A Design Science – Informed Process for Lean Warehousing Implementation

Anna Corinna Cagliano[1[0000-0002-6283-1518]], Giovanni Zenezini[1[0000-0002-0996-6739]], Carlo Rafele[1[0000-0002-4464-6992]], Sabrina Grimaldi[1[0000-0002-0421-9654]] and Giulio Mangano[1[0000-0002-2792-505X]]

[1] Department of Management and Production Engineering, Politecnico di Torino, Corso Duca Degli Abruzzi. 24, 10129 Torino, Italy
anna.cagliano@polito.it,giovanni.zenezini@polito.it, carlo.rafele@polito.it, sabrina.grimaldi@polito.it, giulio.mangano@polito.it

Abstract. Warehouses usually include a number of non-value-added activities that increase costs, so they are a suitable field for applying Lean Thinking. In fact, Lean Warehousing has recently established as a promising research topic. However, most of the available contributions lack a practical though generalizable and theoretically relevant approach. Additionally, Lean is currently not enough explored as a preliminary effort to pave the way for a smooth application of Industry 4.0, neither in manufacturing nor in logistics. Inspired by Desing Science Research, the present work develops a structured process for implementing Lean Warehousing aimed at fostering continuous improvement to facilitate the introduction of Industry 4.0 technologies. To this end, multiple Lean tools, such as Value Stream Mapping, Spaghetti Chart, 5W+1H, and 5S analysis, are integrated. The application to a warehouse in the food industry is illustrated. Future research will focus on carrying out a complete validation. Moreover, performance measurement through a set of warehouse Key Performance Indicators will be introduced to assess both wastes and the associated improvements after implementing the appropriate corrective actions.

Keywords: Lean Warehousing, Design Science, Implementation Strategy, Industry 4.0.

1 Introduction

Nowadays the growing complexity of supply chains (SCs), mainly due to heterogeneous operational tasks and multiple partners sometimes with very distant geographical locations, introduces several non-value-added activities that hinder the related performances [1]. In this context, Lean Thinking principles have played a key role to streamline and optimize entire SCs in the last decade [2, 3]. A "Lean SC" can be defined as a set of suppliers and customers linked by flows of products, services, technologies, information, and money, with the aim of reducing costs and waste as well as minimizing the non-value added activities and thus increasing value to SC agents [4].

From a structural point of view, suppliers and customers are connected by a network whose nodes are represented by manufacturing plants and warehouses. In particular, warehouses constitute key SC nodes, representing the second expenditure item in overall logistics costs after transportation. Additionally, warehouse operations largely contribute to determine the SC customer service level, economic performance, and business competitiveness [5].

However, within SC processes, warehousing is often perceived as the "weak link" comprising several non-value-added activities that drain costs and efforts from companies. In fact, warehousing might include useless material movements or excessive stocks. For such a reason, warehouses are an interesting subject to be studied by applying the Lean SC concept, in order to optimize the associated costs and time [6]. These issues, together with the awareness that warehouses cannot be completely eliminated from SCs [7], being a vital connection among their echelons, paved the way to Lean Warehousing [8]. Lean Warehousing has emerged in the last ten years as a very relevant topic in Lean Thinking [9, 10]. It applies Lean concepts and tools to traditional warehouse management with the aim of enhancing the quality of the logistics service by optimizing the use of the available resources and activities through the reduction, when not the elimination, of wastes [11]. In such a way, Lean Warehousing helps achieving efficiency, which is a more and more compelling need to streamline processes in order to prepare them for the application of Industry 4.0 technologies, such as for instance Advanced Automation and Virtual and Augmented Reality, to warehouses [12]. In fact, it was proven that Lean and Industry 4.0 technologies can mutually benefit each other. The Lean culture helps strengthening the effects brought by Industry 4.0 technologies, which in turn increase the effectiveness of Lean approaches [13].

However, several organizations are having a difficult time adopting Lean SC practices due to a scarce awareness and lack of proper implementation strategies [14]. The present work is based on Design Science Research (DSR) and proposes a structured process for applying Lean Warehousing in order to address and remove all those criticalities that might hinder the success of Industry 4.0 technologies prior to their implementation in a warehouse environment. DS can be currently considered a frontier in Operations Management (OM) research, still dominated by the explanation approach, rather than the exploration, problem solving-oriented one [15, 16]. Grounded in Herbert Simon's work [17], DSR develops a solution to a practical problem, named "artifact", based on a specific practice setting. After that, the findings are generalized in order to prove the theoretical relevance of the solution.

The goal of the contribution is twofold. First, it promotes a structured integration of several Lean tools to create the necessary logistics process settings and mindset to support a smooth implementation of Industry 4.0 in warehouses. Second, it aims at providing an application of DSR to warehouse management, one OM field where this approach is still pretty much unconsidered. In this way, the present work contributes to develop a culture of finding solutions to problems rather than only focusing on the explanation of them in OM. The developed Lean Warehousing process is discussed following the main DSR phases.

2 Research Background

2.1 Warehouse Management and Lean Warehousing

Warehouse management is a stream of research that has been long debated in literature from different perspectives, such as warehouse physical design, including material handling and storage systems, inventory management, storage allocation policies, product tracking, and performance measurement [18]. Most of the works are focused on meeting the main warehouse challenges in terms of enhanced productivity, a decreased number of defects, improved customer satisfaction, as well as stock and operational costs reduction. This can be summarized in just one phrase: "a need for efficiency" [19]. Therefore, in order to accomplish such a goal, it is quite straightforward to try to apply Lean Thinking to warehouse management, which have originated the Lean Warehousing topic [8].

A significant number of authors have developed literature contributions about Lean Warehousing so far. Among the most recent ones, a number of them provide classifications of warehouse wastes based on the Ohno's taxonomy [20] and the main warehouse activities, namely receiving, put away, picking, and dispatching activities [2, 9, 11, 21]. Other authors implement specific Lean tools, either in a single or in a combined way. Value Stream Mapping (VSM) is by far the most commonly applied tool. [9] relies on VSM for developing solutions to reduce a number of warehouse wastes and assessing the associated benefits through lead time assessment. [22] combine VSM with Spaghetti Chart and Multi-Criteria ABC Analysis to address the material handling problems derived from a poor warehouse layout design. [23] use again VSM and Multi-Criteria ABC Analysis, but together with 5S, Gemba, and Work Standardization tools, to improve inventory management so that to increase the delivery compliance indicator of a warehouse in the metalwork sector. Recently, [24] combine VSM with Discrete Event Simulation for the case of a warehouse in the pharmaceutical sector. Finally, another recent attempt to undertake a wide perspective on Lean Warehousing has been carried out by [25], who select the Lean Six Sigma approach to focus on all the warehouse processes of a third party logistics with the ultimate goal to increase productivity.

Lean Warehousing works usually lack a perspective on the interconnection between Lean Thinking and Industry 4.0, although it has been the subject of a significant number of recent contributions in the manufacturing field (e.g. [26]). In particular, as highlighted by [27, 28], most of the research efforts have been spent on how digitalization, underpinning the Industry 4.0 notion, can support the application of Lean but how Lean principles can facilitate the introduction of Industry 4.0 is a topic that still deserve further attention. This is the debate the present research aims to contribute to through a lens which is still quite rare in OM research in general, and in warehouse management in particular, namely DSR [16]. The motivation for choosing such an approach is that companies need detailed and structured methods that can be implemented to streamline warehouse processes, where many wastes can be nested, and to be able to get full benefits from the application of Industry 4.0 technologies.

2.2 The Design Science Approach

The DS approach lies at the intersection between problem solving and explanatory science to explore, create, and test solutions (the so called "artifacts") to problems with a practical relevance [16]. It is not opposed to explanatory research but it complements it. In fact, its four steps are as follows, where the first two ones pertain to exploratory research while the last two are part of explanatory research [29]:

- Solution incubation: the problem to be tackled is framed and a first potential solution is designed.
- Solution refinement: the solution is subjected to empirical testing, usually in one real setting, and refined.
- Explanation I – substantive theory: the theoretical relevance of the solution is established in order to understand to what research discourse it contributes to. It usually involves introducing the solution in multiple settings. A DSR effort may stop at this step.
- Explanation II – formal theory: strengthening the theoretical and statistical generalizability of the solution to derive a formal theory from it.

By following the present methodological approach, the next sections develop a Lean Warehousing process that can be implemented by organizations to support them to improve their logistics processes and eliminate wastes prior to the adoption of Industry 4.0 technologies. The Explanation I phase is performed by discussing the theoretical relevance of the proposed Lean process based on its comparison with literature evidence. The Explanation II phase has not been carried out at the moment.

3 Solution Incubation: the Lean Warehousing Process

The first DSR step is understanding the problem to solve. This is here drawn from a schematic summary of the outcomes of the literature review discussed in Section 2.1:

- Many authors have developed Lean Warehousing approaches to achieve efficiency. Several of them rely on an integrated application of multiple Lean tools. However, they are intended to meet several goals, such as for instance reducing congested warehouse routes or increasing the customer order fulfillment rate, but none of them is specifically aimed at preparing warehouse processes to Industry 4.0 implementation.
- Practical approaches are needed providing companies with guidelines about how to apply Lean Thinking to pave the way for Industry 4.0.

Thus, the problem can be posed as: *how could a detailed Lean Warehousing process be structured in order to address and eliminate wastes in a systematic way as a preliminary step towards Industry 4.0?*

The Lean Warehousing process presented in this contribution, thus the "artifact" produced in the DSR effort, has been developed starting from the preliminary works of

[30] and [31]. It consists of three interconnected steps that form a closed loop coherent with a continuous improvement effort (Figure 1):

1. Process Mapping.
2. Waste Identification and Analysis with 5W+1H.
3. Improvement Action Definition with 5S and Associated Assessment.

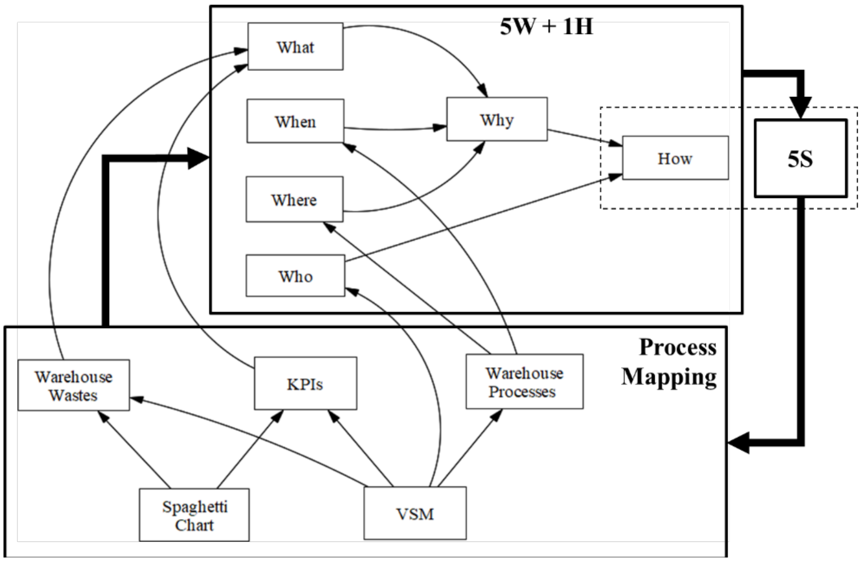

Fig. 1. The proposed Lean Warehousing Process

3.1 Step 1: Process Mapping

The first step of the Lean Warehousing Process is devoted to map the current situation of warehouse processes with the aim of identifying and assessing the existing wastes. This is performed through two selected Lean tools, namely the VSM and the Spaghetti Chart [32, 33].

Once the wastes have been identified, their current effects on warehouse performances are assessed by KPIs selected according to the nature of the affected activities and the related kinds of inefficiencies as highlighted by the VSM and the Spaghetti Chart. The values of these measures (i.e. time, distance KPIs, etc.) will be compared with the ones after the application of improvement actions (Section 3.3) to estimate the benefits provided by the process implementation.

3.2 Step 2: Waste Identification and Analysis with 5W+1H

In the second step of the Lean Warehousing process the existing warehouse situation is analyzed, focusing on identifying the causes for wastes. Here the wastes in warehouse operations are investigated and classified and such an activity has to be carried out after an accurate process mapping. The causes for wastes are assessed via the 5W

+ 1H tool [34]. This method allows to give an exhaustive overview of the warehouse wastes by answering the following questions:

- What happens (What)?
- What is the source of the waste (Where)?
- Who is the person in charge (Who)?
- When in the process does the waste occur (When)?
- What are the reasons for the waste occurrence (Why)?
- What suggestions for improvements are needed to be done (How)?

Inputs for the 5W + 1H analysis stem from the VSM and the Spaghetti Chart. Hence, each warehouse waste is associated with its type according to the Ohno's classification [20] in the "What" section of the 5W + 1H tool, together with a quantification of the waste impact via a suitable KPI. Furthermore, the VSM tool supports the framing of the warehouse processes, which in turn highlights the locations where the wastes occur, both in terms of spatial location ("Where) and time-wise ("When"). Finally, the VSM identifies the responsible for each process, hence outlining the "Who" of the wastes. After process mapping and the analysis of the first 4Ws, there are enough informational data to gather insights and proceed onto framing the underlying reasons for waste occurrence ("Why") and finally set up a response for waste reduction and elimination ("How"). This last step of the 5W + 1H is often times left to the creativity of the warehouse management. The authors propose a more structured approach for this step in the following sub-section.

3.3 Step 3: Improvement Actions Definition with 5S and Associated Assessment

The proposed Lean Warehousing process completes the "How" phase of the 5W+1H analysis by relying on a fourth Lean tool, namely the 5S analysis . It unfolds through five steps, Sort, Straitening, Shining, Standardizing, and Sustaining, that not necessarily are applied in a consecutive way [23]. Such steps suggest the main intervention areas to be addressed to reduce and control waste. Thus, they offer guidelines for formulating improvement actions and help defining standard processes and ensuring continuous improvement according to the Kaizen philosophy. Only selected "Ss" can be considered according to the nature of processes and wastes.

The effectiveness of the improvement actions should then be monitored and, to this end, the present Lean Warehousing process suggests again undertaking the Process Mapping step and updating the VSM and the Spaghetti Chart after their implementation. On the one hand this will support assessing the benefits introduced by the process application. On the other end, a new analysis of warehouse processes will allow uncovering further waste that should be approached.

4 Lean Warehousing Process Implementation and Refinement

The proposed Lean Warehousing process has been refined by applying it to a company operating a chain of grocery stores in North Eastern Italy and seeking to prepare its logistics processes to Industry 4.0 implementation. This company employs around 1,700 workers and sells products via a network of 69 shops. The authors took part in a 6-months process of Lean implementation in the largest warehouse of the company, working as part of a Project Team including the warehouse managers and workers and continuously receiving feedbacks from them in an iterative process.

4.1 AS IS Situation and Waste Analysis

The authors have focused on non-perishable and fresh processed food products. Fresh groceries have not been considered because they are just cross-docked to the shop within few hours from the arrival at the docking bay. As part of Step 1 of the process, Figure 2 shows the current VSM for non-perishable products including the main warehouse processes. In order to draw this state map the notation by [35] was adopted and several steps were undertaken, namely:

- The stakeholders were identified and assigned to the different tasks and responsibilities. Three stakeholders take part in the warehousing process, namely the Supplier, the Buyer (i.e. the shop) and the Purchasing Department.
- The ordered quantities and the daily shipments are retrieved from the company. Data showed that these two quantities are almost equal, as the percentage of backlog orders is very close to non-existing and can be neglected.
- Warehouse processes are identified and are differentiated between processes entailing continuous product flows and processes which contain an interruption of the product flow. Interruption of the flows are associated with accumulation of stock, which in turn is one of the most relevant waste of a warehouse.
- Data are compiled for each process. In particular, the cycle time and the number of employees are associated with each warehouse process.
- Each warehouse process is associated with its guiding principle. Processes from orders receiving to stowing follow a “push” principle guided from the Purchasing Department, while processes from picking to shipping are driven by the customers’ orders and are thus associated with a “pull” principle.
- Finally, each process is timed differentiating between value added and non value-added processes. The overall warehouse lead time is calculated as the summation of all the warehouse processes.

The time to perform the picking and packaging tasks is remarkably higher than the time needed to carry out the other warehouse activities because one roll pallet, delivered to a given shop, is constituted by heterogeneous products in very different quantities.

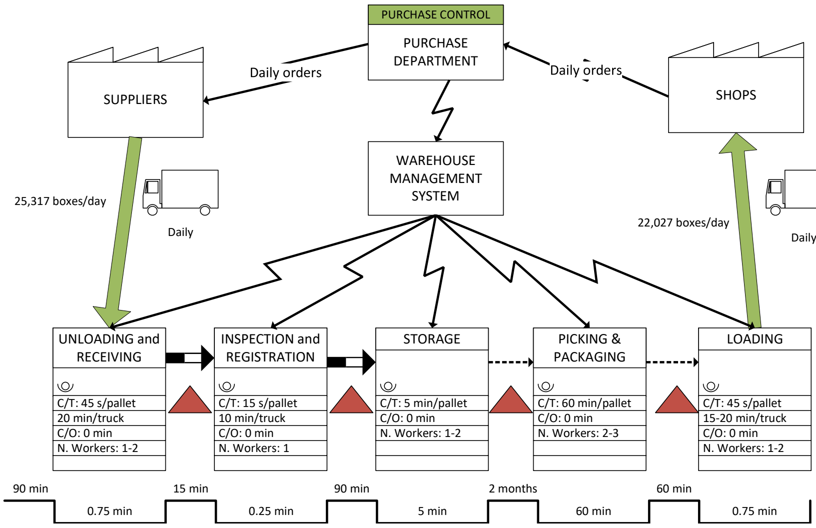

Fig. 2. Current State VSM for non-perishables

Hence, three cycle times are calculated through the current state map analysis: i) time for value-added processes; ii) time for non-value-added processes; iii) total warehouse lead time. For non-perishable products they are equal to 66 minutes and 45 seconds, 255 minutes, and 321 minutes and 45 seconds respectively. For fresh processed products these time values are 66 minutes and 45 seconds, 235 minutes, and 301 minutes and 45 seconds. Such values have been computed by the Project Team through direct observation of activities and recording of the associated time. The non-value-added time does not include the average time products remain stocked in the warehouse. This comes from specific company policies and was out of the scope of the present application.

A Spaghetti Chart of the general movements of warehouse workers has been drafted by observing daily operations across different days of the week. The Spaghetti Chart cannot be disclosed here due to the confidentiality of the complete warehouse layout. The Spaghetti Chart tool allows for calculating the minimum and maximum distance travelled by the warehouse personnel for the different warehouse activities, as shown in Table 1.

Table 1. Estimation of travelled distances via the AS IS Spaghetti Chart.

Warehouse Activity	Minimum Distance [m]	Maximum Distance [m]
Unloading Non-Perishable Products	5	20
Unloading Fresh Products	17	45
Stocking Non-Perishable Products	35	180
Stocking Fresh Products	10	70
Picking Non-Perishable Products	-	607

Picking Fresh Products	-	595
Shipping Non-Perishable Products	40	83
Shipping Fresh Products	32	67
Truck Loading Of All Products	5	20

Furthermore, the Spaghetti Chart analysis reveals that there are some areas of the warehouse where multiple paths of the workers overlap, creating potential wastes. In particular, flows overlap where goods are stored waiting to be shipped and at the entrance of the controlled temperature section of the warehouse where perishable products are stored. The identification of overlapping flows enables to identify a first layer of warehouse wastes. This type of wastes can only be overcome through a reengineering of the warehouse layout. Both Spaghetti Chart and direct observation were used as methods to identify wastes and assess their causes in Step 2 of the process. The wastes are as follows:

- Long Waiting Time for Truck to Access Receiving Docks
- Long Waiting Time of Incoming Pallets before Storage
- Poor Attention to Storage Priority
- Long Waiting Time of Outgoing Pallets before Shipping
- Incorrect Positioning of Outgoing Pallets

A sixth type of waste was identified in the damages suffered by the products being handled, and was found to be caused by the overlapping of workers' movements in the controlled temperature area detected through the Spaghetti Chart. This waste was however deemed to not be relevant due to its negligible impact on the company's performance. Table 2 shows an excerpt from the performed 5W+1H analysis focusing on the waste "Long Waiting Time for Truck to Access Receiving Docks". The complete analysis is available from the authors upon request. It is worth reminding the reader that the HOW phase of the analysis will be performed in Step 3 of the process.

Table 2. Excerpt from 5W analysis of warehouse wastes.

Waste	5W step	Description
Long Waiting Time for Truck to Access Receiving Docks	WHAT	Waste Type: Waiting Description: Trucks wait before connecting to an available unloading bay. KPI: Average truck waiting time = 1.5 hours
	WHEN	Warehouse process: Receiving Warehouse sub-process: Prior to the unloading process
	WHERE	In the loading/unloading yard
	WHY	Insufficient number of unloading bays and workers; Lack of scheduling for truck arrival
	WHO	Purchasing Department

4.2 Waste Reduction - Identification of Improvement Actions with 5S

The aim of Step 3 of the Lean Warehousing process is defining improvement actions to reduce waste based on the outcomes of the analysis of the associated causes carried out through the 5W+1H methodology. To this end, the 5S approach was applied to the wastes identified for the case warehouse through several brainstorming sessions involving the Project Team. Table 3 presents an excerpt from the outcomes of such a process: only the relevant 5S steps are mentioned. Different integrated actions are suggested for each waste. The complete analysis is available from the authors upon request.

Table 3. Excerpt from 5S analysis of warehouse wastes.

Waste	5S step	Improvement action
Long Waiting Time for Truck to Access Receiving Docks	Sort	Moving the outgoing pallets placed in the receiving area, so as not to occupy the receiving docks
	Set in Order	Revising the schedule of the incoming trucks and making it coherent with the shipping schedule
	Standardize	Implementing an online system where suppliers can book their delivery time within predefined time slots. This is completed by a GPS tracking system to detect any truck delay
	Sustain	Disseminating the new procedures and checking their application periodically

An ex-ante assessment has been then carried out to evaluate the proposed improvement actions in terms of time and physical flow savings. As an example of the adopted approach, the following analysis is focused on the three wastes that most impact the non-value-added time, namely Long Waiting Time for Truck to Access Receiving Docks, Long Waiting Time of Incoming Pallets before Storage, and Long Waiting Time of Outgoing Pallets before Shipping.

An online supplier delivery booking system has been proposed in order to reduce the waiting time for an available receiving dock. The Project Team estimated that up to 5 truck arrivals can be scheduled every 20 minutes because the warehouse is equipped with 5 receiving docks and 20 minutes is the average unloading time computed based on a direct observation of this operation. Such a solution allows to reduce the average truck waiting time from 90 minutes to 20 minutes in case of delays in unloading the previous truck at a same dock. However, the waiting time might be even shorter thanks to a GPS tracking system that enables addressing delays by rescheduling the next arrivals. Coming to the goods waiting time before storage, increasing the number of workers assigned to storing activities is the identified solution. The associated time savings cannot be calculated in an ex-ante assessment, thus they were estimated through expert judgment. In particular, according to the Warehouse Manager, the waiting time after implementing this improvement action can be reduced from 90 to 30 minutes per each single pallet. Finally, the solutions to reduce the waiting time of pallets before being shipped to shops mainly rely on placing the goods close to the dock area shortly before the truck arrival. The time savings were estimated to be equal to 20 minutes and 30 minutes for fresh processed and non-perishable products respectively. It is very important to be able to reduce the waiting time of fresh products since, being perishable goods, they stop outside the cold room during this time and the cold chain is interrupted.

The time savings introduced by the discussed improvement actions originate important reductions in the overall warehouse lead time and this can be highlighted by the Future State VSM. As already done for the current state analysis, two VSMs are developed for both fresh processed and non-perishable products. Table 4 summarizes the expected value-added time, non-value-added time, and total warehouse lead time for each single pallet, together with the percentage decrease compared with the current values. Future state VSMs are available from the authors upon request.

Table 4. TO BE time and savings.

Fresh Processed food		
	TO BE	DELTA
Value-added time	66 minutes and 45 seconds	0%
Non-value-added time	85 minutes	-41.4%
Warehouse lead time	151 minutes and 45 seconds	-28.4%
Non-perishables		
	TO BE	DELTA
Value-added time	66 minutes and 45 seconds	0%
Non-value-added time	95 minutes	-42.4%
Warehouse lead time	161 minutes and 45 seconds	-30.3%

In order to complete the analysis of the future warehouse situation, an ex-ante assessment of the staff movements after the potential application of the proposed improvement actions has been carried out and a Future State Spaghetti Chart drawn. In particular, moving outgoing pallets from the receiving area to the shipping one (Incorrect Positioning of Outgoing Pallets waste) allows to remove the overlaps in the staff flows that occurred in the area where goods are stored waiting to be shipped. Correctly placing outgoing pallets in the shipping area also originates relevant changes in the distances traveled by staff, as revealed by the quantitative evaluation of physical flows in the future warehouse situation. To be more precise, the minimum distance travelled to place outgoing fresh processed products increases from 40 m in the current situation to 60 m in the TO BE one, while the maximum distance to place non-perishable products decreases from 67 m to 45 m. However a significant flow streamline can be gained. All the other physical flows do not show any significant variations from the current state to future state configuration. Also the future state Spaghetti Chart cannot be disclosed for confidentiality reasons.

5 Relevance of the Proposed Lean Warehousing Process

As the third step of a DSR approach, the findings should be generalized and the theoretical contribution demonstrated. Currently, such a phase has not been completed yet, thus the relevance of the proposed Lean Warehousing process is here discussed based on literature evidence.

First, the relevance lies in the underlying research methodology. Through the development of the Lean Warehousing process the authors offer an application of DSR in OM and in particular in warehouse management. If DSR in OM is still in its infancy [36, 37], it is even more in the field of warehousing, where, to the best authors' knowledge, no works exist. However, DSR could be highly beneficial in the logistics field, whose problems have practical roots and might find viable and effective solutions through a research approach that is centered around the real needs of professional practice. Adopting DSR in Lean Warehousing is also a way of introducing practical but also generalizable approaches for the application of Lean Thinking to warehouse management. In fact, the available literature either offers theoretical guidelines for the implementation of Lean in warehouses and the associated performance assessment [11] or focuses on case studies driven by the particular situations of specific organizations [7, 22].

Second, the authors think the relevance of the present research is also related to suggesting a detailed roadmap about how to streamline warehouse and logistics process to make them ready to get full benefits from Industry 4.0 technologies. Thus, it helps closing the research gap on the role of Lean as an endeavor that should start before the application of digital technologies [13, 28] to then continue after it to always ensure an appropriate operational environment.

6 Implications and Conclusions

This study offers both theoretical and practical implications.

From an academic point of view, as discussed in Section 5, it not only contributes to advance the state of the art about Lean Warehousing but also promotes research on integrating it with DSR. The presented process and its discussed application provide researchers with guidelines about structuring Lean Warehousing approaches. In this way, they foster deepening the knowledge of how Lean principles can positively affect not only production but also logistics flows, with the aim of preparing them to Industry 4.0 application.

From a practical perspective, both manufacturing and logistics companies can benefit from the Lean Warehousing process. First of all, it might constitute for managers a ready-to-go approach to assess and improve their warehouse processes. The wastes discussed in the implementation help organizations to identify their own warehouse wastes by suggesting those activities that might be investigated. Then, the Lean improvement actions could offer companies a chance to leverage the implementation of Industry 4.0 technologies in logistics. Therefore, the Lean Warehousing process can become a means to approach the so-called Logistics 4.0 in an informed manner and not just by following a trend. In a nutshell, relying on structured methods to seek continuous improvement in warehouses is of paramount importance for their managers. In fact, as a front end towards the next SC echelon, warehouses need to always guarantee responsiveness by trying to "absorb" those delays and inefficiencies originating upstream in the chain.

However, so far the proposed Lean Warehousing process has undergone just one single application. Moreover, the devised improvement actions were not implemented and the related benefits were estimated according to the company experts' knowledge and experience.

Future research efforts will be directed towards testing the process in multiple industries and warehouse settings in order to completely validate and refine it. Particular attention will be given to the actual implementation of the proposed actions to either limit or remove wastes, with the aim of fully capturing the effectiveness of the approach. The possible integration of additional Lean tools in the process will be explored as well, together with the introduction of a catalogue of warehouse KPIs to measure both AS IS wastes and their reduction after the process application.

References

1. Jasti, N.V.K., Kurra, S.: An empirical investigation on lean supply chain management frameworks in Indian manufacturing industry. Int. J. Product. Perform. Manag. 66, 699–723 (2017).
2. Buonamico, N., Muller, L., Camargo, M.: A new fuzzy logic-based metric to measure lean warehousing performance. In: Supply Chain Forum: An International Journal. pp. 96–111. Taylor & Francis (2017).
3. Arif-Uz-Zaman, K., Nazmul Ahsan, A.M.M.: Lean supply chain performance measurement. Int. J. Product. Perform. Manag. 63, 588–612 (2014).
4. Librelato, T.P., Lacerda, D.P., Rodrigues, L.H., Veit, D.R.: A process improvement approach based on the value stream mapping and the theory of constraints thinking process. Bus. Process Manag. J. 20, 922–949 (2014). https://doi.org/10.1108/BPMJ-07-2013-0098.
5. Kembro, J.H., Norrman, A., Eriksson, E.: Adapting warehouse operations and design to omni-channel logistics: A literature review and research agenda. Int. J. Phys. Distrib. Logist. Manag. 48, 890–912 (2018). https://doi.org/10.1108/IJPDLM-01-2017-0052.
6. Dotoli, M., Epicoco, N., Falagario, M., Costantino, N., Turchiano, B.: An integrated approach for warehouse analysis and optimization: A case study. Comput. Ind. 70, 56–69 (2015).
7. Shah, B., Khanzode, V.: Designing a lean storage allocation policy for non-uniform unit loads in a forward-reserve model: An enterprise information management with an e-decision support system. J. Enterp. Inf. Manag. 31, 112–145 (2018). https://doi.org/10.1108/JEIM-01-2017-0018.
8. Sharma, S., Shah, B.: Towards lean warehouse: transformation and assessment using RTD and ANP. Int. J. Product. Perform. Manag. 65, 571–599 (2016).

9. Abhishek P.G, Pratap, M.: Achieving Lean Warehousing Through Value Stream Mapping. South Asian J. Bus. Manag. Cases. 9, 387–401 (2020). https://doi.org/10.1177/2277977920958551.
10. Raghuram, P., Arjunan, M.K.: Design framework for a lean warehouse – a case study-based approach. Int. J. Product. Perform. Manag. 71, 2410–2431 (2022). https://doi.org/10.1108/IJPPM-12-2020-0668.
11. Abushaikha, I., Salhieh, L., Towers, N.: Improving distribution and business performance through lean warehousing. Int. J. Retail Distrib. Manag. 46, 780–800 (2018).
12. Mahdavisharif, M., Cagliano, A.C., Rafele, C.: Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review. Appl. Sci. 12, (2022). https://doi.org/10.3390/app12020586.
13. Frecassetti, S., Ferrazzi, M., Portioli-Staudacher, A.: Lean as a Facilitator for AGVs Implementation: A Case Study. (2023). https://doi.org/10.1007/978-3-031-25741-4_10.
14. Tortorella, G.L., Miorando, R., Tlapa, D.: Implementation of lean supply chain: An empirical research on the effect of context. TQM J. 29, 610–623 (2017). https://doi.org/10.1108/TQM-11-2016-0102.
15. van Aken, J., Chandrasekaran, A., Halman, J.: Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management. J. Oper. Manag. 47–48, 1–8 (2016). https://doi.org/10.1016/j.jom.2016.06.004.
16. Romme, A.G.L., Holmström, J.: From theories to tools: Calling for research on technological innovation informed by design science. Technovation. 121, (2023). https://doi.org/10.1016/j.technovation.2023.102692.
17. Simon, H.A.: The Sciences of the Artificial. 3rd, (1996).
18. Ramirez, C., Neuenfeldt, A.L., Siluk, J.C., de Ataíde, L.: A literature overview about warehouse management. Int. J. Logist. Syst. Manag. 42, 153–175 (2022). https://doi.org/10.1504/IJLSM.2022.124184.
19. Kolinski, A., Sliwczynski, B.: EVALUATION PROBLEM AND ASSESSMENT METHOD OF WAREHOUSE PROCESS EFFICIENCY. In: Proceedings of the 15th International Scientific Conference Business Logistics in Modern Management, October 15, 2015. pp. 175–188. , Osijek, Croatia (2015).
20. Ohno, T.: Toyota Production System: Beyond Large-Scale Production. Productivity Press, New York (1988).
21. Salhieh, L., Altarazi, S., Abushaikha, I.: Quantifying and ranking the “7-Deadly” Wastes in a warehouse environment. TQM J. 31, 94–115 (2019).
22. Aksütoğlu, A., Bıkmaz, E., Sırkıntı, N.E., Pala, M.Ö., Ekinci, E.: Lean Warehouse Application in a Meat Producer Company. (2021). https://doi.org/10.1007/978-3-030-62784-3_76.
23. Anton, A., Roque, M., Ramos, E.: Lean Warehousing Model to improve the Order Fulfillment in a Metalworking Company. In: ACM International Conference Proceeding Series. pp. 90–95 (2022). https://doi.org/10.1145/3568834.3568881.
24. Abideen, A., Mohamad, F.B.: Improving the performance of a Malaysian pharmaceutical warehouse supply chain by integrating value stream mapping and

discrete event simulation. J. Model. Manag. 16, 70–102 (2021). https://doi.org/10.1108/JM2-07-2019-0159.
25. Adeodu, A., Maladzhi, R., Kana-Kana Katumba, M.G., Daniyan, I.: Development of an improvement framework for warehouse processes using lean six sigma (DMAIC) approach. A case of third party logistics (3PL) services. Heliyon. 9, (2023). https://doi.org/10.1016/j.heliyon.2023.e14915.
26. Rossini, M., Costa, F., Tortorella, G.L., Portioli-Staudacher, A.: The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers. Int. J. Adv. Manuf. Technol. 102, 3963–3976 (2019). https://doi.org/10.1007/s00170-019-03441-7.
27. Buer, S.-V., Strandhagen, J.O., Chan, F.T.S.: The link between industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda. Int. J. Prod. Res. 56, 2924–2940 (2018). https://doi.org/10.1080/00207543.2018.1442945.
28. Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J., Martínez-Jurado, P.J.: Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review. Int. J. Prod. Res. 58, 5034–5061 (2020). https://doi.org/10.1080/00207543.2020.1743896.
29. Holmström, J., Ketokivi, M., Hameri, A.-P.: Bridging practice and theory: A design science approach. Decis. Sci. 40, 65–87 (2009). https://doi.org/10.1111/j.1540-5915.2008.00221.x.
30. Mustafa, M.S., Cagliano, A.C., Rafele, C.: A proposed framework for lean warehousing. Pioneer. Solut. Supply Chain Perform. Manag. Concepts, Technol. Appl. 137–149 (2013).
31. Cagliano, A.C., Grimaldi, S., Schenone, M.: Proposing a new framework for lean warehousing: First experimental validations. In: Proceedings of the Summer School Francesco Turco (2018).
32. Bait, S., Di Pietro, A., Schiraldi, M.M.: Waste Reduction in Production Processes through Simulation and VSM. Sustainability. 12, 3291 (2020).
33. Al-Zubaidi, S.Q.D., Coli, E., Fantoni, G.: Automating Production Process Data Acquisition Towards Spaghetti Chart 4.0. Int. J. Ind. Eng. Manag. 13, 145–157 (2022). https://doi.org/10.24867/IJIEM-2022-3-308.
34. Petrillo, A., De Felice, F., Zomparelli, F.: Performance measurement for world-class manufacturing: a model for the Italian automotive industry. Total Qual. Manag. Bus. Excell. 30, 908–935 (2019).
35. Chen, J.C., Cheng, C.-H., Huang, P.B., Wang, K.-J., Huang, C.-J., Ting, T.-C.: Warehouse management with lean and RFID application: a case study. Int. J. Adv. Manuf. Technol. 69, 531–542 (2013).
36. Dresch, A., Lacerda, D.P., Cauchick-Miguel, P.A.: DESIGN SCIENCE IN OPERATIONS MANAGEMENT: CONCEPTUAL FOUNDATIONS AND LITERATURE ANALYSIS. Brazilian J. Oper. Prod. Manag. 16, 333–346 (2019). https://doi.org/10.14488/BJOPM.2019.v16.n2.a13.
37. Su, S.-L.I., Fan, X., Shou, Y.: A design science-based case study of retail chain delivery operations and its implications. Int. J. Phys. Distrib. Logist. Manag. 51, 212–235 (2021). https://doi.org/10.1108/IJPDLM-11-2019-0352.