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► **To cite this version:**

Mariagrazia Dotoli, Giuseppe Petruzzelli, Biagio Turchiano. A LEAN WAREHOUSING APPROACH USING UNIFIED MODELLING LANGUAGE AND VALUE STREAM MAPPING: A CASE STUDY. 9th International Conference on Modeling, Optimization & SIMulation, Jun 2012, Bordeaux, France. hal-00728573

HAL Id: hal-00728573

<https://hal.science/hal-00728573>

Submitted on 30 Aug 2012

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A LEAN WAREHOUSING APPROACH USING UNIFIED MODELLING LANGUAGE AND VALUE STREAM MAPPING: A CASE STUDY

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ABSTRACT: *The paper focuses on the design and optimization of production warehouses using lean manufacturing tools. Using the internal logistics of a world leader of pasta production as a reference, we propose an approach to lean warehousing employing the well-known Unified Modelling Language (UML) and Value Stream Mapping (VSM) tools, together with the so-called Shikumi methodology. The procedure is iterative and hierarchical. Starting from a detailed description of the warehouse logistics by UML, the VSM graphical approach allows the identification of non-value adding activities, and the Shikumi technique leads to a ranking of such system anomalies. The further application of the VSM tool produces an overall picture of the desired warehouse, and the UML framework allows to describe in detail the updated system activities. Application of the approach to the case study shows its effectiveness and leads to an innovative proposal for the warehouse automation and optimization.*

KEYWORDS: *Manufacturing systems, Warehouse logistics, Optimization, Automation, Value Stream Mapping, Unified Modeling Language, Information and Communication Technologies.*

1 INTRODUCTION

Nowadays, factors like globalization, productivity, and reduction of time-to-market make the impact of logistics on production by far wider than in the past. Such a complex scenario originated considerable interest for the design, planning and control of warehousing systems as new research topics (De Koster et al. 2007, Dotoli and Fanti 2005, Dotoli and Fanti 2007, Gu et al. 2007, Rouwenhorst et al. 2000). Warehouses may be defined as material handling stations dedicated to receiving, storage, order-picking, accumulation, sorting and shipping of goods (Van Den Berg and Zijm 1999). Order picking is the most labour-intensive and costly activity for almost every warehouse, its cost being estimated about 55% of the total warehouse operating expense (De Koster et al. 2007). The definition of warehouse covers a wide variety of systems, which may be further characterized depending on the industrial application. Three types of warehouses may broadly be identified (Van Den Berg 1999): i) distribution warehouses, ii) production warehouses, iii) contract warehouses. In this paper we consider production warehouses, a class that covers the vast majority of warehouses and may be defined as production sites facilities for storing raw materials, semi-finished products, and final products (Van Den Berg 1999). Moreover, considering the traditional classification of strategic, tactical, and operational problems, we focus on the strategic design of production warehouses, that has been shown to be a sector in need for investigation, as opposed to the strong analysis oriented research on isolated sub-problems that seems to be dominant in the current literature (Rouwenhorst et al. 2000).

The available literature on production warehouse design may be classified based on three main issues (Gu et al. 2007): contributions addressing warehouse design decisions; papers proposing analytic models; and publications on benchmarking, case studies, and other surveys. However, the existing contributions do not typically consider the problem of warehouse design in a continuous improvement context. On the contrary, with the increased customer demand, for most manufacturing industries it has become increasingly important to continuously monitor and progress the warehouse process. The most widely known approach for industrial improvement, originating from the Toyota production system, is lean manufacturing (or lean production). Lean manufacturing is a multi-dimensional approach integrating a variety of management practices, e.g., just-in-time, quality systems, supplier management, and many more, into a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah and Ward 2003). Basically, the major goal of the lean manufacturing tools is to reduce cost by eliminating waste. The seven sources of waste identified by lean manufacturing are: over-production, waiting time, transportation, over-processing, inventory, motion, and scrap (Narasimhan et al. 2007). Although companies are involved in the lean change in their entirety with all their different areas, a decisive role is played by internal logistics and particularly warehouse management, which is aimed at optimizing the flow of material and information within the company to maximize profit (Christopher 2010). The related literature includes several application examples of VSM to discrete manufacturing systems (see for instance Keil et al. 2011, McManus and Millard,

2002, Ramesh et al. 2008), but few papers employ VSM for lean warehousing.

This paper proposes a lean warehousing approach for the analysis and optimization of production warehouses by way of a case study, one of the world leading pasta manufacturers, namely, F. Divella SpA. Using the company's product warehouse as a reference, we employ the well-known Unified Modeling Language (UML) formalism (Miles and Hamilton 2006) to describe the internal logistics, and the well-known Value Stream Mapping (VSM) lean manufacturing tool (Abdulmalek and Rajgopal 2007) as a simple and effective approach to identify and reduce waste, while improving the overall operational control. In particular, the lean warehousing approach first employs UML to describe in detail the warehouse activities. Second, VSM is used to visualize the overall process activities, identifying the system anomalies (waste or muda, in Japanese) in the value stream. If some muda are detected, the Shikumi approach (the Japanese for engineering method, Womack and Jones 1996) is used to assess the best response actions to eliminate them. Based on the Shikumi results, the VSM approach is hence used to establish the future vision of the value stream, with a reduced impact of non-value added activities. Thus, UML is employed to re-design the manufacturing system, removing the main system anomalies. Finally, the designed changes are implemented. The procedure is iterative, to ensure that improvement is continuously achieved. With respect to the classical VSM technique, the proposed procedure offers several advantages: 1) it can be applied to complex warehousing systems; 2) it leads at the same time to detailing the process activities (thanks to the use of the UML formalism) and to depicting the overall value stream into a high level picture (using the VSM conciseness); 3) it allows the quantitative assessment of the system anomalies (thanks to the Shikumi methodology). The application of the proposed technique to the case study leads to the improvement of some Key Performance Indicators (KPI) in the company production warehouse, enlightening the approach effectiveness and leading to an innovative proposal for the warehouse automation and optimization, with particular reference to the key order picking process.

The remainder of the paper is structured as follows. Section 2 describes the case study current internal logistics. Section 3 describes the current mapping of the company warehouse using VSM and details the muda identification by the Shikumi approach. Section 4 describes the future mapping of the case study and Section 5 presents the conclusions and possible future developments. The paper is concluded by a reference section.

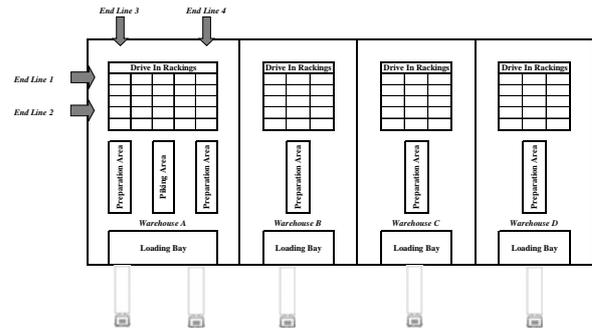


Figure 1: Scheme of the company warehouse layout.

2 THE COMPANY PRODUCTION WAREHOUSE

2.1 Description of the Internal Logistics

The internal logistics at F. Divella SpA is managed by a traditional warehouse supported by a dedicated Information and Communication Technologies (ICT) system. The warehouse receives goods coming either from inside or outside the company. In the former case the inflow refers to:

1. automated production of pasta;
2. automated production of biscuits;
3. automated production of flour.

In the case of inflow due to products from outside the company, it refers to:

4. co-packers: contract packers, or co-packers, are companies that produce pasta for the company using raw materials supplied by F. Divella SpA, e.g., bran, with the company brand on the packages;
5. partners: these produce other kinds of products (e.g. snacks, peeled tomatoes, tomato sauces, rice, couscous, polenta, fresh pasta stuffed with meat and/or vegetables, etc.), entirely within their own structures. They expose the company brand on packages but also indicate the actual production location.

The company production warehouse handles about 100,000 parcels-per-day in total and 65,000 of those are pasta. A vast majority -about 95%- of these quantities is produced by the company itself and is stocked in its warehouse. Hence, the warehouse may be regarded as the decoupling point between production and external logistics. In the sequel we focus on the internal logistics referring to pasta that is produced in-house, since it amounts to about 70% of the internal logistics and as such is the main product flow to be managed in the warehouse. There are four production lines which deliver daily the same kinds of pasta. On each end of line there are no more than five different kinds of pasta. A scheme of the production warehouse is reported in Fig. 1: the warehouse includes the main storage area (warehouse A) and some backup storage areas (warehouses B, C, and D) where products are stored in case the primary warehouse is full and from which they are either returned to the main warehouse or shipped (after a preparation phase) through a truck loading area.

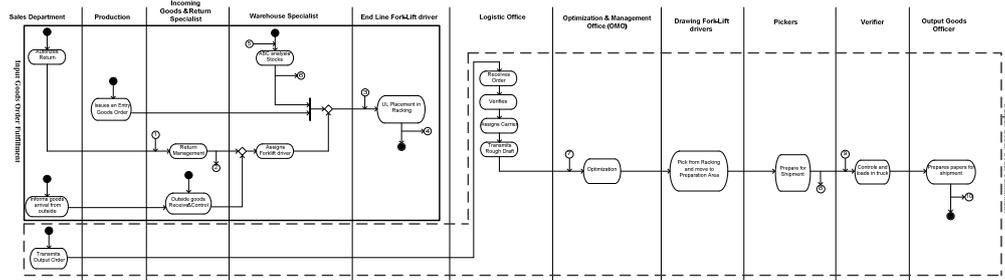


Figure 2: Macro activity diagram of the company production warehouse (current solution).

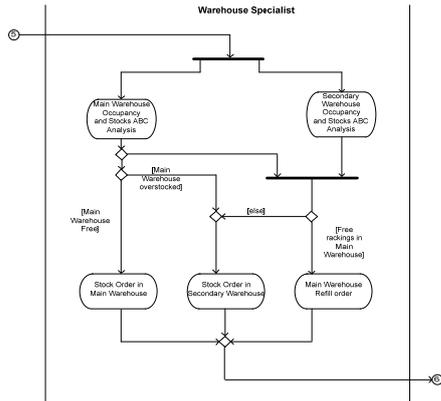


Figure 3: Activity diagram of the ABC Analysis/Stocks.

In the main storage area, products are picked and packages are prepared for shipping and subsequently loaded on trucks through the loading bay. Packages entering the warehouse are stored in Unit Loads (UL) that are composed of half pallets, having a height of about 120 cm. This choice requires using more UL than with bigger pallets, but it allows increasing productivity because:

1. logistics platform of large distribution and mass retailers (supermarket chains) currently require as a standard the adoption of half-pallets. Accordingly, no additional manpower is required from the internal logistics during the truck loading operations;
2. half-pallet dimensions are optimal for truck storage, as two stacked pallets completely saturate the height of the vehicle, which is about 270-275 cm. The load in the truck is made by overlapping two half-pallets to form a stack, with the resulting gain of 1 layer per pallet, if compared with storing one higher pallet.

Referring to pasta, a UL is generally made of 3 to 5 layers and each layer of packages is composed by a minimum of 6 up to a maximum of 12 parcels. The number of packages in the UL depends on the product type, because package dimensions depend on the kind of pasta. Pallets are stocked in the production warehouse in multiple-depth drive-in lanes, each dedicated to one kind of product.

2.2 Activity diagrams of the warehouse internal logistics

A mapping of the warehouse logistic flows was carried out using the UML activity diagrams (Miles and Hamil-

ton, 2006). These are used to describe procedural logic, business processes and workflows. UML activity diagrams are similar to flowcharts but allow representing parallel processing in order to explain the critical points in the activities and workflow of a system, pointing out all the possible paths, parallel processes, and their subdivisions. Activity diagrams therefore provide a dynamic view of the system and are useful to those who will take care of the model implementation. The main elements of these diagrams are:

- the initial activity, indicated by a solid circle;
- the final activity, indicated by a bull's-eye symbol;
- activities, represented by rectangles with rounded edges;
- arcs representing flows that link activities;
- forks and joins, both represented by a thick horizontal bar:
 - o forks refer to actions whose execution begin simultaneously;
 - o joins indicate that all incoming actions must end before the flow can proceed;
- decisions, which represent alternate paths, represented by diamonds with options written on each arrow emerging from the diamond;
- swim lanes, which express the actor responsibilities.

Figure 2 reports the current UML activity diagram of the company production warehouse, which allows analyzing the internal logistics flows. The figure reports a general overview of the activities (called macro activity). The analysis has been carried out with a top-down approach, representing the overall scheme of the F. Divella S.p.A. internal logistics. We can identify the following main flows in Figure 2, identified by panes and further detailed in the sequel:

1. Input Goods Order Fulfillment (solid box): such a flow refers to goods entering the warehouse either from the company (from the internal production or from the management of returns to be stocked in the racks) or from outside the company (from partners or co-packers);
2. Output Goods Order Fulfillment (dashed box): all these activities refer to order dispatching, in which goods are drawn from the warehouse and loaded on trucks.

2.2.1 The Input Goods Order Fulfillment Flow

This first flow in the warehouse (solid box in Fig. 2) is initiated when production issues an input goods order in the warehouse: this activity ends when the end of line automatic printer places the logistic label on the UL,

detailing its destination in the warehouse. The warehouse specialist organizes the UL storage in the drive-in racks and assigns to the end of line forklift driver the job of picking UL from the production end lines and placing them in racks. More precisely, the warehouse specialist performs an ABC inventory analysis (Pareto, 1971) of the primary and backup warehouses depicted in Fig. 1 and this activity, shown in the sub-activity diagram labeled as 5-6 in Fig. 2, is detailed in Fig. 3. The warehouse specialist uses the ABC analysis to optimize the management of warehouse stocks and, according to the analysis results, focuses on factors that produce the greatest added value for storage. The ABC analysis consists, regardless of scope, in grouping stock-keeping units into three classes in a descending order of importance for the company's business, according to a specific criterion (Pareto, 1971):

1. Class A, including the stock-keeping units of primary importance for the warehouse. Typically, few items (about 20% of the total stocks) contribute with 80% to the business;
2. Class B: it collects secondary importance elements (about 30-40% of stocks). They affect the business on average of about 15% of the total;
3. Class C: it collects the remaining stocks (40-50% of the total), impacting no more than 5% on the business.

By coupling two ABC analyses considering different criteria, a crossed-class analysis is obtained (Flores and Whybark, 1986). Data are organized in a matrix allowing one to distinguish items by their impact on the two criteria.

For the case study the ABC analysis is performed considering two criteria, namely the output (i.e., the average percentage of packages of a given type of pasta with respect to the overall packages in output from the warehouse in a period of time equal to one year) and the stock (i.e., the average percentage of total UL stocked in the warehouse in a period of time equal to one year), as follows. Let N be the number of items produced/managed by the company. The single item n_i with $i=1, \dots, N$ generates an output quantity of packages Q_i from the warehouse with $i=1, \dots, N$. Let Q be the output total quantity $Q = \sum_{i=1}^N Q_i$. All items are listed in a table, in a decreasing order of importance, showing for each item in a separate column the relative weight (percentage) $\frac{Q_i}{Q} \cdot 100$ it brings to the total amount. In an additional column the cumulative weight $CW_i = \sum_{i=1}^i \left(\frac{Q_i}{Q} \cdot 100 \right)$ is calculated for each item n_i with $i=1, \dots, N$. Hence: all items whose cumulative weight is in the range 0%-80% are assigned to the A class; all items whose cumulative weight is in the range 80%-95% are assigned to the B class; all the remaining items are assigned to the C class. Obviously, the results may be plotted reporting on the x-axis the

cumulative weight of items, and on the y-axis the cumulative weight of each product.

Similarly, an ABC analysis of the stock is conducted. Figure 4 (first five columns of the Table and increasing graph) reports as an example the ABC analysis of the outputs for the "large consumption - long formats" pasta, referring to the year 2010. The same analysis is conducted for the stock, see Fig. 4 (last five columns of the Table and decreasing graph). Carrying out the crossed ABC analysis, we obtain the matrix in Fig. 5, showing that Spaghetti, Linguine, Vermicelli and Spaghettini are in the AA class, i.e., the most required types of pasta and the most present in stock. In addition, the analysis shows that Bavettine are in the CC class, i.e., the less required product and less stocked one.

Accordingly, the warehouse specialist task consists in maximizing attention to products belonging to the AA class and trying to reduce as much as possible the presence in the main warehouse of those in the CC class. As for items belonging to the remaining classes, other kinds of analyses are performed (e.g., forecasts analysis) in order to verify whether either specific action plans are required (e.g., to increase the stock or cut it out), or the analysis results are influenced by other external factors.

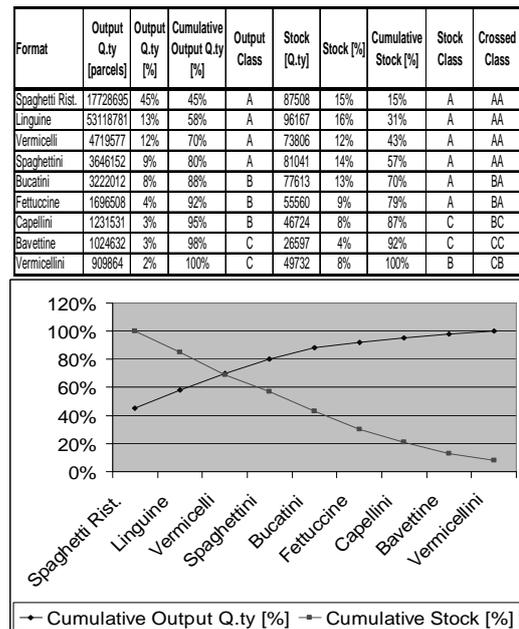


Figure 4: ABC analysis of large consumption -long format pasta.

		Outputs		
		A	B	C
Stocks	A	Spaghetti Rist. Linguine Vermicelli Spaghettini		
	B	Bucatini Fettuccine		Capellini
	C		Vermicellini	Bavettine

Figure 5: crossed class ABC analysis for large consumption -long format pasta.

Returning to the macro activity diagram reported in Fig. 2, the sales department performs the following activities in parallel with the ABC analysis performed by the warehouse specialist:

1. it informs the Incomings & Returns Specialist about the arrival of products from outside. In such a case the Incomings & Returns Specialist checks the correspondence between the delivery note and the products that are actually present. He also verifies the status of packages and, in case of non-compliance with the company requirements, the goods are refused. If no anomaly is detected, he requires the assignment of a forklift driver to have goods stored in the warehouse racks;
2. it announces the arrival of authorized returns to the Incomings & Returns Specialist, who performs a dedicated procedure. UL enter the warehouse authorized by a Supplier Entering Order. The goods are stored in half-pallet or pallets.

2.2.2 The Output Goods Order Fulfillment Flow

The second flow in the warehouse (dashed box in Fig. 2) is started when the sales department informs the logistic office about the presence of an order to be dispatched. The logistics office receives all details of the order that at this step is called "rough draft", since it is not optimized for the operations necessary to execute the order. The rough draft contains the details on type, quantity, and number of required half-pallets, and weight of all packages. It also shows the required total weight and volume. Starting from the rough draft, the logistics office performs a consistency test and assigns a specific carrier, with suitable transportation parameters, such that the required weight and total volume are allowed to the carrier. Hence, the logistics office sends the rough draft to the so-called Optimization and Management Office (OMO) for the next steps. The OMO processes the rough draft and coordinates eventual UL picking operations from the drive-in racks, required when the order contains various kinds of product, in lower quantities than those of a UL (mixed pallets). Selecting forklift drivers, the OMO coordinates the retrieval of UL from racks and their storage in the preparation area (see Fig. 1). Pickers instead are dedicated to mixed pallets and to other kinds of preparations, e.g. cellophane pallets covering. When all such jobs are completed, the verifier controls and loads all packages in the truck. Finally, he informs the output goods officer who will execute all the procedures and processes to complete the order shipment and authorizes the vehicle departure.

3 VALUE STREAM MAPPING: CURRENT SITUATION

In this section we identify in detail the problems occurring during the various phases of a part of the logistics flow described in the previous section, with the aim of identifying the sources of errors and inefficiencies and removing them. It is an example of what could be applied to the entire warehouse. The purpose is to describe all existing interactions between the parts composing the

warehouse processes, in order to standardize and optimize them. To this aim, we use the Value Stream Mapping (VSM) technique, a fundamental tool of the so-called lean philosophy. VSM provides a graphical mapping of all processes and activities of a logistic flow, allowing the identification of waste and its cause, so as to develop improving solutions (Abdulmalek and Rajgopal, 2007).

3.1 Value Stream Mapping

The typical elements of the VSM procedure are as follows (Pan et al. 2007):

- 1) *Identifying the product or service to map*: the value stream to be improved is determined, with its start and end points;
- 2) *Drawing the current state map*: the current situation (state) of the flow of material and information in the value stream is described, including all available information (tasks, costs, time for each task, delays in between stages of the process, etc.). To produce the current state map, a team observes the manufacturing processes and documents facts (cycle times, buffer sizes, personnel requirements, etc.) which are described in the map with standardized icons (see Braglia et al. 2006 for a list);
- 3) *Assessing the current state map*: the procedure analyzes qualitatively whether each process activity is adding value, so that the system anomalies are identified. In particular, the so called Key Performance Indicators (KPI) are introduced as relevant metrics to measure both the material and information flow (e.g., lead time, inventory, etc.). The detected imperfections in the flow (i.e., non-satisfactory values of KPI) are signaled by means of icons called *bombs* and evaluated quantitatively using several matrices and vectors that are described in the sequel.
- 4) *Drawing the future state map*: the subsequent step is to re-design the overall picture of the system eliminating (a number of) the identified non-value adding activities. Hence, the future state map is drawn, describing the ideal future state of the system and showing the desired way in which the process in the stream should look in the future after the elimination of the (top) critical points;
- 5) *Updating the value stream*: the identified improvement plans are implemented in the system, so that the envisaged future state can be obtained.

Obviously, to ensure continuous improvement and to verify the implementation plans, the VSM procedure is continuously iterated, i.e., it is recursively repeated at least annually.

3.2 The current state map

With reference to the case study, the UL is identified as the value that flows through the warehouse. It consists of goods that: come from the internal or external production; are stored in the warehouse; are prepared for shipment; are loaded onto trucks.

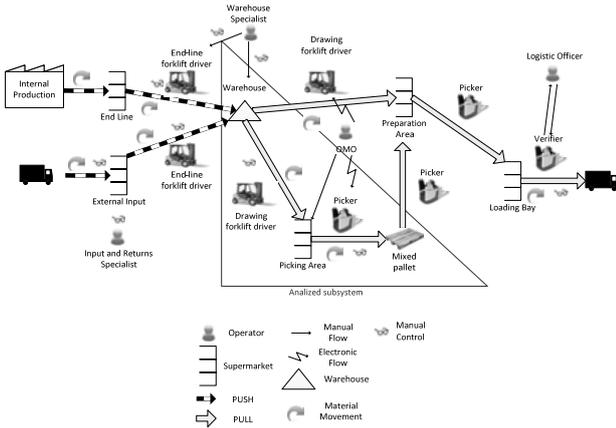


Figure 6: The overall warehouse current state map.

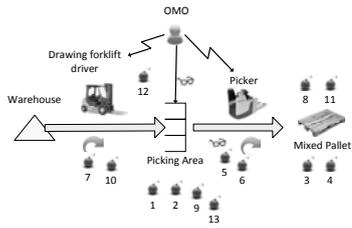


Figure 7: The analyzed subsystem current state map with bombs: picking and mixed pallet preparation.

Applying VSM to the warehouse allows obtaining the overall current state map in Figure 6, showing the object flow, from left to right, and the information flow from right to left. Other symbols are described in the legend. In particular, Figure 6 depicts graphically all the actors and supply policies. More in detail, UL are received from production according to a push policy (labeled by the so-called *Push Arrow Icon* in Figure 6) while they are stored and retrieved by a pull strategy (labeled by the *Pull Arrow Icon* in Figure 6). Hence, as mentioned in the previous section, the F. Divella SpA production warehouse is the decoupling point between production and distribution: it receives UL in presence of incoming goods and supplies them in presence of an order. More precisely, if an output order is active, the goods are moved to the loading bay, where a so-called “supermarket” inventory structure is available to pickers. This is a stock with a suitable inventory policy, signaled by the so-called *Supermarket Icon*, with daily supply and a re-order logic based on a visual check performed by the assigned employee, who verifies whether the supermarket containers are empty and, if this is the case, requests the supply. Figure 6 also shows that UL are prepared in the picking area if mixed pallets are required in the order. Otherwise, if a complete pallet is required, the UL is retrieved from the racks and it is put in the preparation area without any additional job. Hence, all the UL required by the order are moved to the loading bay, where the operations of verification and truck loading are performed. Figure 6 shows in a triangle shape the analyzed sub system of the production warehouse, consisting in the bulk packages picking activities. The corresponding current state map is reported in Figure 7, with the identified anomalies, each depicted by a bomb icon and detailed in the sequel. We select such a sub-system since it

is the most affected by errors, leading to quality loss. Indeed, in the current configuration all picking operations are performed manually: pickers use a PDA showing for each format the number of parcels to take, but not providing any additional information. Hence, pickers are free to dispose parcels on the pallet as they prefer. The lack of a scheme and the fact that operations are performed manually lead to errors, with an error probability of about 0.3% (i.e., assuming that the order is composed by row details, 3 rows are wrong on average over a total of 1000). Although such an error probability is low, it still leads to significant profit losses, since each mistake corresponds to several costly actions to solve the problem, namely, returns management, restoring, and shipment.

3.3 Waste identification and evaluation

To identify waste, the so-called Shikumi approach (Womack and Jones 1996) is adopted, consisting in going physically on the field, when a problem occurs, and interviewing all the involved people. According to this philosophy, the team examined the process and wrote down on a paper all the detected anomalies, summing up to 13 main problems as depicted in Figure 7 and depicted in the waste or muda matrix in Figure 8. Such a matrix leads us to immediately understand that current problems in the warehouse are generated by a lack of ICT and automation, producing wasted time, unnecessary movements and over-processing. Moreover, denoting by p the number of bombs in the current state map, we define the correlation matrix $\mathbf{C} = \{c_{ij}\} \in \{0,1\}^{p \times p}$, as a binary square matrix of dimension p that allows comparing in a pairwise manner each bomb and assessing the degree of correlation between them. In particular, the generic element c_{ij} of \mathbf{C} with $i, j = 1, \dots, p$ and $i \neq j$ is set equal to 1 (0) if the i -th identified problem is (is not) correlated with the j -th identified issue. Moreover, the generic diagonal element of \mathbf{C} c_{ii} with $i = 1, \dots, p$ is set equal to zero. Hence, the correlation vector $\mathbf{CV} = \{cv_i\} \in \mathbb{N}^p$ is determined such that each element cv_i of \mathbf{CV} equals the summation of the elements in the i -th row of \mathbf{C} , i.e.:

$$cv_i = \sum_{j=1}^p c_{ij} \text{ for each } i=1, \dots, p. \tag{1}$$

	Overproduction	Underproduction	Movements	Space	Waiting time	Safety	Overprocessing	Problem	Man	Method
1			x	x			x	Picking places with repeated references	x	x
2	x				x		x	Picking places with missed references		x
3			x		x	x	x	UL bases not stable	x	x
4			x	x	x		x	UL not saturated	x	x
5			x	x	x	x	x	Obstacled paths	x	x
6			x	x	x	x	x	Repeated paths		x
7	x						x	UL prepared with earliest deadline		x
8			x		x	x	x	UL height not optimal		x
9			x	x	x		x	References difficult to find		x
10			x	x	x		x	UL can be allocated on a not pre-determined place		x
11			x	x	x		x	Pallet-arranging-schema not automatically controlled		x
12	x		x	x	x		x	Picking Area provisioning not automatically controlled		x
13			x	x	x		x	Picking Paths not automatically controlled		x

Figure 8: The waste matrix.

Therefore, the generic correlation vector element quantifies the level of correlation of each issue with respect to the other problems. The higher such a correlation, the higher the corresponding vector element.

Subsequently, the priority matrix $\mathbf{P} = \{p_{ij}\} \in \mathbb{Z}^{p \times k}$ is computed, evaluating the impact of each identified issue on each of the k selected KPI. In particular, the generic element p_{ij} of \mathbf{P} with $i=1, \dots, p$ and $j=1, \dots, k$ is set equal to 1 (-1) if the i -th identified problem has a positive (negative) impact with the j -th chosen KPI. Moreover, note that we set $p_{ii}=0$ when no impact is detected. Hence, the priority vector $\mathbf{PV} = \{pv_i\} \in \mathbb{Z}^p$ is determined such that each element pv_i of \mathbf{PV} is set equal to the summation of the elements in the i -th row of \mathbf{P} , i.e.:

$$pv_i = \sum_{j=1}^k p_{ij} \text{ for each } i=1, \dots, p. \quad (2)$$

In this way, the priority vector values quantify how each issue impacts on the chosen KPI. The higher such a priority, the higher the corresponding vector element.

The analysis is completed by summing up the two vectors and obtaining the so called double correlation vector $\mathbf{DCV}=\mathbf{CV}+\mathbf{PV}$, whose elements quantify the severity of the issues in the current state map. Hence, the greater the value of such elements, the greater the need for an immediate resolution to the problem.

The correlation matrix for the case study is represented in Figure 9, whose last column reports the correlation vector. Examining Fig. 9 we remark that:

- issue 11 “Pallet-arranging-schema not automatically controlled” in the waste matrix relates to 3 more bombs;
- issue 12 “Picking area provisioning not automatically controlled” relates to 5 more problems;
- issue 13 “Picking paths not automatically controlled” in the waste matrix relates to 3 problems, too.

In order to classify the problems importance the following KPI are selected:

1. error percentage, i.e., the percentage of wrong lines in an order;
2. profit, i.e., the number of shipped parcels per hour;
3. service quality, detected by interviews.

The overall ranking of the issues is reported in the last column of Figure 10, reporting the priority matrix and vector with the double correlation vector. It is clear that issues 12, 11, 13 are those requiring an urgent action plan, in a descending order of importance. To solve these issues we propose in the subsequent section to set up a dedicated Warehouse Management System (WMS).

Problem Description	Picking places with repeated references	Picking places with missed references	UL bases not stable	UL not saturated	Obstacled paths	Repeated paths	UL prepared with earliest deadline	UL height not optimal	References difficult to find	UL can be allocated on a not pre-determined place	Pallet-arranging-schema not automatically controlled	Picking Area provisioning not automatically controlled	Picking Paths not automatically controlled	CV
cv1	Picking places with repeated references													1
cv2	Picking places with missed references													1
cv3	UL bases not stable													1
cv4	UL not saturated													1
cv5	Obstacled paths													1
cv6	Repeated paths													1
cv7	UL prepared with earliest deadline													1
cv8	UL height not optimal													1
cv9	References difficult to find													1
cv10	UL can be allocated on a not pre-determined place													1
cv11	Pallet-arranging-schema not automatically controlled													3
cv12	Picking Area provisioning not automatically controlled	1	1											5
cv13	Picking Paths not automatically controlled													3

Figure 9: The correlation matrix.

cv _i	Description	CV	KPI			PV	DCV
			Error percentage	Profitability	Service Quality		
cv12	Picking Area provisioning not automatically controlled	5	1	1	0	2	7
cv11	Pallet-arranging-schema not automatically controlled	3	1	1	0	2	5
cv13	Picking Paths not automatically controlled	3	1	1	0	2	5
cv6	Repeated paths	2	0	1	0	1	3
cv9	References difficult to find	1	1	1	0	2	3
cv10	UL can be allocated on a not pre-determined place	1	1	1	0	2	3
cv1	Picking places with repeated references	1	1	0	0	1	2
cv2	Picking places with missed references	1	0	1	0	1	2
cv3	UL bases not stable	1	0	1	0	1	2
cv4	UL not saturated	1	0	1	0	1	2
cv5	Obstacled paths	1	0	1	0	1	2
cv7	UL prepared with earliest deadline	1	0	0	1	1	2
cv8	UL height not optimal	1	0	1	0	1	2

Figure 10: The priority matrix, the priority vector and the double correlation vector.

4 VALUE STREAM MAPPING: PROPOSED SOLUTION

4.1 The Proposed Solution: A Warehouse Management System

In order to remove the identified system anomalies, we propose to implement an automated control of the picking area, pallet layer schemas and pickers paths by a dedicated Warehouse Management System (WMS). A WMS is an ICT system used to physically control the warehouse database (Shiau and Lee 2010): it is a driven computer application used in logistics to improve the efficiency of the warehouse by directing cutaways and to maintain accurate inventory by recording warehouse transactions. WMS is a key tool in warehouse managing because it coordinates all activities, such as UL movements, UL storages, transactions, shipments, returns, picking, etc. WMS embeds the so-called Warehouse Control System (WCS) that handles real time warehouse activities (Tompkins and Smith 1998). In fact, WCS optimizes all operational processes, material handling and activities, providing a common control interface for all machinery, such as automated storage/retrieval systems, carousels, conveyors, palletizers, etc. WCS is interfaced to WMS in order to share information relevant to warehouse management. Usually, WMS uses Auto Id Data Capture (AIDC) devices in order to reduce errors, such as: laser optical scanner for bar-codes, data matrix, remote PDA, wireless LAN, active and passive radiofrequency devices (TAG or transponders).

Some advantages characterizing WMS are as follows: balancing work among all sub-systems involved in the logistic flow, assigning real-time optimized jobs to operators, availability of UL sorting algorithms, optimizing picking paths, optimizing retrievals, etc. Besides, WMS provides, together with WCS: improved precision and

efficiency, eliminating the use of paper; reduced errors; better operation control; improved quality control, reducing order fulfillment cycle times by ensuring timeliness and precision; reduced manpower costs by fewer training requirements; increased storage capacity by an efficient use of available spaces and stocks arrangement according to requirements; reduced emergency stocks thanks to the analysis of historical data with efficient methods; fast and readable reporting; easy to use graphical human-machine interface; efficient historical data archives. Hence, the main focus of WMS is to provide an automated platform in order to: manage information relevant to storage; provide a logic representation of material and information flows; coordinate in the best way picking related operations.

According to the WMS solution, we draw the future state map of the proposed solution, realizing that it leads to eliminating all bombs and manual controls, thus reducing the error probability and increasing profitability (see Figure 11). Obviously, the implementation requires the KPI monitoring of the novel solution, so as to estimate how much this action plan corresponds to our expectations (reduction to zero of error probability, profit and service quality increase). Clearly, applying in a recursive way the method described in this and in the previous section, all improvements are identified and quantified.

Drawing the future state map of the overall warehouse in Figure 12, we can subsequently describe by UML the macro activity diagram of the production warehouse by a top-down approach taking into account the WMS in the novel solution (see Figure 13). Just as in the current state of Figure 2, also in the proposed solution of Fig. 13 we can distinguish between two main flows: Input Goods Order Fulfillment (solid box) and Output Goods Order Fulfillment (dotted box).

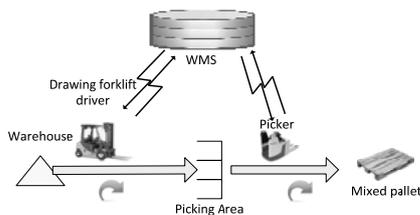


Figure 11: The subsystem future state map with WMS.

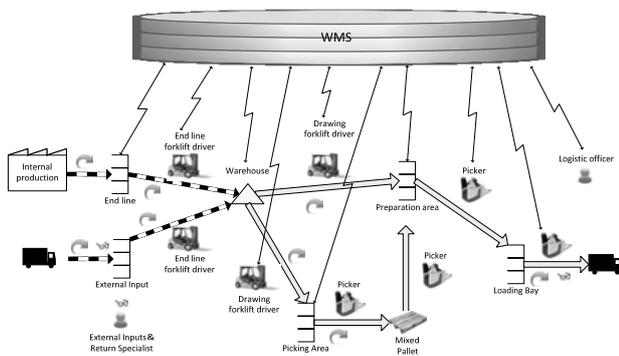


Figure 12: The overall warehouse future state map.

4.2 The Input Goods Order Fulfillment Flow

In the novel configuration the role of the end of line PLC is enhanced (solid box of Figure 13): this PLC labels all UL in input to the warehouse, and works in communication with the WMS. More in detail, when a UL has to leave the production line, the PLC receives the UL parameters from sensors, reads the UL bar-code and transmits these data to the WMS. This receives data also from the Sales Department and, if necessary, it requires the action of the Input&Returns Specialist, who keeps role and activities of the current configuration in Figure 2, so that returns management activities are unchanged in Figure 13 and Figure 2. Upon receipt of data from the Input&Returns Specialist and/or the end of line PLC, the WMS processes them, checking for correspondences. Then it performs the ABC analysis (that was originally performed by the Warehouse Specialist as detailed in Figure 3), according to the activity diagram in Figure 14. In particular, the WMS verifies the warehouse state and based on this it chooses the UL location on racks in the main warehouse (class A, in such a way to minimize goods movements, and class B, anywhere else) or in the backup warehouse (class C products). Accordingly, the WMS sends label data to the automated printer installed on the end-line (or to the Input&Returns Specialist if the goods come from outside the company) that prints label to put on the UL indicating its storage allocation. Hence, in this new configuration the ABC analysis is performed in real-time, constantly providing information on the updated warehouse state. On the contrary, in the current configuration data are provided periodically and manually by the Warehouse Specialist. In addition, assignments to end of line forklift drivers are automatically determined, with a dedicated priority algorithm, and performed using PDA that show exact UL rack locations and warehouse information (main or backup). Finally, bar-code reading activities are unchanged from Figure 2.

4.3 The Output Goods Order fulfillment Flow

The flow is initiated by the Sales Office, who communicates all order details to the WMS (see the dotted box of Figure 13). Then the order to dispatch is flagged according to commercial agreements. The WMS selects the most suitable carrier for the shipment using information on available carriers stored in the WMS database and applying a rostering algorithm when multiple carriers with the same features are available. Hence, the Logistic Office confirms or modifies, if necessary, the proposed solution. So, in this new configuration the WMS replaces the current Optimization and Management Office of Figure 2: as soon as it receives confirmation by the selected carrier, it sends missions to drawing forklift drivers and picking schemes to pickers. Upon completion of the preparation phases, the WMS coordinates control and loading operations performed by the Verifier. Finally, it receives all information on the loading operations and, when finished, grants automated support to the Logistic Officer to authorize the shipment.

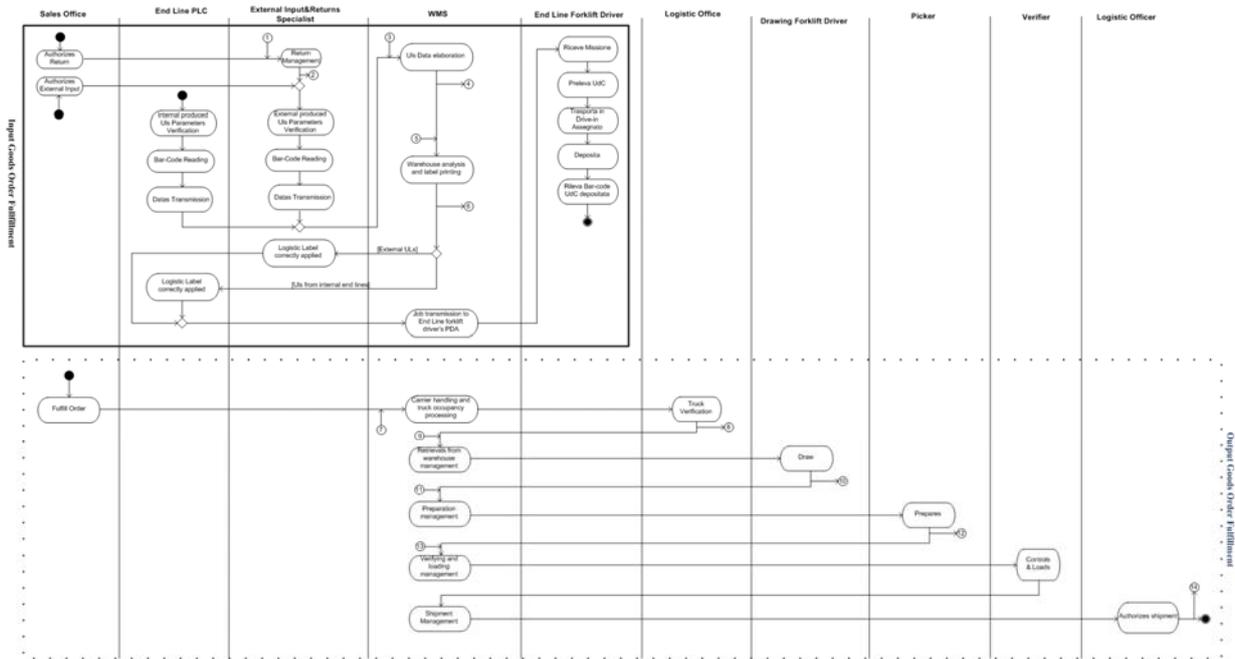


Figure 13: Macro activity diagram of the company production warehouse (proposed solution with WMS).

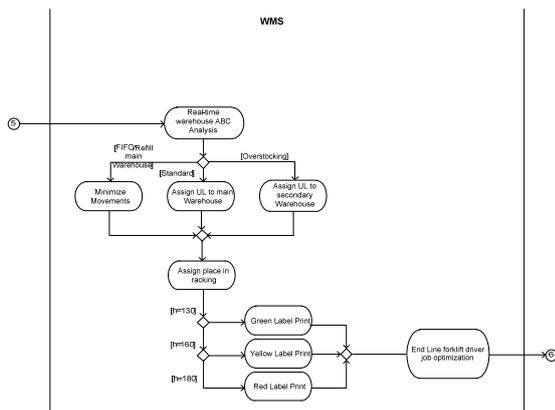


Figure 14: UML Activity Diagram: WMS – ABC Analysis based Warehouse management and logistic label printing

5 CONCLUSIONS AND FUTURE DEVELOPMENTS

This paper presents a lean warehousing approach dedicated to the design, analysis and optimization of production warehouses. To describe the technique, we employ the internal logistics of a world leader manufacturer of pasta as a case study.

The approach employs a top-down view and applies the well-known Unified Modeling Language, Value Stream Mapping, and Shikumi methodologies. The integration of such techniques allows detecting the real criticalities of the system processes and assessing them quantitatively, in order to identify the most appropriate response actions to achieve the desired improvement. The technique is applied to the case study with a focus on mixed pallets picking operations that are characterized by the highest percentage error in the warehouse. The analysis demonstrates that the problems

affecting the picking operations efficiency are caused by the absence of an automated control of the composing phases. We show that the adoption of a Warehouse Management System (WMS) supported automated system would optimize the production warehouse, leading to increases in profitability and quality level, as well as to reductions in error probabilities.

Future research directions consist in extending the procedure application to the whole production warehouse of the case study, enhancing the approach including simulation as a final step to dimension the WMS, and adopting a lean view for the external logistics.

ACKNOWLEDGMENTS

The authors wish to thank F. Divella S.p.A and particularly the Logistics Department with its head Eng. Vincenzo Marrone for their support in the preparation of this paper.

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