S. (2020),” “Key ingredients for evaluating Industry 4.0 readiness for organisations: a literature review”, *Benchmarking: An International Journal*, Vol. 27 No. 7, pp. 2213–2232. https://doi.org/10.1108/BIJ-09-2018-0284

Srisuk, K., and Tippayawong, K.Y. (2020), “Improvement of raw material picking process in sewing machine factory using lean techniques”, *Management and Production Engineering Review*, Vol. 11.

Toljaga-Nikolić, D., Todorović, M., and Bjelica, D. (2018), “Application of the FMEA technique in a project risk analysis”. *European Project Management Journal*. Vol. 8, pp. 36–42.

Van Gils, T., Ramaekers, K., Caris, A., and de Koster, R.B. (2018), “Designing efficient order picking systems by combining planning problems: State-of-the-art classification and review”. *European Journal of Operational Research*, Vol. 267, pp. 1–15. DOI: https://doi.org/10.1016/j.ejor.2017.09.002

Vanheusden, S., van Gils, T., Caris, A., Ramaekers, K., and Braekers, K. (2020), “Operational workload balancing in manual order picking”, *Computers & Industrial Engineering*, Vol. 141, p. 106269. DOI: https://doi.org/10.1016/j.cie.2020.106269

Villacrez-Zelada, A., Liñer-Hernandez, J., & Viacava-Campos, G. (2022, March). Service Level Optimization Using ABC Distribution, Forecasts and the Packaging and Stowage Model through Lean Warehousing at a SME Marketing Company. In 2022

8th International Conference on Information Management (ICIM) (pp. 171-175). IEEE.

Voss, C., Tsikriktsis, N., and Frohlich, M. (2002), “Case Research in Operations Management”, International Journal of Operations & Production Management. Vol. 22 No. 2, pp. 195–219. http://dx.doi.org/10.1108/01443570210414329

Welsh, I. and Lyons, C.M. (2001), “Evidence-based care and the case for intuition and tacit knowledge in clinical assessment and decision making in mental health nursing practice: an empirical contribution to the debate”, *Journal of Psychiatric and Mental Health Nursing*, Vol. 8 No. 4, pp. 299–305. DOI: https://doi.org/10.1046/j.1365-2850.2001.00386.x

Woodside, A.G. (2010), *Case study research: theory, methods and practice*, Emerald Group Publishing Ltd., Bingley, UK.

Yadav, G., Luthra, S., Huisingh, D., Mangla, S.K., Narkhede, B.E., and Liu, Y. (2019), “Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies”, *Journal of Cleaner Production*, Vol. 245, p. 118726. DOI: https://doi.org/10.1016/j.jclepro.2019.118726

Yener, F., & Yazgan, H.R. (2019). “Optimal warehouse design: Literature review and case study application”, *Computers & Industrial Engineering*, Vol. 129, pp. 1–13 DOI: https://doi.org/10.1016/j.cie.2019.01.006

Zvidzayi, J. (2021). Analysis of critical Success factors of Gemba Kaizen in Lean Manufacturing within SA Industries. In Proceedings of the International Conference on Industrial Engineering and Operations Management (pp. 2250-2259).

Figures

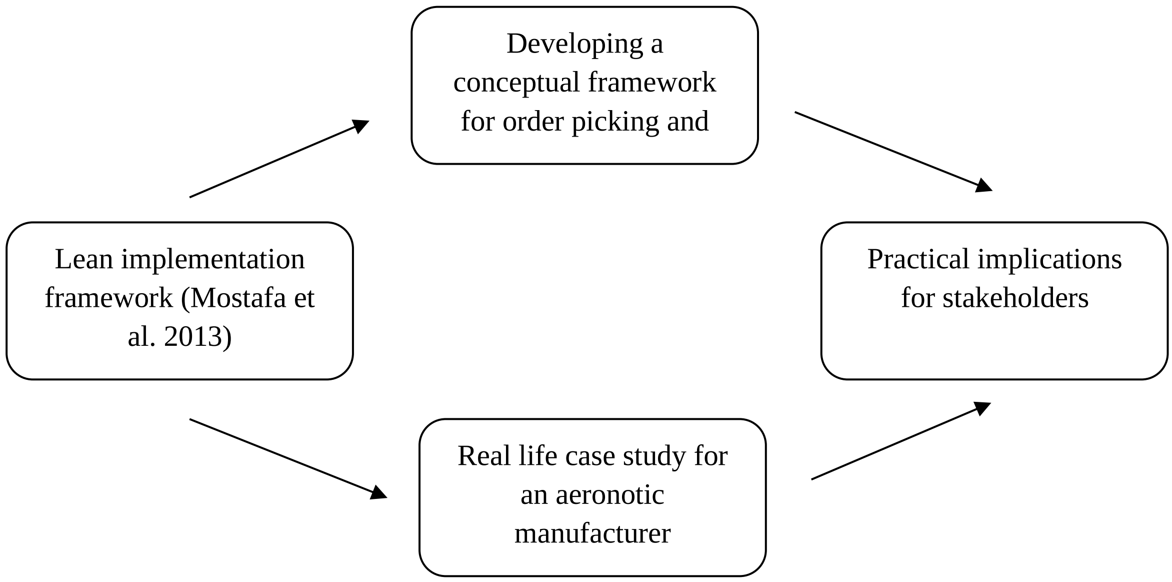


Figure 1: Research design

Conceptual phase	• Form the team • Define the picking and packing analysis scope (functional analysis) • Lean training • Risk assessment with respect to the organization’s features (FMEA) • Frame the communication channels • Define the value added of the order preparation from the customer perspective (CTQ)
Implementation design phase	• Pick and pack process mapping (SIPOC, SADT) • Analysis of input flow of orders • Identify picking and packing waste (flowchart) • Waste analysis • Types of wastes • Plan the pick and pack lean transformation • Assess current versus future states
Implementatio n and evaluation	• Training of employees • Evaluation of implementation
Lean transformatio n phase	• Documentation • Standardization

Figure 2:Suggested lean framework.

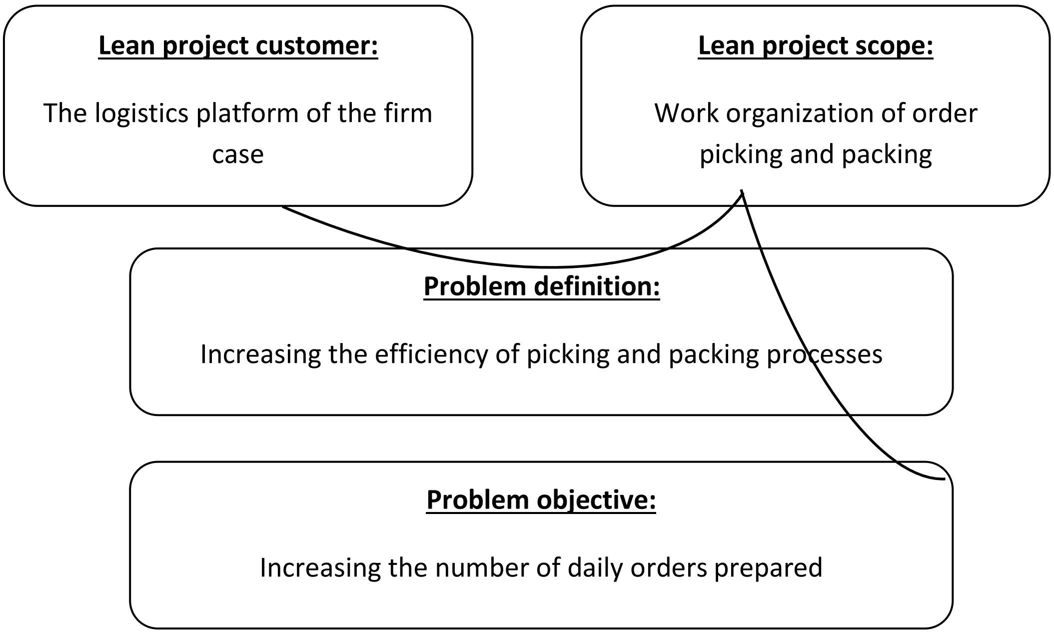


Figure 3: Problem definition: Functional analysis diagram. The suggested lean picking and packing framework based on Mostafa *et al*., 2013.

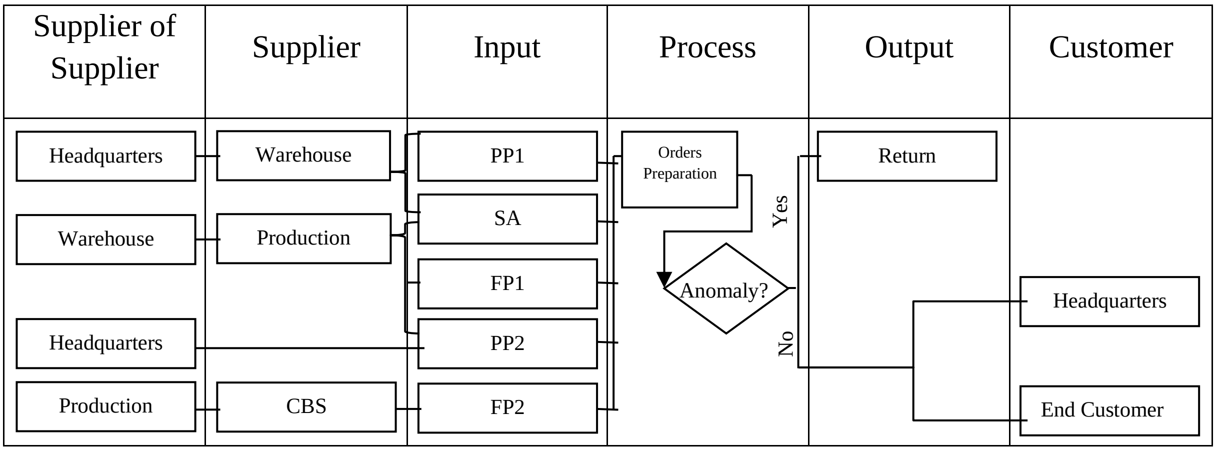


Figure 4: SIPOC analysis.

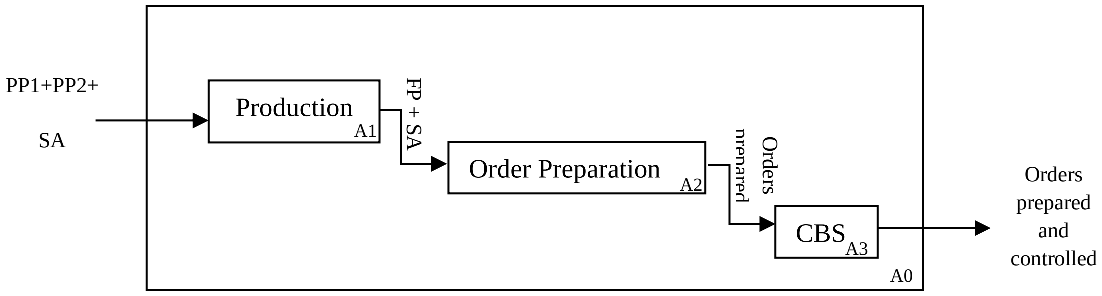


Figure 5: SADT macro-mapping: A0 level.

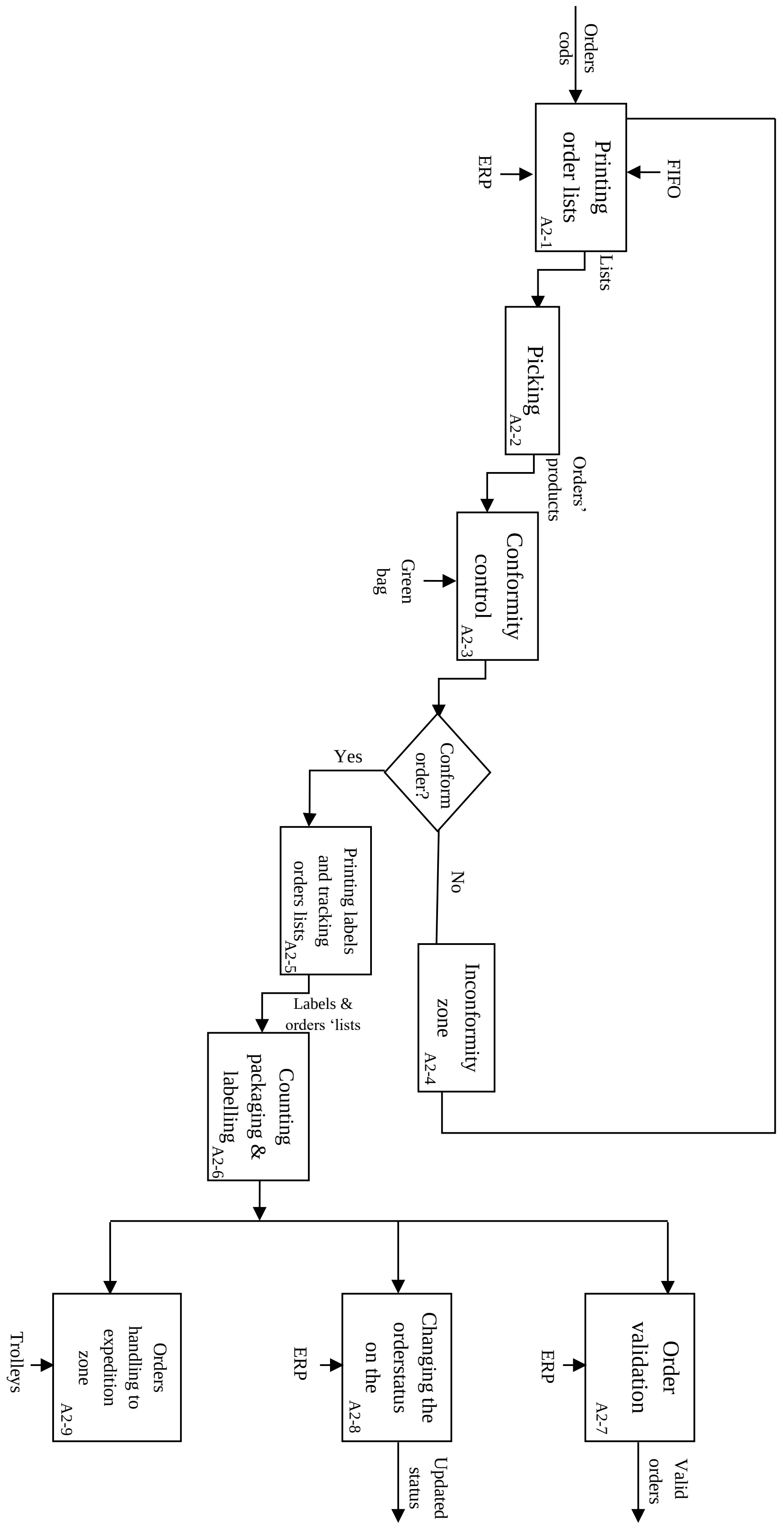


Figure 6: SADT micro-mapping: A1 level.

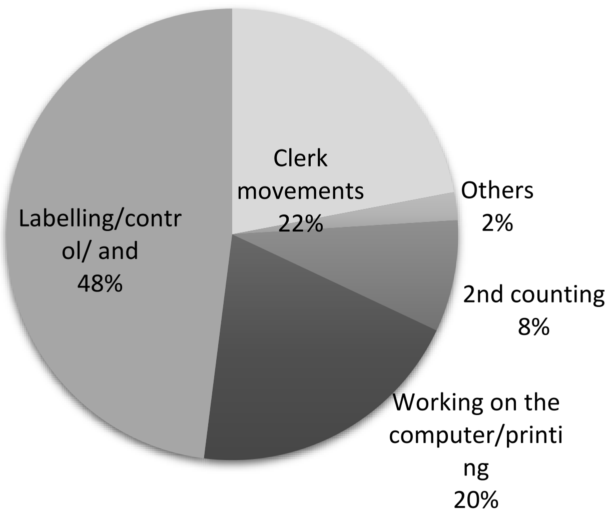


Figure 7: Ratios of time spent per operation.

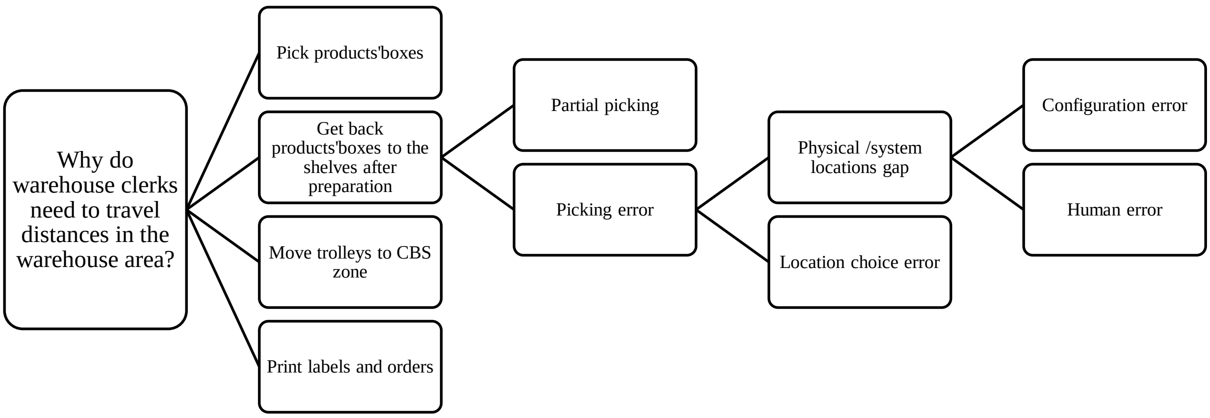


Figure 8: Five Whys classification tree of distance travelling causes.

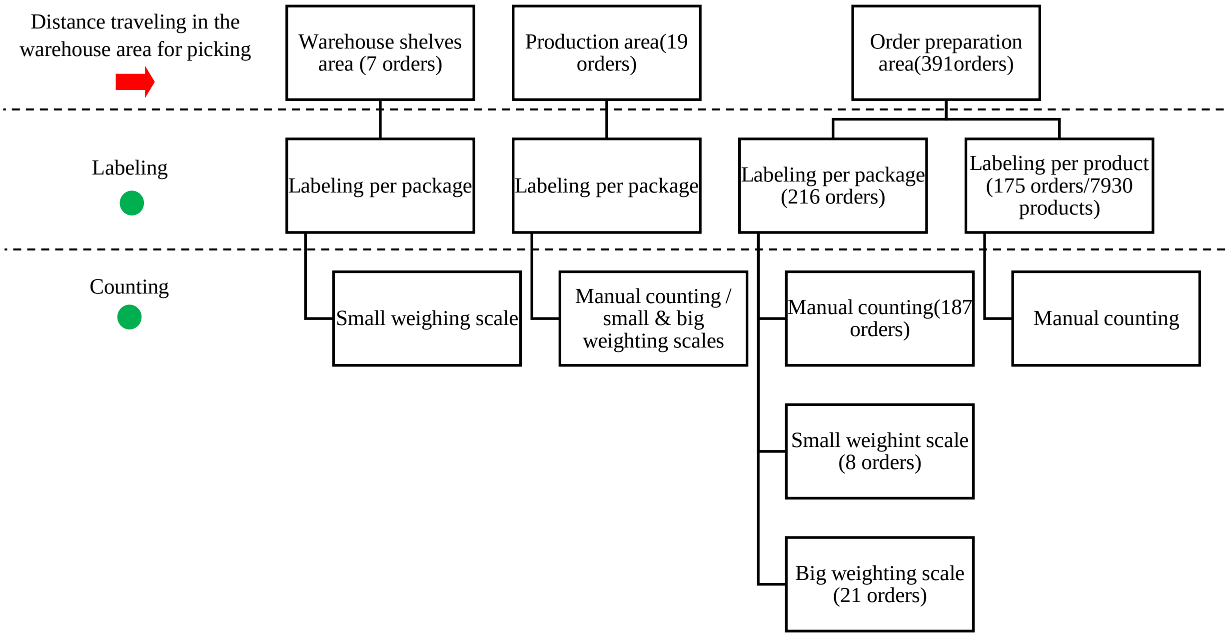


Figure 9: Classification mining tree of the order picking and preparation operations by type of value added and non-value added.

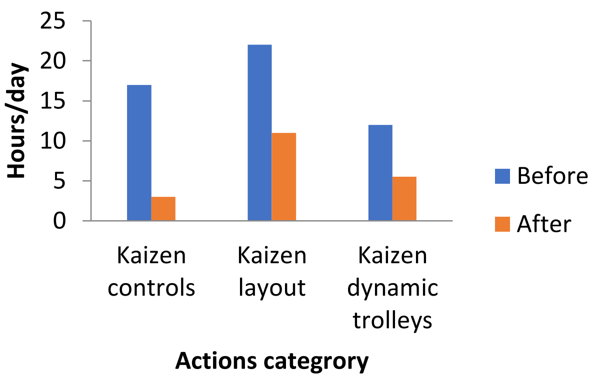


Figure 10: Simulated gained time per action category.

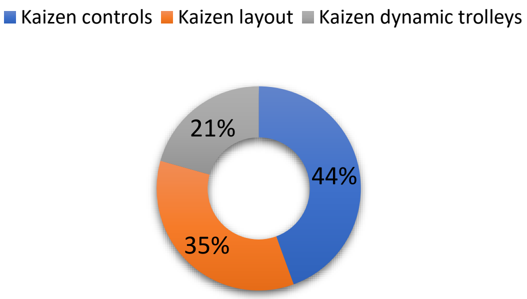


Figure 11: Synthesis of simulated gained time ratios.

Table I: Strengths and weaknesses of previous studies providing frameworks for lean warehousing

Paper	**Strengths**	**Weaknesses**
Dixit *et al*. (2020)	Increasing picking productivity and reducing error detection by mapping the picking performance measures and wastage assessment	Sequencing of the outlets to be delivered can be done more efficiently
Shah and Khanzode (2017)	Illustrating lean thinking in designing storage allocation strategy while reducing wasted space in the forward buffer	The provided logic is complicated for implementation
Harun *et al*. (2019)	A conceptual framework for the relationship between 5S lean tool, value stream mapping and warehouse performance is provided	The lean toolset used in the study is limited
Raghuram and Mahesh (2021)	A simplified design procedure for designing a lean warehouse, including picking operations, leading to effective use of resources with lean tools	Even though the lean principles are applicable in the kitting operations, the resulting change in the system should be tailor-made for each situation and requires considerable expertise in lean tools and operations management.

Tables

Table II: Research gap compared to recent papers.

Scope	Methodology	Order picking	Order packing	Functional analysis	Classification tree	Spaghetti	SADT	5 Why	CTQ	FMEA
Potentiality of productivity for manual order picking to prevent clerks from musculoskeletal disorders	Laboratory experiments to identify retrieval times for storage units located on different heights in a warehouse rack.	The scope of the study	Not considered	No	no	no	no	no	no	no
QR Code on Mobile Platform for lean factory warehouse	Operation research - smart phone’ s 3D sensor- mobile platform	The scope of the study	Considered	No	no	no	no	no	no	no
Identify waste and causes in packing processes and explore warehouse automation potential	Single case study and lean tools	Considered	The scope of the study	no	Yes	no	no	yes	No	no
achieve minimum total cost for the lean order picking system	Simulation	The scope of the study	Not considered	No	No	No	No	No	No	no

Methodology	Order picking	Order packing	Functional analysis	Classification tree	Spaghetti	SADT	5 Why	CTQ	FMEA		Authors
Heuristics	The scope of the study	Considered	No	No	No	No	No	no	no	Lean order picking	Cajner et al. (2022)
Case study and process design framework with lean tools	Considered	Considered	No	No	No	No	No	No	no		Pipatprapa (2019)
Mathematical model - framework	The scope of the study	Considered	No	No	No	No	No	No	no		Åberg (2019)
Framework SPSS - Structural Equation Modeling	Not considered	Not considered	No	No	No	No	No	No	no		Lin (2010)

Order picking	Order packing	Functional analysis	Classification tree	Spaghetti	SADT	5 Why	CTQ	FMEA		Authors	Scope
Considered	Not considered	No	no	no	no	No	no	no	Lean order picking	Kong (2007)	Design and management of lean order picking system
									Lean order packing	Raghuram and Arjunan (2022)	Develop a framework for designing a warehouse incorporating lean principles.
										Dixit et al. (2020)	Discuss picking issues pertaining to storage assignment policy affecting productivity.
										Harun et al. (2019)	Analyze the relationship between 5S lean tool, value stream mapping and warehouse performance among Malaysian manufacturing industry.

	Authors	Scope	Methodology
Lean order packing	Shah and Khanzode (2017)	designing lean buffers in forward-reserve model:	Framework – test case

Table III: CTQ analysis.

Needs	Requirements	Characteristics
Tracking	Declaration	Number of returns
Correct order, with zero anomalies	The needed reference	Number of returns
Correct label	Labels	Number of returns

Table IV: Value added flowchart.

To the stocking area+ picking	Printing + controlling	To the work station	1st piece control	1st counting	Labeling	Check list	Partial picking	CBS	2nd counting

Table V: Syntheses of time wastage.

Non-value added operation	Waste time [hour/day]
Double counting	12
Green bag control	5
Double system control	1.5
Distance traveling in order preparation area	18
Distance traveling to related areas (CBS/ trolleys)	3
Total	38

Appendices

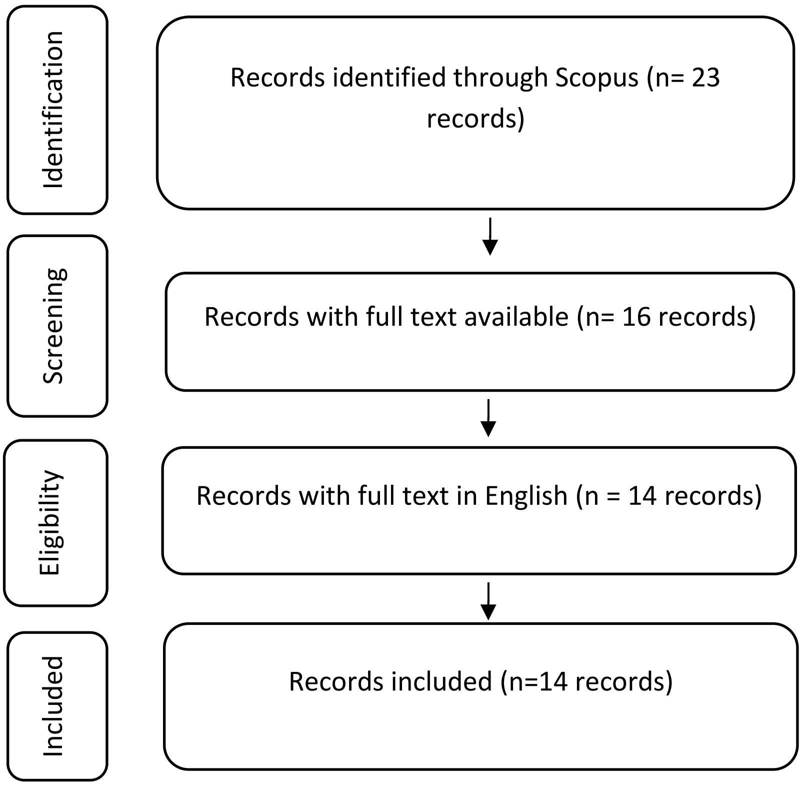
Appendix1: Number of publications per year

Year	Number of publications
2023	2
2022	6
2021	4
2020	2
2019	1
2018	2
2016	1
2015	1
2014	1
2008	1
2007	1
2004	1

Appendix2: Number of publications per country

Country	Number of publications
Peru	9
India	2
Indonesia	2
Italy	2
Poland	2
United States	2
Croatia	1
Ecuador	1
Portugal	1
Slovenia	1
Undefined	2

Appendix3: PRISMA protocol diagram



Appendix4: Comparative table of the literature review records

Paper	scope	objective	approach	key practical implications
Faccio et al. (2018)	Investigating macro and micro-logistic aspects in defining the parts-feeding policy in mixed-model assembly systems	Analysing the most effective part-feeding policy including hybrid strategies, between kanban and kitting systems	integrated approach to include both logistic levels within the part-feeding policy study for a manual mixed-model assembly system, considering the picking activities, applied to five case studies in addition to a simulation	kanban system is more suitable for small and frequently picked part, while hybrid part-feeding policy merging kanban and kitting systems are better for complex models requiring large sets of parts for their assembly
Shah (2023)	Expoloring what should be lean buffer threshold for the forward reserve warehouse	Determining the right size of Forward Buffer and investigating the impact of Forward Buffer capacity and demand variations on Forward Buffer leanness.	VSM, mathematical model with MATLAB, framework development	The customer service level increases monotonically; nevertheless , the results concerning spent efforts towards increasing customer service level gets diminished with raised demand variances

Gomes et al. (2022)	Continuous Improvement of Logistics Processes using lean tools	continuous improvement of the internal logistics processes of the production line	Plan-Do-Check-Act (PDCA) and various Lean tools, such as the Kaizen, Visual Management, Standard Work and 5S	The impact of the solutions created for the processes of picking the material and supplying it to the line was very noticeable in the duration of these tasks
Isidro et al. (2021)	warehouse management proposal under the lean warehousing philosophy	Developping a Warehouse Management Model Under the Lean Warehousing Philosophy to Reduce Product Returns in the Marketer	Creating a model with various lean warehousing tools	a reduction of the picking time from 3.5 to 1.5 h was obtained, an increase in the reliability of inventories of a 75 to 95%, an increase in operator performance from 50 to 85% and a reduction of expired products from 19 to 2%.
Cagliano et al. (2018)	Proposing a new framework for lean warehousing: first experimental validations	proposes a novel lean warehousing framework combining 5W, 5S, and VSM and presents the first outcomes of its validation campaign	Framework development and application of the framework to the warehouse of an automotive company	the proposed framework offers a generic approach that can be adapted to different situations since Its tools, i.e. 5W, 5S, and VSM, are quite intuitive and can be easily applied to any situation
Sanchez et al. (2021)	Implementation of Lean and Logistics Principles to Reduce Non-conformities of a Warehouse in the Metalworking Industry	analyzing the problem of non-conforming products in the warehouse, which affects delivery on time and perfect orders	Case study , using various lean tools such as ishikawa,and muda analysis	The implementation of VSM, 5S, wave picking, and slotting could contribute to the improvement of the performance of a warehouse by reducing waste, improving the operating procedure, and reducing non-conformities with the 5S, VSM and logistics tools.

Bonilla-Ramirez et al. (2019)	Investigating the implementation of Lean Warehousing to Reduce the Level of Returns in a Distribution Company	Resolving the problem of high levels of returns of orders to be dispatched, affecting distribution companies of the mass consumption sector	A proosed model for lean warehousing	Lean tools, although they originated in the production environment, are suitable for the warehouse environment as well.
Figueroa-Rivera E. et al. (2022)	the application of tools of the lean warehouse methodology in a 3pl warehouse	A continuous improvement model that optimizes the use of resources used in operational processes, reducing cost overruns related to excessive use of labor in the process of picking and storage	standardiza tion through 5S, route optimization with SLP, reduction of rework through FEFO, and flow optimization with operator load balancing.	increase in picking productivity by 26.7% and storage productivity by 33.8%.
Serna-Ampuero et al. (2022)	Analysing the Inventory Management under the Lean Warehousing Approach to Reduce the Rate of Returns in SME Distributors	improving warehouse management and the inventory control and recording process .	through the 5S, ABC classification, and a continuous inventory review model (Q, r)	It is expected to reduce picking search time by 53.89%. It is also expected to reduce the inaccuracy of the inventory register to 8.36% and the percentage of stock out to 8%.
Kong et al. (2008)	Investigating methods for Design and Management of a Fast-Pick Area in a Warehouse	Analysing an order picking system that was developed to apply the principles of lean manufacturing to warehouse operations.	Heuristics are described to assign SKUs to the zones and then to sequence the orders for picking so that the full benefits of the buffers can be obtained.	The performance of the system with the heuristics is shown to produce better throughput per worker than the same system with random assignments or a traditional system where orders are picked in waves.

Oey and Nofrimurti (2018).	Investigating Lean implementation in traditional distributor warehouse – a case study in an FMCG company in Indonesia	help the company under studied creating an implementation framework of warehouse management system for its traditional distributors using Lean principle	Lean warehousing techniques were used as a practical tool to introduce a good and efficient warehouse practice for its distributors	Implementation was done for the first two stages in one pilot distributor, resulting to 26% increase in picking productivity and a more balanced warehouse operation
Prasetyawan et al. (2020)	Implementation of lean warehousing to improve warehouse performance of plastic packaging company	Resolving the problem of maximizing the storage space and eliminating the floor stock for the case study	Lean warehousing with value stream mapping and process activity mapping	The warehouse performance after improvement shows that the financial and cycle time indicators decrease while utilization, quality and productivity indicators increase
Villacrez-Zelada et al. (2022)	Service Level Optimization through Lean Warehousing	This case study focuses on the application of the Lean Warehousing methodology through Demand Forecasting, Inventory Policies, and the improvement of the Picking and Packaging processes to increase service levels	The study is based on the Perfect Order indicators at a SME retailer	It is expected that, with this methodology, the company's service level will reach at least 95%, which is the minimum to be in suitable conditions to satisfy customer requirements.
Cajner et al. (2022)	Bi-objective Assignment Model for Lean Order Picking in a Warehouse	exploring the possibility of productive work while preventing order pickers from Work-Related Musculoskeletal Disorders.	laboratory experiment	determining retrieval times for units with different characteristics and study required postures by guidelines of Revised NIOSH Lifting Equation.

Appendix 5: FMEA analysis.

Risk type	Risk description	Eventual effect	Eventual causes	Evaluation				Actions	Assessment of the potential actions impact			
				Probability of detection (D)	Probability of occurrence (O)	Severity (S)	Risk Preference Number (RPN)		Probability of detection (D)	Probability of occurrence (O)	Severity (S)	Risk Preference Number (RPN)
Planing risk	Erroneous results and unrealistic planning	Undesirable project output	Underestimation of the complexity of the analysis	3	4	8	96	Continuous update of the schedule according to the state of progress	1	2	3	6
			Undervaluation of human and/or technical resources					Try to plan several tasks parallelly so as not to shift the final date of the end of the project				
Data risk	Erroneous data	Difficulty	Failure to enter	1	2	10	20	Review the reliability of the	0	0	0	0

		performing analysis	transition codes in SAP					data with the supervisor before starting the analyses				
		Incorrect analysis results	Miscalculation					Carefully revise each calculation made				
Organizational risks	Refusal of proposed improvement actions	Actions not performed	Expensive solution	4	6	7	168	Perform a quantified study of the various gains generated by the proposed solution in terms of costs, time, profitability, as well as a study of non-measurable gains	4	5	5	100
		No real added value in relation to the company	Refusal to perform additional tasks due to process change									