Design of a centralized warehouse layout and operation flow for the automotive industry: A simulation approach

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Abstract

Nowadays, world dynamics and the competition between companies are becoming more aggressive, such as the automotive industry, so their industrial and business models need to be transformed as well to compete. More products with high complexity lead to an End to End Logistics model design, but the implementation becomes tough and difficult. The main purpose of this project was to elevate the performance execution of the materials storage strategy, designing and simulating the operation flow of a centralized warehouse, in order to reduce missing critical materials and controlling the supply of the materials at the assembly lines. The designed model is supported by lean techniques and warehouse design and management techniques, integrating different tools to identify non-value adding activities and, therefore, to design a lean material flow, distribution, and operation of the new flexible and integrated storage center facility. The supply chain also become redesigned improving the KPI's performance at the assembly lines. Previous lean manufacturing studies and its effects were mostly applied to production systems, whereas lean studies in warehouse are scarce. This document provides a substantial contribution for the design of material supply systems using lean principles improving performance of the centralized storage operations and the supply to the shop floor according to the simulation results.

Keywords

Centralized warehouse design, Automotive industry, Inventory and warehouse management, Material supply strategy, Lean principles.

1. Introduction

The objective of a supply chain must be to maximize the total value added. The planning and control of logistics activities require accurate estimates of product and service volumes that will be handled by the chain. Derived from this, one of the basic reasons for using a storage space is to coordinate the supply and demand of an organization.

The warehouse plays an essential role in the operations of the supply chain, since it is used for the storage of material, distribution, and consolidation of the necessary inventory to satisfy the demand. That said, the complexity of the business model in Daimler Buses Mexico and the seasonal demand for its products are a priority need for the storage and administration of its materials and products in its logistics network.

The objective of this project, developed for the Daimler Buses plant located in García, Nuevo León is to design the flow and layout of a consolidated warehouse, as well as the operation and handling of materials within the storage system in order to supply the company's demand, taking into account its fluctuation and variation over time. In this way, the project is a logistics strategy for the improvement of service at the supply chain level.

1.1. Problem statement

Since 2014, the chassis assembler company has rapidly extended its business model. Just 3 years ago, they assembled 3 families of chassis and 15 variants. Now, they assemble 6 families and 32 variants. To make this possible, the company has a wide network of suppliers worldwide, having a list of more than 40 suppliers, where 73% are international providers.

This vast number of suppliers and the rapid growth of the business model were reflected in the fact that the storage strategy also grew irretrievably in order to maintain the operational capacity required by the business. Today, the plant has 3 material warehouses, one in-plant warehouse and the other two located near the plant.

However, even with the storage capacity insured, with regard to inventory turnover, there is an average of 6.5 turns, which is approximately equivalent to the material being used every 55 days in the year, whereas the ideal turns should be 16, or, every 22 days. In the same way, the value of the inventory in the 3 warehouses is more than $24 MOD, when the strategic objective of the company establishes that it should not exceed $13.5 MOD.

On the other hand, even with this total in the value of the inventory of materials and the low turnover, the inventory of dead units[1] produced is 62% per month on average, according to the record from March to June 2017. If this is separated by the responsible areas, the 19%, corresponding to almost 200 dead units, is attributed to missing material in storage, as can be seen in Figure 1, where the main cause of these shortages is the difference in physical inventory against inventory accounting.

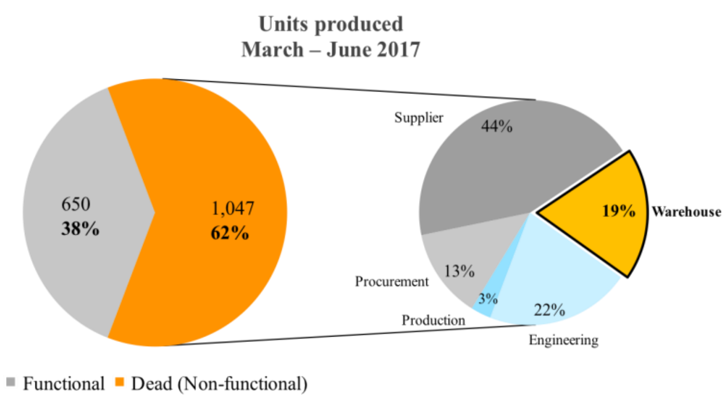

Figure 1. Units produced from March to June 2017.

1.2. Objective

[1] Dead unit: Non-functional unit produced by Daimler Buses México. In other words, it is a chassis that does not turn on due to a critical missing material.

This project objective was to design the flow and operation of a consolidated warehouse in order to improve 20 p.p[2]. in the OTIF[3] indicator for the supply of raw material. This objective is intended to be achieved through: a) defining a material inventory strategy, b) designing the flow of material, arrangement and operation of the consolidated material warehouse, c) establishing performance indicators for the consolidated warehouse: decrease 10 p.p. stock out and increase 3 p.p. in the reliability of inventory in parts classified as type A[4].

2. Methodology

The PGIS[5] methodology is a structured form of intervention systems, both soft and hard, which aims to develop solutions and action plans to improve a current problem to a desired situation. This process is shown in Figure 2 and consists of four major stages that are: 1) pre-diagnosis, 2) analysis, 3) design and 4) implementation.

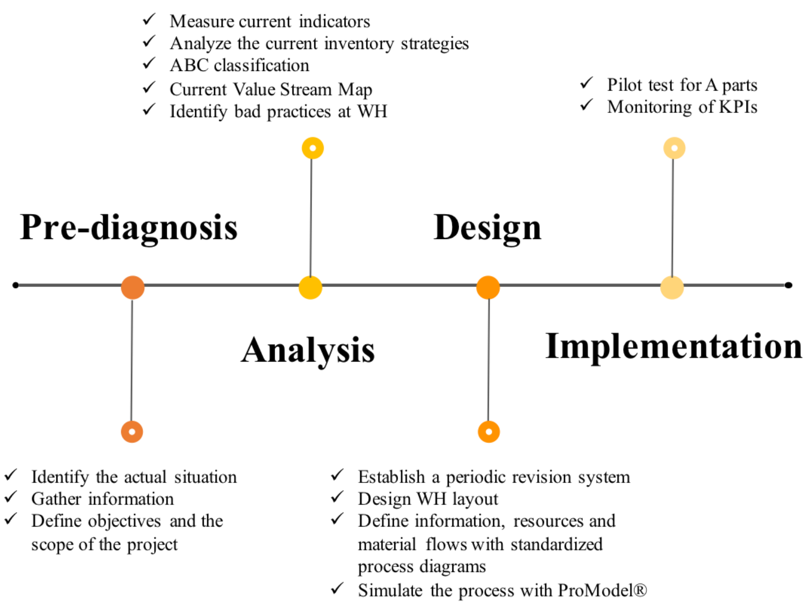

Figure 2. Implementation of PGIS methodology.

3. Analysis

The main objective of this section is to identify the situations that are causing the poor functioning of the warehouses and the lack of material in the assembly line. It explains the analyzing tools and findings on which the improvement proposals are based.

3.1. Inventory Analysis

3.1.1. ABC Classification

The basis of the ABC classification is the Pareto Rule, which establishes that 80% of the effects are the consequence of only 20% of the causes, which is useful in logistics for categorize and identify the important products that make up the largest percentage of the inventory value. So, the materials with greater consumption by the production line from

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[2] PP: Percentage Points

[3] OTIF: On Time, In Full. This means that all orders shipped from the consolidated warehouse arrive on time and complete to the plant, with the correct documentation and without damage.

[4] According to ABC Inventory Classification methodology.

[5] PGIS (in spanish): General Process of Systems Intervention

2016 to 2017[6] were identified and resulted in 3,090 SKUs[7]. On the other hand, the record of all the materials that have been used since 2004 was a list of 15,857 SKUs.

Once the information was gathered, the equation used to classify the inventory was the following,

$$C = P \times D \qquad \text{Equation 1}$$

Where P, the purchase cost per unit times D, the annual demand of each material, results in C, the annual demand in cost. In this way, it was possible to classify the material in the ABC categories, leaving 85% of the annual consumption in cost for materials A, 10% for materials B and 5% for materials C, these criteria were defined in conjunction with the company.

Table 1. Daimler Buses Mexico ABC Classification resume

Classification	**A**	**B**	**C**	**O[8]**
Annual consumption in cost	85%	10%	5%	-
Materials quantity	324	489	2,277	12,767

3.1.2. Lack of material analysis

Following the incidences of non-functional units in the assembly line, from March to June 2017, a total of 2,217 ANDON alerts were recorded due to lack of critical material and a non-existent replenishment strategy. According to the frequencies per material, a Pareto diagram was made and resulted that half of the materials that most affect the line are type A.

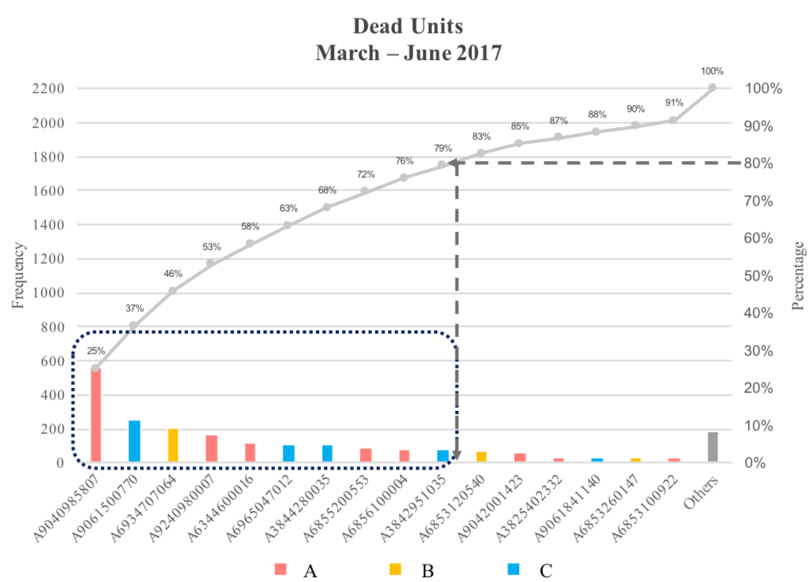

Figure 3. Dead units by lack of material within March - June 2017.

[6] The materials used from 2016 to 2017 are the unique active materials.

[7] SKU: Stock Keeping Unit

[8] Materials from 2015 and before that are considered as obsolete.

3.2. Logistics Process Analysis

3.2.1. Current Value Stream Map

The value stream map shows the flow of materials and information from the supplier to the customer (Rother & Shook, 2009). In this case, the VSM of the CKD[9] material flow was constructed from the Brazilian supplier until the finished product is released. This material is the worst-case scenario, since its delivery time is the longest and most complex. The VSM is presented in Figure 4.

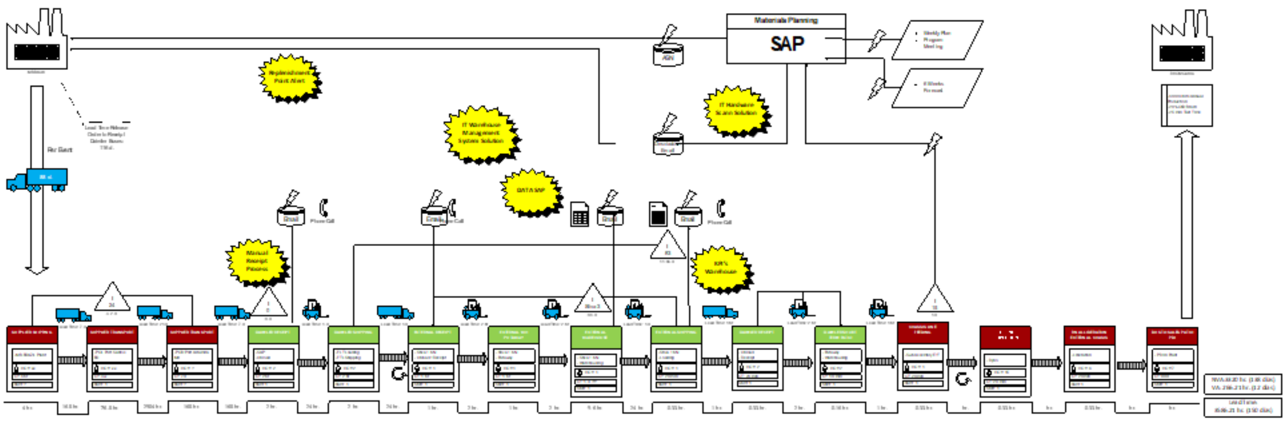

Figure 4. Value Stream Map of the CKD Brazilian Supplier

Due to this mapping, it was possible to identify some solution proposals for the design and improvement phase, which are the following:

1. Warehouse performance metrics
2. Information technology hardware: scanners
3. SAP data modules
4. Warehouse Management System
5. Reorder point and replenishment alert
6. Process of entry of material into the system

4. Design

The objective of this section is to explain the proposed solutions which are based on the findings in the previous phase.

4.1. Proposal 1

The first proposal was created in order to achieve a strategy for inventory that seeks to eliminate the lack of critical material in the production line by optimizing inventory levels and ensuring the supply of materials.

4.1.1. Periodic Revision

According to Toomey (2000), the advantages of this technique are that it creates a single purchase or requisition, as well as provides the ability to order items of slow movement in smaller quantities. In this system, there is no fixed order quantity, but orders are placed in quantities according to the determined supply levels (p.81).

The factors that determine these levels are demand (D), lead time (Lt), review period (T) and safety stock (SS). The review period or review interval is calculated based on the operation plans, lot size and inventory levels. Thus, if the review period is weekly, then the average lot size should be the weekly demand.

[9] Complete Knock Down material kit for one chassis unit assembly.

As already mentioned, one of the objectives of the project was to establish a system of administration and control of inventory of materials, to maintain an optimum level of supply of inputs for the production plant. Likewise, this system exercises strict control over the inventory levels to avoid missing critical materials and excesses of other materials, which are the main problems of the project.

With this, we referred to Piasecki's (2009) mathematical model, which includes the periodic review system where the maximum inventory levels (M) are calculated, or, the objective level of the inventory. The available inventory will never reach that level unless the demand of the production line ceases during the time of production. This system is described in the following model:

$$M = D(T + Lt) + SS \qquad \text{Equation 2}$$

Where,

M	Maximum inventory level
Lt	Lead time
D	Demand rate
T	Duration of the review period
SS	Safety Stock

With I as current inventory and Q as order quantity, the order quantity is equal to the maximum level minus the available quantity of inventory:

$$Q = M - I \qquad \text{Equation 3}$$

$$Q = D(T + L) + ss - I \qquad \text{Equation 4}$$

4.2. Proposal 2

This proposal is the most inclusive because the whole system with its components is developed within it. Its objective is related to the design of the infrastructure, flow, and operation of the warehouse.

4.2.1. Material Decision Algorithm

An algorithm was made for the decision making regarding the placement of the different part numbers in the consolidated warehouse. The objective was to have a functional and standardized logic for storage, to increase the inventory reliability due to not having a record of where the material was stored.

The first decision that is made is the category of the part number that is received, the part numbers classified as 'GLT[10]' are those that are above 2 kg, so they are categorized as large. Whilst, part numbers classified as 'KLT[11]' are those that are below or equal to 2 kg, so they are categorized as small.

Once the category is identified, the decision flow is continued, which in this case would be to verify the type of container in which it arrives. There are four possibilities of container type:

1. A part number per container. E.g. Engines
2. Same part number in more than one container. E.g. Fans, transmissions, air tanks.
3. More than one-part number per container. E.g. The boxes that arrive from international suppliers.
4. Not controllable. E.g. Screws, gears, nuts.

Subsequently, the material passes to the cross-dock area, where the part number is processed, and it is identified in which Pool of the production line the material is used. This is important since the racks are identified by pool according to the production line. With this we move on to the next decision that is once the material is identified by Pool we need to see where it will be stored, meaning which rack. After identifying the rack, we take into account the product's

[10] GLT: Großladungsträger. German word meaning 'the containers for big bulk'.

[11] KLT: Kleinladungsträger. German word meaning 'containers for small bulk'.

category (A, B or C). Finally, the construction group is considered and then the station to which it will arrive in the production line. Depending on all the above is where in the rack the product will be stored.

4.2.2. Calculation of storage and areas in the centralized warehouse

Daimler Buses Mexico had only the rented space for where the consolidated warehouse would be, everything was on blueprints, nothing was constructed yet at the time, but it was important for the project to make the necessary calculations in order to design the layout of the warehouse. Therefore, for the calculation of the general warehouse area, the part numbers were divided into two categories, the GLT and the KLT. For the large materials, GLT, a container that can withstand the weight of 900 kg and the volume is 8.46 cubic meters was defined and for the small materials, KLT, a container of 16 kg and 0.016 cubic meters, this was due to the standard used by Daimler. The steps for calculating storage were the following:

1. Calculating weight and total cubic meter

The weight and total volume of each one of the SKUs is calculated. That is done by multiplying the weight or volume by the maximum inventory there is of that material, with this, the weight and total volume is obtained.

2. Calculating containers

The containers for each material were calculated, to do this the result obtained in the previous step was divided by the capacity of each one of the containers (900kg or 16kg). This procedure was performed for weight and volume.

3. Determining maximum

The maximum was defined by the number of containers obtained between weight and volume, choosing the option that occupies the most containers.

4. Calculating spaces

The necessary pallet spaces for the GLT containers and the shelf spaces needed for KLT were calculated. For GLT, the number of containers was divided by 4, which are the spaces that are available in each rack and for KLT the number of boxes was divided by 108 which are the shelf spaces that are available.

5. Calculating racks

The calculation for number of racks that will be needed for the warehouse, was to divide the total number of racks by 5, which are the levels that each rack must have due to security issues.

6. Calculating the footprint

In this step the total footprint was calculated, which was obtained by multiplying the number of racks by the square meters that each one covers, plus the square meters of the corridors.

Furthermore, the in-plant warehouse lacks space which is why they do not have a designated area for the segregation of material, this is a problem because when looking for a specific part number this can be found in a container with other part numbers which makes it difficult to collect and process. It is from this need that the cross-dock area is created, where it is planned to carry out the process of segregation and subsequent identification of part numbers to be stored in its corresponding rack.

Thus, for the calculation of the areas of receipt, cross dock and shipping the following formula was used:

$$Total\ Space = \frac{NL \times HU}{TS} \times NP \qquad \text{Equation 5}$$

NL: Number of Loads
HU: Hours of Unloading
TS: Time of Shift
NP: Number of Pallets

4.2.3. Layout of the centralized warehouse

After having carried out the necessary calculations to determine the square meters of each area, the next step was to design the layout in AutoCAD® of the physical distribution of the centralized warehouse.

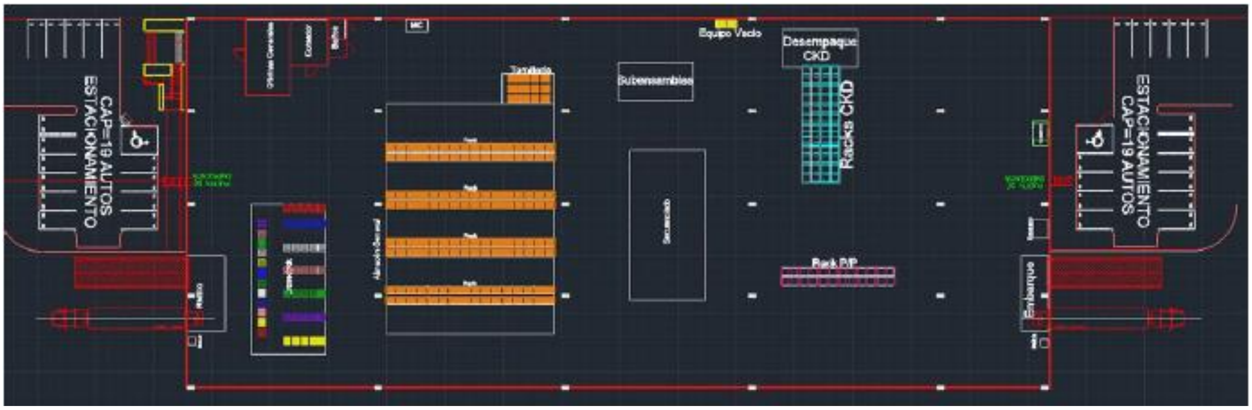

Figure 5. Layout of the rendered warehouse, top view

4.2.4. Warehouse Processes

Due to significant changes in the material storage process, the standard process diagrams were redesigned based on the lean methodology, eliminating all downtime, waste, and inefficiencies within them. These were then later approved by the Daimler Integral Management System, which then was ready for execution in the consolidated warehouse. The process diagrams covered all of the internal logistic processes within the warehouse and were detailed with cross functions to analyze the activities associated with the different areas within the logistics department and, in this way, define responsibilities for each of the actions, contributing to a culture of communication, transparency and continuous improvement for the organization.

4.2.5. Warehouse Management System

Within the definition of the processes in the new consolidated warehouse, it was decided to intervene in the SAP system in order to structure a new automated work methodology that ensures the control of material inputs and outputs in a physical and systematic manner. This would be the key to keep traceability and accuracy of the numerous part numbers that the warehouse employees handle daily.

Accordingly, we worked with the information technology team and managed to purchase two handhelds, which are able to scan bar and QR codes to record the movements of materials. These handhelds would be tested in the pilot test to see the how it worked and if it was adequate for the intended final purpose. The main functions of this tool are: 1) receipt of material, with the entry of the supplier's ASN; 2) the put away of the material, with a transfer order issued by SAP automatically upon receipt of the material; and 3) the output of material, with a transfer order issued by SAP by the production line. With this information it would be able to keep track of all the material movements in the different processes of the warehouse.

4.3. Proposal 3

This proposal aims to visualize and monitor the various performance indicators that influence the warehouse, hence person responsible for the Shop Floor Management is the warehouse supervisor.

4.3.1. Key Performance Indicators and monitoring

Additional to the indicators the company already had, others were proposed, which are going to be calculated, monitored, and presented every day in the shop floor. The indicators are the following:

- Accidents
- Complete kits sent to the line
- OTIF

- Dock to stock
- Pick rate
- Warehouse utilization
- Inventory rotation
- Tons of waste

These indicators are directly related to the Daimler´s operating system, Bus Operating System BOS +, and were determined in order to correctly set the desired focus parameters for the new warehouse.

4.3.2. Shop Floor Management

The key performance indicators will be visually present in the 'floor' of the new warehouse, as "a form of management of operations that facilitates communication and decision making" (Pérez, 2014). The dashboard of K.P.I's manages the control of the activities within the warehouse and allows to standardize the processes, which enables an organizational culture of quality and routine with those responsible and the associates. This achieves the purpose of creating transparency and clarity in the information, managing, and improving communication, stimulating participation, and creating greater value for the client.

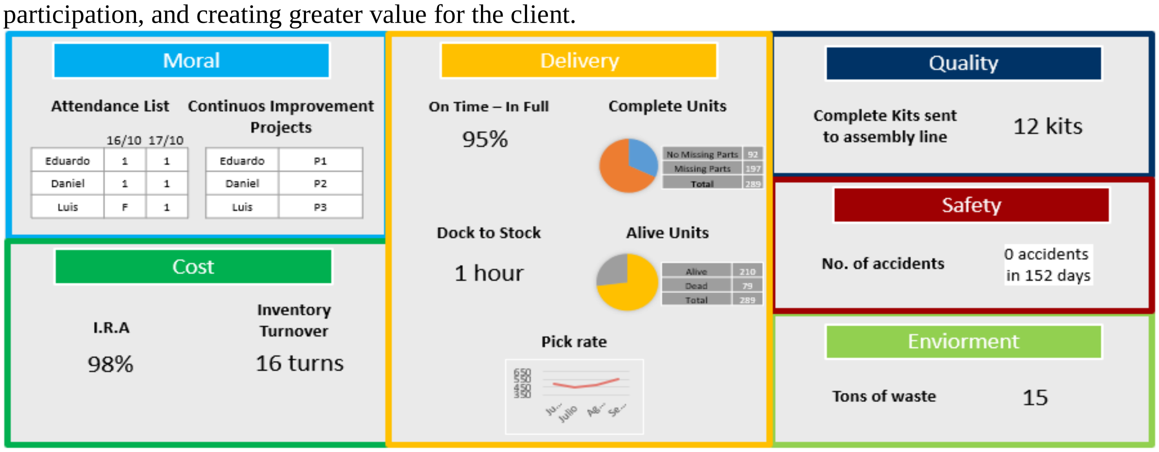

Figure 6. Shop Floor Management Board for the warehouse

4.3.3. Future Value Stream Map

In the previous stage the current VSM was made to analyze the current process, nonetheless to get a better view in this stage the future VSM was made, this would help us compare between both processes and observe the improvements in them.

The desired process was as follows:

- Receipt in consolidated warehouse
- Put away
- Storage
- VA[12] Kitting and just-in-sequence
- Shipment to plant
- Receipt in plant

Making the entry of the material to the SAP-WMS system with a scanner using handhelds. With the appropriate corrections we were able to reduce the lead time to 135 days, which is an 8% decrease from the current VSM.

[12] VA: Value Added Activities

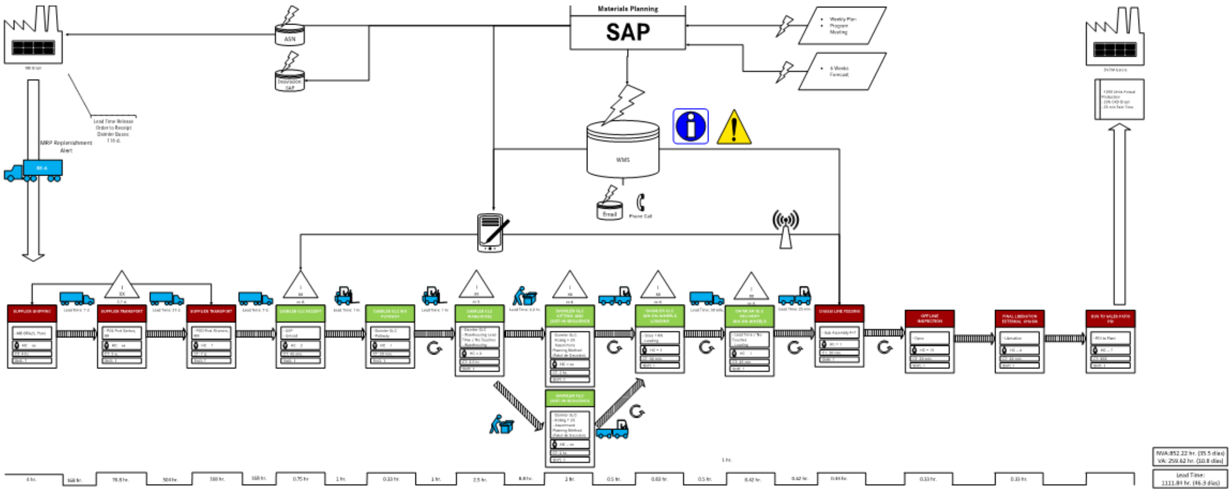

Figure 7. Future Value Stream Map

5. Implementation

This section shows the results of the pilot test of the designed solutions. In addition, within this stage the results obtained are shown based on the objectives proposed from the beginning of the project.

5.1. Pilot Test

A pilot test was carried out, which consisted on running the designed processes and decision flow of the new warehouse. This would help identify the negative effects, wasted resources or downtime of a certain process so that it could later be modify.

5.2.1 Planning

Before starting the pilot test, there were two weeks of preparation, in which the strategy to be followed for the correct execution of the project was defined. Small phases were established to ensure compliance with all the requirements. The duration of the pilot test was one week, which was divided as follows: 3 days for part by part materials and 2 days for CKD materials. For the first option, we used a sample of the materials, which was defined by a list the production line gave us from the missing materials in a certain period and for the second option a full batch of the LO model, which is the high runner of the CKD modality, was used. This would help us measure the designed processes and the different scenarios previously defined.

5.2.2 Training

Prior to the beginning of the pilot test, a training was carried out with the warehouse blue collars. The new processes to be carried in the warehouse were explained and key information was delivered to them. It was also explained, to the warehouse team, the objective of the pilot test and the metrics that would be analyzed during the test. In addition to explaining the new processes, the staff was also trained in the new tools previously designed, such as the SFM[13] and the daily plan of activities.

5.2.3 Execution

As mentioned above the test lasted a week, every day it started with a SFM meeting at 7:00 a.m. There we explained the plan of the day that was to be followed, this meeting was carried out with the warehouse supervisors, warehouse blue collars and the warehouse manager because they are the most involved in the system.

[13] SFM: Shop Floor Management

The pilot test was divided as follows, the first 3 days for part by part material and the last 2 days for CKD material. Each of the processes that were designed in the previous stage were run, some of these processes were modified to see the improvements while the process was running. In addition to the processes that were piloted, improvements were also made regarding the ergonomics of the process.

6. Results

The daily results of the pilot test were monitored through the shop floor management, which includes the indicators of the project.

OTIF
The results were observed day by day and a gradual increase could be noted, reaching the proposed objectives in each of the branches of the indicator. In general, there was an increase of 14 percentage points. In the physical inventory the increase was 26 percentage points, in the no damage it remained 100%, and on time increased by 10 percentage points and the documentation needed was an increase of 32 percentage points.

Inventory Record Accuracy
Once the implementation phase was completed, in which the pilot test was carried out to run the designed processes, we were able to perceive an increase of 3 percentage points was achieved in the Inventory Record Accuracy, reaching 98%.

Stock out
In the case of material shortages, the 10% reduction of critical material on the line was proposed as an objective. However, the previous results show that 32 percentage points exceeded the objective, since it was reduced by 42%. In October, at the beginning of the implementation, the measurement of shortages was 180; while, in November, at the end of the test, the missing measurement was 105 part numbers.

The realization of the piloting was very important because the model designed in the previous stage could be put to the test, obtaining as a result the correct execution of the processes, with the estimated times and planned resources. There was the opportunity to observe the system functioning prior to the full implementation, this was helpful to evaluate the possible risks and to make improvements to the system according to the results obtained.

On the other hand, the objectives of the project were defined from the beginning and as noted in the results section mentioned above, the percentages were met in addition to exceeding the objectives proposed by the team making this a successful intervention.

7. Conclusions

One of the transcendental logistical decisions in an organization is the way in which inventories are handled. During the project, methodologies served as support during the planning and construction of the logistics and storage strategy. With this, "the allocation of inventories to the storage points against the exit to the storage points by inventory supply rules, represent two strategies" (Ballou, 2004, p. 40). The selective location of different items in the centralized warehouse and the management of inventory levels through the use of different methods of inventory control, are other strategies.

Taking this into account, the intervention of the team was of utmost importance for the organization, because the proposed strategic objectives of service improvement were met, and even exceeded. In general, the main objective of the project is a guide that will serve as a reference in the new warehouse to monitor and control the level of service of warehouse to the production line, where the inventory reliability is assured and leads to a minimum reduction of shortages of material on the line.

According to this, it is stated that "distribution, when it provides the adequate levels of service to meet the client's needs, can lead directly to an increase in sales, greater market share and, finally, to a higher contribution and growth of profits" (Krenn and Harvey, 1983, p. 593), with which it can be concluded that some of the most important elements of customer service are logistical in nature (Sterling and Lambert, 1989, p.17).

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