Proposing a new framework for lean warehousing: first experimental validations

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Abstract: Lean principles have been increasingly adopted in manufacturing over the last decades and they have just recently spread their applicability to supply chains. In such a context, lean warehousing plays a significant role in order to achieve lower costs of logistics operations and increase flexibility and efficiency in pull supply chains driven by customer demand. However, both academic and professional literature is still poor and lacks structured methodologies and case studies integrating different lean techniques to optimize warehouse processes. This paper proposes a novel lean warehousing framework combining three well-known lean tools and presents the first outcomes of its validation campaign. In particular, it discusses the framework application to a raw material and component warehouse of an international company in the automotive sector. Results show that time savings up to 36% might be achieved in receiving, put away, and picking operations, bringing significant economic benefits in terms of labour, service level, and warehouse space. This study provides researchers with new opportunities for fostering continuous improvement in warehouse operations, while practitioners might benefit from it as a basis for evaluating and re-engineering warehouse processes towards lean principles. Future research will further validate and progress the lean warehousing framework.

Keywords: lean, warehouse processes, waste, improvement

1. Introduction

Current business challenges, such as for instance short product life cycles, increasing manufacturing costs, and globalized markets, make supply chain management more and more crucial in order to efficiently and effectively satisfy customer needs. The first steps to achieve such a goal are identifying and removing, or at least decreasing, the many non-value-added activities that are performed throughout supply chain processes (Jasti and Kurra, 2017). In this context lean principles (Ohno, 1988; Womack and Jones, 1997) play a key role. As a matter of fact, the focus of lean philosophy has recently evolved from a single workstation level to value chains spanning multiple companies (Hines et al., 2004). If lean has been long used to improve companies' internal logistics, only in the last decade it has started being applied to streamline and optimize entire supply chains (Buonamico et al., 2017; Dotoli et al., 2015; Myerson, 2012; Arif-Uz-Zaman and Nazmul Ahsan, 2014). Although there is no generally accepted definition of "lean supply chain", it can be defined as a set of supplier and customer organizations linked by flows of products, services, technologies, information, and funds with the ultimate purpose of reducing costs and waste as well as maximizing the value added to supply chain agents (Vitasek et al., 2005; Wee and Wu, 2009).

Being the nodes of distribution activities, warehouses link upstream and downstream supply chain echelons and largely affect business competitiveness, especially in terms of economic levels and customer service (Phogat, 2013). However, the related costs are usually remarkably high due to the existence of many non-value-added activities (De Koster et al., 2007). Thus, warehouses are an interesting subject to be studied by taking a lean supply chain perspective in order to optimize the associated costs and time (Dharmapriya and Kulatunga, 2011). These issues, together with the awareness that warehouses cannot be completely eliminated from supply chains (Shah and Khanzode, 2018), paved the way to lean warehousing. Although the term "lean warehousing" was already used by Jones and others back in 1997, it is a relatively new research topic in logistics and supply chain management (Buonamico et al., 2017). Lean warehousing is the application of a collection of factors intended to improve warehouse functions. It aims to make customer response faster with decreased storage space and inventory together with increased accuracy (Sharma and Shah, 2016). The expected outcomes can be summarised as improved velocity and flow (Garcia, 2004), which means more efficient material flows and work organization, productivity enhancement, process standardization, enhanced quality of operations, reduced lead time and transportation, as well as better supply chain visibility (Phogat, 2013). The key benefits associated with lean warehousing make it critical in current pull supply chains more and more driven by customer demand.

Although literature emphasizes the need for lean warehousing (Bozer, 2012), currently there are few academic works and implementation experiences about it (Shah and Khanzonde, 2018). A possible reason is that adapting lean manufacturing principles to supply chains is not straightforward because waste is easier to be detected at shop floor level than at supply chain level. In fact, several organizations are having a difficult time adopting lean supply chain practices due to scarce awareness and lack of proper implementation strategies (Marodin et al., 2017; Tortorella et al., 2017). Furthermore, there is a limited number of approaches that combines different

lean tools for warehouse systematic analysis and optimization.

In order to contribute to close this research gap, the present work proposes a novel structured framework for lean warehousing integrating different techniques part of the so-called "Lean Toolbox". The application to an international company in the automotive industry is discussed with the aims of both exemplifying the framework and providing the first results of the validation campaign that is currently ongoing to test and improve it.

The paper is organized as follows. Section 2 gives an overview of lean warehousing literature. Section 3 presents the proposed framework. In Section 4 the case study is presented and the application of the framework discussed. Finally Section 5 summarizes the findings and contributions of this study, as well as its implications and limitations, and proposes future research directions.

2. Literature background

In order to improve velocity and flows, both warehouse design and physical operations need to be addressed (Myerson, 2012). These are the two streams the available literature about lean warehousing can be broadly divided into. Additionally, there are some works setting the ground for the topic or investigating its level of implementation.

The main contributions will be discussed in the next sub-sections.

2.1 Lean warehouse design

A limited number of contributions deal with warehouse design driven by lean principles. Among them Dharmapriya and Kulatunga (2011) provide a Simulated Annealing heuristic to find the best location for each item type. Their approach assigns products to the storage area in order to minimize waste in terms of handling costs and unused space. Moving from layout to material handling and storage equipment design, Shah and Khanzode (2015) state that the recent increase in product variety requires appropriate systems able to make warehousing more flexible and agile. These authors presents a conceptual framework that allows to assess the selection of storage and material handling equipment by means of performance measures (e.g. response time, storage capacity, resource utilization, and cost) in order to understand the inefficiencies they can generate and consequently refine the choice. They suggest using lean management techniques such as the Value Stream Map (VMS) to balance system performance and reduce waste.

2.2 Lean warehouse operations

The first work that can be mentioned within the present stream is the one by Garcia (2004) who discusses the application of VSM to increase the efficiency of warehouse flows. In particular the author points out that warehouses usually appear in VSMs as inventory triangles and shipping arrows. Such representations are not enough to appropriately capture the existing waste. Thus, it is necessary to show and analyse the single operations taking place in a warehouse such as receiving, palletizing, put away, order picking, order preparation, truck loading, and shipping. Following the advice by Garcia, Gopakumar and others (2008) focus on the transportation waste in the good receiving process at a food distribution centre. To this end, VSM is combined with Discrete Event Simulation to model warehouse flows, uncovering inefficiencies, and quantifying them. An algorithm is developed in order to assign trucks to docks so that to minimise the distance travelled by goods from the incoming area to their put away aisle. Abdoli and others (2017) embody statistical and mathematical analysis into VSM to quantitatively address the waste due to uncertainty in supply, process parameters, and customer orders. VSM to study detailed warehouse operations is also used by Chen and others (2013), again in a distribution centre. As a result, process reengineering and consequent changes in warehouse layout are performed as well as RFID technology is introduced to further improve the results. The total operation time is estimated to reduce by 79% by only using lean principles and by 87% with RFID integration.

Some contributions tackle stocks. Shah and Khanzode (2018) seek to reduce waste and improve throughput by developing a lean storage policy based on dynamic product allocation. Inventory turnover can be another source of inefficiency and Demeter and Matyusz (2011) discuss how lean philosophy can be implemented to improve it.

Most of the lean warehousing research applies single tools and few works take advantage of the effects of a synergy among different methods. To this end, it is interesting to mention Dotoli and others (2015) who develop and apply a novel approach integrating Unified Modelling Language for mapping warehouse processes, VSM to find non-value-added activities, and Genba Shikumi philosophy to rank inefficiencies and assessing their impacts on warehouses.

Besides VSM, which is by far the most used lean tool, 5S can be purposefully applied to lean warehousing as well. This is proved by Venkateswaran and others (2013) through the comparison between traditional 5S and a hybrid version of the approach including inventory management tools in three different hospital central warehouses. This study is important because it not only shows the use of 5S to investigate warehouses but also introduces healthcare as an industry that might benefit from lean warehousing as much as the manufacturing sector.

2.3 Implementing and assessing lean warehousing

Particularly inspiring is the report by Bozer (2012) where lean warehousing is recognized as a topic that is gaining a tremendous momentum although there is a lack of available resources and information on it. This author presents a review of lean warehousing concepts and tools and provides examples of companies that have already moved the first steps in such a field.

In more recent years, a number of researchers have developed approaches to assess lean warehousing initiatives. Wu and others (2016) deal with the need to accurately measure the performance of lean practices and propose a multi-attribute group decision making

framework that is then applied to evaluate the adoption of lean philosophy in the distribution centres of a commercial tobacco company in China. Sharma and Shah (2016) combine the Delphi method and the Analytic Network Process to develop a decision-making model aimed at improving warehouse performance in a manufacturing company through the application of lean concepts. Finally, Buonamico and others (2017) put forward a performance indicator scorecard to help setting goals as well as monitoring the practical implementation of lean warehousing. This is constituted by a hierarchy of different metrics contributing to the assessment of the overall level of leanness achieved by a warehouse. The authors also define an eighth waste in warehouses, adding to the Ohno's (1988) seven types of waste: underutilised employees. Lean warehousing requires a change in the company culture in order to be sustainable over time and the new proposed waste addresses the improper use of the employees' creativity to reduce the other seven types of waste.

The performed literature review reveals that despite the increasing attention that lean warehousing has received in recent years the related body of contributions is still limited. Additionally, lean tools are usually applied on an individual basis, although they are sometimes coupled with simulation and statistical approaches. Relying on more than one lean tool would enable to analyse warehouse criticalities under multiple perspectives and find better solutions (Dotoli et al., 2015). However, it is recognized that choosing the correct lean tools for improving warehouse performance is a not straightforward task (Sharma and Shah, 2016). Thus, there is a need for formalised lean warehousing approaches identifying appropriate lean techniques and combining them in a structured fashion. The present work helps covering this gap by proposing a novel lean warehousing framework integrating the 5W method, 5S analysis, and VSM. In order to show its practical implementation, the first results of the ongoing validation process are discussed. Moreover, a reflection on how the framework might be refined is presented.

3. Introducing the lean warehousing framework

The purpose of the proposed framework is contributing to the development of a strategy for lean warehousing. It aims to be a roadmap for investigating both material and information flows, identifying their weaknesses, and setting appropriate improvement actions. As Figure 1 shows, three steps compose the framework. The first step is focused on the investigation and classification of waste in warehouse operations and has to be carried out after an accurate process mapping. The authors suggest to combine the application of the seven waste categorization with the 5W lean tool (Caetano et al., 2012; Michlowicz, 2013). Such a method involves asking a number of questions to explore the cause and effect relationships underlying a particular problem, with the purpose to determine its root causes (Pol and Inamdar, 2012). In the proposed framework the main goal of this step is

identifying the sources of waste: knowing what, when, where, why, and by who is a given activity of a process suffering waste. It is interesting to note that the overproduction waste type is not considered as warehouse operations do not include the transformation of raw materials into finished products. Then, the second step follows with the application of 5S. This is a five phase tool, Sorting, Straitening, Shining, Standardizing, and Sustaining, aiming to organize and manage a workflow to improve it and reduce variability. Its steps provide a guide to devise appropriate actions in order to reduce and control waste activities, define standard processes, and ensure continuous improvement according to the Kaizen philosophy. The 5S technique has been chosen because it is a generic, structured, and straightforward approach that proves to be particularly suitable for starting lean applications (Michlowicz, 2013; Venkateswaran et al., 2013). Moreover, as demonstrated by Sheldon (2007), it is a standard approach that can be applied to a variety of contexts including supply chains. Finally, the third step of the framework aims to support the implementation of the improvements suggested in the previous step and to quantify the associated effects throughout the VSM. By taking a supply chain perspective, a VSM can be defined as the process of mapping the material and information flows required to coordinate the activities performed by manufacturers, suppliers, and distributors to deliver products to customers (Sundar et al., 2014). It is now widely recognized as a fundamental tool when it comes to implementing the lean approach (Michlowicz, 2013) and in literature there are several applications in different industry sectors, such as logistics, healthcare, product development, and maintenance services (Chen et al., 2013; Garcia, 2007; Purba et al., 2018; Romero and Arce, 2017; Tortorella et al., 2017).

The proposed framework intends to integrate the three mentioned lean tools in a structured and systematic way with the purpose of supporting the definition of the optimal warehouse system configuration. For more details on the framework the reader can also refer to Mustafa and others (2013).
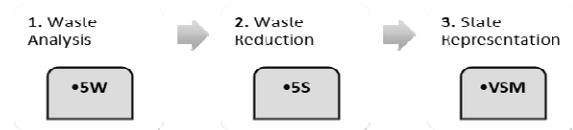

Figure 1: The three steps of the framework

4. Validating the lean warehousing framework: first results

In order to assess the applicability and the accuracy of the framework, a validation campaign is currently being carried out in different industries all needing to quickly adapt to demand variations. In particular, the following sectors have been selected:

- *automotive,* industrial sector where lean was born and has been long applied especially to manage manufacturing;
- *electronic components,* whose supply chains are characterised by a great variety of different items

which quickly get obsolete and have heterogeneous demand and stock requirements;

- *food & beverage*, where the need to reduce logistics inefficiencies is driven not only by the multitude of different items but also by their short product lifecycles;
- *packaging production and customization,* to check how the framework works in a relatively simpler supply chain than the ones in the above mentioned sectors.

This section discusses the first results of the validation campaign by presenting the application of the framework to the warehouse of an automotive company.

4.1 Case company basic information

The case study concerns an international company whose name cannot be disclosed due to confidentiality reasons. The focus plant is located in Spain and produces rear lamps for cars and trucks which are supplied to both Original Equipment Manufacturers (OEMs) and Original Equipment Suppliers (OESs). According to the manufacturing process performed in the facility, some components are obtained by plastic injection moulding, some others by metal casting, and finally all the components, both produced in-house and purchased from suppliers, are assembled together to obtain the finished product.

The 2017 turnover was approximately equal to 87 M€. The focus plant counts 700 employees and hosts two warehouses: the raw material and component and finished good one.

4.2 Process mapping of the studied warehouse

The case study setting is the raw material and component warehouse of the company, whose main function is supplying raw material for injection moulding and metal casting as well as components for product assembly.

Table 1: Warehouse processes and activities

1. **Receiving**	Raw materials - Small-sized components - Bulky components

· Unloading materials from the truck and storing them in a free space in the unloading area.
· Recording the delivery note in the WMS.
· Printing labels in order to identify the items within the warehouse.

2. **Quality control**	Small-sized components - Bulky components

· If a material requires a quality control, a "Q" will appear in the label and the system will not allow to put away it.
· Quality Department staff randomly pick a pallet from the unloading area and move it to the quality area to perform the check.
· If everything is correct the material will be returned to the unloading area, otherwise the Quality Department will immobilize the goods until next notification.

3.1 **Components put away**	Small-sized components – Bulky components

· Taking components from the unloading area and storing them in a specific warehouse location. Bulky components have a fixed storage location for each part number in FIFO lanes, while the small-sized components are stored randomly. Therefore, the pallets of such materials will be placed in any

empty space in the racks, except for the floor level, which is dedicated to the supermarket storage.

3.2 **Raw materials put away**	Raw materials

· Raw materials are stored in two dedicated areas. The first one is constituted by FIFO lanes and is located inside the focus warehouse. However, due to space limitation there is a second raw material storage area next to the injection moulding lines.

4. **Supermarket replenisment**	Small-sized components

· The supermarket is located on the floor level of the rack area. All the components, but the bulky ones, are picked from the supermarket. The replenishment takes place throughout a kanban call.

5.1 **Picking from supermarket**	Small-sized components

· The picking of components from the supermarket is carried out in order to feed assembly lines. It is done by means of trains composed by 4 wagons carrying from 5 to 20 boxes each. Each train is assigned to an assembly line and carries the components in the corresponding areas of the supermarket. The process is cyclic and consists in: picking components, transporting them to the line, taking the empty boxes, bringing them back to the warehouse, and doing the picking again.

5.2 **Picking bulky components**	Bulky components

· The picking of bulky components follows approximately the same procedure detailed for small-sized components

Table 1 summarizes the processes and the associated activities performed in such a warehouse together with the types of materials involved. The numerical studies that will be detailed in the next sections regard a selected group of part numbers.

4.3 Step 1: waste analysis

For the identification and classification of waste, a deep investigation of the warehouse was done. For this purpose a working team was formed including the authors, logistics and warehouse managers as well as members of the warehouse staff. Table 2 gathers the descriptions of the identified waste classified according to the seven types suggested by Ohno (1988). Mixed flows associated with different materials undergoing different operations (e.g. labelling, quality control, storing, etc.) were one of the most relevant criticalities affecting the warehouse at issue.

Table 2: Waste classification

Type	Identified waste
1. Transport	1.1 Moving other materials in order to reach the material required
	1.2 Need to move materials in order to create empty places
	1.3 Moving materials around the unloading area looking for an empty space to place them
	1.4 Long driving around the warehouse aisles looking for an item
	1.5 Transporting back full boxes that have not been used in the assembly line
	1.6 Moving items of different part numbers when just one part number is needed to be moved to the supermarket
2. Inventory	2.1 Storage area saturated by excess inventory or misplaced materials
	2.2 Impossibility to store all the incoming materials

	2.3 Lack of inventory to perform production tasks
3. Motion	3.1 Walking around the warehouse looking for the material required
	3.2 Walking around searching for equipment
	3.3 Walking around looking for a member of the warehouse staff
	3.4 Walking around the warehouse searching for empty spaces for placing the unloaded items
4. Waiting	4.1 Waiting to use equipment
	4.2 Materials waiting to be stored
	4.3 Trucks waiting either to enter the dockyard or to start the unloading
	4.4 Waiting for other staff members to empty an area for placing materials
	4.5 Waiting for the material to be replenished
5. Defects	5.1 Incorrect labelling/re-labelling
	5.2 Incorrect material amount received
	5.3 Wrong material picking
6. Over processing	6.1 Re-storing materials
	6.2 Constant cleaning and tidying of the area
	6.3 Need to clear out the path to move through
	6.4 Searching for a part number in a pallet containing several part numbers
	6.5 Going back to the assembly line to recall the required materials to supply
	6.6 Bringing material back from the assembly line

As the framework proposes, in order to find out the sources of waste an extensive 5W analysis was performed. Table 3 shows an example of the outcomes; readers can refer to the authors for further details.

Table 3: Example of 5 Ws analysis output

Waste 1.3	
What:	Moving materials around the unloading area looking for an empty space to place them
When:	Once items are unloaded from the truck
Where:	In the unloading area
Why:	The unloading area is very full and it is difficult to find an empty space
	There are a lot of materials that need to be put away and this creates a bottleneck in the unloading area
Who:	Warehouse staff

The working team decided to integrate the 5W analysis with the assignment of an impact to each identified waste. This task, not prescribed by the applied framework, was accomplished by using the following 4-item semi-quantitative scale: 0 – No impact; 1 – Low impact; 2 – Medium impact; 3 – High impact.

The total impacts per process and per type of waste are presented in Figure 2. The central cells of the table collect the sum of the different impacts assigned to each type of waste per each process. The colours of the cells represent a scale of impact where the strongest red is the highest impact and the smoothest green is the lowest. The total waste impact for the warehouse equals 92. By dividing the waste impact of each process by the total waste impact it can be obtained the percentage of the total impact that a process is responsible for. The same is calculated per type of waste.

Based on this study, the Receiving, the Quality Control and the Picking from Supermarket processes are the once suffering more from waste. On the other hand, the most impacting type of waste is Transport followed by Inventory and Waiting.

Warehouse processes								
Waste types	Receiving	Quality control	Components put away	Raw materials put away	Supermarket replenishment	Picking from supermarket	Picking bulky components	% waste impact per process
Transport	6	3	4	2	1	3	2	23%
Inventory	5	5	0	2	4	2	1	21%
Waiting	1	6	4	1	1	3	2	20%
Motion	3	2	1	1	1	4	1	14%
Over Processing	1	3	0	3	1	2	2	13%
Defects	3	1	2	1	0	1	1	10%
% waste impact per process	21%	22%	12%	11%	9%	16%	10%	

Figure 2: Waste impacts

4.4 Step 2: waste reduction

Once waste occurrences are identified and the associated causes investigated, the following step is defining proposals of improvement in order to either reduce or mitigate them. As the framework suggests, 5S is a convenient tool because it addresses the root causes of waste and prevents its recurrence.

The working team performed an extensive definition of improvements and collected them in tables, one for each warehouse process. As an example, Table 4 presents an excerpt from the table about the Receiving process. The actions included in the Sorting, Straitening, and Shining rows should be executed, while the actions collected in the Standardizing and Sustaining rows should be carried out in order to keep the benefits of improvements. The complete tables are available from the authors.

Table 4: Example of 5S application to Receiving

Receiving	
Sorting:	Classifying all the materials in incoming area
Straitening:	Defining material flows in the incoming area according to the material type
Shining:	Cleaning the unloading area after every receiving
Standardizing:	Defining procedures for each receiving step
Sustaining:	Providing training for the new procedures

However, not all of these improvements are equally achievable and, additionally, some of them could prevent a waste but scarcely contribute to the global improvement of warehouse operations.

According to the waste analysis outcomes, the incoming area resulted to be the most critical in terms of waste impact and contribution to the whole warehouse operational performance. The incoming area includes the unloading and quality control areas. Receiving and Quality Control are the two processes involved.

The main problems of the incoming area are the quantity of materials stored, the lack of free spaces, the poor communication between the Warehouse and the Quality Departments, the multiple designations of tasks to the staff, the lack of information on trucks arrival, and their

scheduling on time. In order to solve these problems and prevent their recurrence, several changes need to be implemented.

The main proposals of improvement in the incoming area are its re-layout and the redefinition of the related material flows. They will be discussed in the next two sub-sections.

4.4.1 Re-layout of the incoming area

The re-layout of the incoming area was addressed after classifying the materials that can be found in the warehouse. Separated areas were designated according to the different functions that need to be performed: the unloading area, the components to store area and the incoming material for quality control area.

The unloading area includes three physical areas, two next to the dockyard for big trucks and one next to the dockyard for small trucks, accounting for a total floor area equal to 48 m² and able to accommodate up to 72 pallets. The function of this area is to temporary stacking the materials just received until they are labelled. Appropriate empty spaces between lanes have to be kept in order to facilitate labelling. Also, no more than two pallet levels are allowed, so that a person can easily reach them. Once materials are labelled, they should be promptly removed from this area.

The components to store area occupies 20 m² and can accommodate up to 32 pallets in two vertical storage levels.

It is equipped with FIFO lanes constituted by gravity flow racks. The goal of this area is to separate those components that can be directly stocked in the warehouse racks. Thus, it is assured that all the labelled components in condition to be stored will be found in those specific lanes, avoiding searching for them among all other materials in the incoming area.

Finally, the incoming material for quality control area accounts for 10 m² and is able to store up to 16 pallets. This area has been defined for the materials that have just been labelled and require quality control. The idea is to make sure that the materials for which a quality control is pending are not accessible to be picked by anyone. The Quality Department staff will go to this area to draw the samples needed for the control. After the quality check, the Warehouse Department staff will remove the materials from the quality control area and move it wherever is needed depending on the result of the control.

Pallets should be stored in one level or exceptionally in two vertical levels if they are from the same part number lot. This will make easier to the Quality Department staff to access the material inside it.

4.4.2 Redefining material flows in the incoming area

Material flows were re-designed jointly with the physical areas. In particular, different steps were defined for small-sized components, bulky components, and raw materials. In this paper the small-sized component flows are discussed.

Components are received from both the dockyards and placed in the unloading area (Step 1 in Appendix A). Once labels are printed and placed on pallets, if no quality control is required, the components are moved to the put away lanes in the components to store area (Step 2 in Appendix A). If a "Q" appears in the label, components are moved to the incoming material for quality control area (Step 3 in Appendix A). Once components pass the quality control, they are moved to the put away lanes like the rest of the components. Otherwise they are moved to an area dedicated to rejects. Finally, good quality components are transported from the put away lanes to the racks (Step 4 in Appendix A), where are stored until a kanban call specifies to withdraw them.

4.5 Step 3: state representation by Value Stream Map

Two VSMs were developed in the present case study. The AS IS VSM captures the current time required to complete warehouse tasks, while the TO BE VSM calculates the time needed to perform warehouse processes after implementing the improvement actions put forward by the working team. The most revealing outcome is associated with the 36% reduction in processing time (including receiving, put away, and picking operations), which moves from 4.3 hours in the AS IS situation to 2.7 hours in the TO BE one. Regarding the lead time, it only decreases by 6% (AS IS: 7.6 days; TO BE: 7.1 days) because the nature of the material flows does not allow to perform processes concurrently.

The decrease in processing time translates into savings in labour costs. In global terms, it contributes with an annual benefit of approximately 30 k€ that can permit assigning new tasks to the current employees who will be more released. Another saving is related to line stops. The designed logistics flows allow to decrease the number of stops due to materials that are not available since they are still in the incoming area and pending to be properly stored. Additionally, there is a reduction in the amount of defected materials that were supposed to be controlled but, due to bad operability, were not, which also contributes to limit line stops. The total line stop savings were estimated around 1.5 k€ per year. Finally, savings up to 1 k€ were calculated because of release of some warehouse spaces and decreased material rejection.

5. Discussion and conclusions

The present case study proved that the proposed framework offers a generic approach that can be adapted to different situations. Its tools, i.e. 5W, 5S, and VSM, are quite intuitive and can be easily applied to any situation. However, four improvements can be suggested. A numerical assessment of waste impacts is recommended at the end of step 1. In fact, after the identification and classification of criticalities, such a task would help to prioritize them for subsequently selecting those ones that should be addressed first. Another proposal that arises from the case study is to develop a methodology that enables to assign economic losses to waste. As said, a numerical analysis is valuable for understanding where to focus improvements but if this analysis is based on real economic losses associated to each particular waste for each process the assessment becomes pretty much more accurate. Moreover, defining economic losses makes easier to estimate the benefits brought by improvements. Additionally, it is also suggested to define a more detailed classification of waste. The seven waste could be considered as a first classification level.

For instance, possible sub-classifications for transport waste could be: Re-storage (extra material handling from one storage area to another); Clear path (move material to clear path to go through); and Search location (extra material moving while looking for where to place goods). Being more accurate in the waste classification improves the level of detail of the analysis and makes much easier to detect the waste root causes as well as to assign impacts. Finally, an AS IS VSM should be developed to compare the current processing and lead times with those achieved in the TO BE VSM after improvement implementation.

This study has both academic and practical implications. The presented framework and its discussed application provide researchers with a starting point to structure lean warehousing approaches. Also, they can inspire studies about combining different lean tools for improving warehouses operations. The case study shows practitioners how to apply the framework for assessing and re-engineering warehouse processes. It helps them to understand how lean principles can be purposefully used for improving not only production flows but also logistics ones. Finally, the estimated time and economic benefits can demonstrate to other companies that lean thinking can really assist in achieving the goal of ensuring warehouse efficiency and flexibility while reducing costs.

The work poses some limitations. The suggestions for improvement were not implemented because of time restrictions and the associated benefits were determined based on the experience of the working team. Furthermore, the study frame only focused on the inbound warehouse of the company, while outbound activities were not considered and improved. A more extended analysis would allow to deepen the knowledge about advantages and disadvantages of the current version of the framework.

Future research will be focused on continuing the validation of the framework by applying it to multiple and different warehouse settings. In this way it will be possible to understand whether the outcomes of the present work are confirmed. Also, the integration of the proposed changes to the framework will be considered.

Acknowledgements

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Appendix A. INCOMING COMPONENT FLOWS

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