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TRABAJO FIN DE MÁSTER

VIRTUAL SIMULATION OF LOGISTIC PROCESSES AT A PHARMACEUTICAL MANUFACTURING PLANT

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Madrid

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SIMULACIÓN DE PROCESOS LOGíSTICOS EN UNA PLANTA DE FABRICACIÓN FARMACÉUTICA

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RESUMEN DEL PROYECTO

LAS modificaciones de los procesos industriales, concretamente en el sector farmacéutico, conllevan una gran inversión y tiempo de afectación al proceso. Para ello las herramientas de simulación permiten crear modelos que reflejen el comportamiento del sistema real y puedan ser utilizados para evaluar diversas situaciones antes de realizar los cambios en el propio proceso. Así, la virtualización, permite una toma de decisiones más fundamentada y bajo una visión completa del proceso junto con una previsión de futuras respuestas del sistema a diversas situaciones y escenarios.

El objeto de este presente proyecto es desarrollar una herramienta de simulación bajo el software SIMIO que permita analizar el funcionamiento del almacén de una planta de fabricación farmacéutica en Alcalá de Henares, Madrid. Durante los últimos años se ha experimentado un aumento de ocupación en las áreas de almacenaje de corta duración del anexo del almacén que son utilizadas para la carga y descarga de materiales como paso intermedio antes del almacenamiento en el silo automático o el suministro a producción. El desconocimiento de las curvas de ocupación a lo largo del tiempo y la experimentada variabilidad del proceso conllevan costes de almacenamiento externo, añadidos a los costes de inventario de la planta, que no están siendo optimizados ni controlados. Para ello, se ha propuesto diseñar un modelo del almacén en SIMIO que permita observar las curvas de ocupación de estas áreas así como evaluar las causas principales de la variabilidad del proceso.

La metodología seleccionada para llevar a cabo el diseño y uso del modelo es de tipo descriptivo/explicativo. Se proponen seis fases para la consecución de todos los objetivos establecidos: estudio y evaluación del sistema real, recolección de datos y adaptación para su entrada al modelo, diseño del modelo, validación del diseño del modelo, obtención de resultados y análisis crítico de los mismos junto a la proposición de recomendaciones para la mejora de los procesos y por último, una evaluación del impacto del aumento de capacidad estimado para el 2023. Algunas de las fases de esta metodología han sido desarrolladas de forma iterativa, sobre todo aquellas de diseño del modelo y verificación del mismo.

Siguiendo la metodología propuesta a lo largo de este documento se presenta un estudio del almacén de la planta así como los distintos procesos, tareas y clasificaciones de los productos fabricados o manipulados. Tras el estudio del almacén, se presenta la herramienta SIMIO junto a los datos recabados y las fuentes de software utilizadas. Los datos de entrada se utilizarán en el modelo para definir los eventos discretos que definen la operación del almacén durante un año completo, que en este caso será el 2018 por ser el último año completo con información disponible. Tras haber recabado los datos necesarios y su acondicionamiento para la utilización en el software SIMIO se ha diseñado el modelo. El presente documento contiene una descripción de la lógica básica utilizada en el software en formato de bloques, y, pese a que hay más condiciones y lógica programada en cada uno de ellos, ésta únicamente ha sido enunciada para explicar las condiciones que delimitan el modelo diseñado. El proceso de verificación que se ha realizado de forma iterativa con el diseño del modelo también se presenta mostrando los diversos criterios evaluados y el grado de satisfacción de los mismos.

Tras el desarrollo del modelo y su verificación se muestra un análisis crítico de los resultados obtenidos mediante la simulación. Se presentan por separado el área de llegadas y de expediciones ya que difieren en tareas, ocupación y tiempos de rotación. Ambas áreas presentan una ocupación con alta variabilidad llegando al límite de su capacidad en los picos, mientras que la ocupación media de las áreas se encuentra por debajo del 50% de la capacidad total de las mismas. En la discusión de estos resultados se demuestra la influencia en la ocupación de las áreas de los métodos de transporte utilizados, los destinos de entrega, los desvíos en las fechas de entregas programadas y el hecho de no poder remontar algunos de los palés de materiales recibidos. Para cada una de estas variables y otros puntos débiles del flujo de trabajo del anexo se presentan recomendaciones que pueden ser implementadas en el propio almacén como medidas correctivas.

Por último, se presenta una evaluación básica sobre el posible impacto de un aumento de capacidad. El estudio se ha realizado basándose en datos esperados de demanda para el año 2023 que ha sido extrapolado a un incremento de flujo de palés siguiendo las curvas de distribución de todas las variables en el año 2018. Los resultados de este análisis muestran que el aumento de demanda esperado influye apenas un 15% en la media de ocupación de las áreas del anexo, (siendo la de expediciones la de mayor variación) pero la variabilidad del proceso se incrementa, siendo los picos de ocupación más pronunciados. Por tanto, el almacén experimentaría los mismos riesgos actuales ante un aumento de demanda futura, siendo necesario reducir la variabilidad del proceso lo máximo posible para así reducir los picos de ocupación y realizar un uso mayor de la capacidad media de las áreas.

En conclusión las áreas de llegadas y expediciones de la planta experimentan una ocupación media por debajo del 50%, siendo ésta muy variable. Evaluando el sistema para el aumento de demanda esperado a cinco años vista se observa que el aumento de demanda total no supera el 15% y que la variabilidad de la ocupación de las áreas aumenta considerablemente. Por ello, se concluye que el principal objetivo del almacén a futuro debería ser suavizar la variabilidad de sus procesos aplicando las recomendaciones que se presentan en este documento sobre las principales variables detectadas como causas de la misma.

VIRTUAL SIMULATION OF LOGISTIC PROCESSES AT A PHARMACEUTICAL MANUFACTURING PLANT

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PROJECT ABSTRACT

ADAPTING and renewing the industrial processes, specifically in the pharmaceutical sector, entails great investments and affects the daily operations. For this purpose the simulation tools are being used in industrial environments to design digital models that reflect the behaviour of real systems. This models can be then used to evaluate different scenarios prior to change the processes or to make relevant investments. This simulation tools allow a more data based decision making as well as possible forecasting of future scenarios impact in the evaluated processes.

This master thesis main objective is to develop a simulation tool in SIMIO software that allows the analysis of a pharmaceutical manufacturing plant's warehouse in Alcalá de Henares, Madrid. During the last years the production plant has experienced an occupation increase of the warehouse annexed areas. This areas are used as short storing locations for the loading and unloading of materials from carriers, making this locations an intermediate step before the storage in the automated silo or supply to the production lines. The lack of knowledge about this areas occupation curve and the experienced process variability leads to external storage costs that are added to the actual plant inventory costs being those neither controlled or optimized. For this purpose, this master thesis propose a SIMIO virtualization model of the warehouse that allows the area occupation observation as well as the evaluation of the different root causes of the process variability. Simulation models have been previously used in the production plant before to model production line investments, but never before

have been modelled logistic processes for its understanding and analysis.

The selected methodology to carry out the model design and experimentation is explanatory and solving oriented. Six different phases are proposed to achieve the proposed objectives: study and evaluation of the real system, data collection and conditioning for its entry in the model, design of the model, validation, pursuing results and critically discussion to propose suitable recommendations that improve the processes, and lastly, an evaluation of a future capacity increase impact. Some of this phases have been performed in an iterative way, specially those of model designing and verification.

Guided by the proposed methodology, a study of the plant's warehouse distribution is presented together with the different processes and task that are performed. Besides this initial warehouse study, the SIMIO tool is presented together with all data collected and the software sources used. This input data will be used in the designed model to define the discrete events that will determine the warehouse operations. Furthermore this document contains the basic logic used in the model designing. The presented logic is in form of programming blocks even though this blocks have inside further logic and restriction conditions. To end with the model designing steps is presented the verification process (that has been carried in an iterative way together with the designing phase) together with the used verification criteria and the fulfillment degree of those.

Once the model is designed and verified, a critical analysis of the obtained results and experimentation is presented. The arrivals and expeditions areas are presented separately since they differ in tasks, occupation curves and rotation times. Even so, both areas present occupation curves along the year with high variability while the average occupation is below the 50% of the areas total capacity. Along this results discussion , the influence of different variable in the areas occupation is presented. This variables are: transport methods used, delivery destinations, carriers delays in deliveries or pick-ups and the unavailability of stacking specific type of arrival pallets. For each of this variables and other founded weaknesses in the annex work-flow are presented suitable recommendations that can be implemented in the mentioned warehouse.

Finally, a basic evaluation and analysis of a capacity increase impact in the warehouse annex is presented. This study was performed based on the expected demand figures for the year 2023, which has been extrapolated to increase the flow of pallets based on the variable distribution curves experienced in 2018. This analysis shows that the expected increase in demand is reflected in a 15% occupation growth of the annex areas (being the expedition area the one varying the most) but the variability of the process occupation increases, experiencing more steep peaks. This analysis indicates that the studied warehouse would suffer the same actual situation being the 2023 performance even more risky due to the increase in variability more than the average capacity occupation.

As a conclusion, the arrivals and expeditions areas of the studied plant's warehouse experience an average occupation below the 50% of its capacity, being this occupation really variable. This variability in the process will be even more sharp in 2023 while the average occupation will only increase a 15% if no recommendations are implemented. Therefore, it is concluded that the main future objective for the warehouse should be to smooth the process variability by impacted in the analyzed variables and to implement the here presented recommendations to improve the warehouse processes.

To the most important people in my life:
my lovely parents and Álvaro.

Thank you for giving me always more that I could ask for.
This success is also yours.

"Lock up your libraries if you like;
but there is no gate, no lock, no bolt
that you can set upon the freedom of my mind."
VIRGINIA WOOLF

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DOCUMENT I

MEMORY

Contents

List of Figures

Chart Index

Acronyms

ICAI	Arts and Industry Catholic Institute
PFC	Master Thesis Project
INE	Statistics National Institute of Spain
GMP	Good Manufacturing Practices
PSS	Product Supply System
SAP	System Applications and Products (ERP software)
ERP	Enterprise Resource Planning
SGA	General Warehouse Management Software
SIMIO	Simulation Modeling based on Intelligent Objects
ISO	International Organization for Standardization
KPI	Key Performance Indicator
ID	Identity Document
WIP	Work in Progress
FIFO	First in First Out
FEFO	First Expire First Out
HQ	Head Quarters
SKU	Stock-Keeping Unit
SMART	Specific, Measurable, Achievable, Relevant and Time-oriented

Chapter 1

Introduction to the Project

THE pharmaceutical industry in Spain is nowadays one of the most productive being the average production a 54 % higher than the rest of the industrial sectors [5]. The pharmacy industry has also a strong economic impact in the country creating a turnover of 13.700 million Euros according to the National Statistics Institute of Spain (INE) [1]. This figures reflect the relevance of the sector and the urge of continuous evolution in terms of technology and business strategy along the years for the business to stay competent. It is because of this that during the last years the manufacturing industry has experienced a disruptive revolution due to the incorporation of automation technologies and digitization into their processes. Furthermore than enhancing the quality and the production efficiency, this technologies have allowed the companies to better organize the production resources and optimize the whole production chain, what we know as industry 4.0.

The pharmaceutical industry has critical product applications and as it is related to consumer health the production methods and outcomes have to be of extraordinary quality. Specifically for this production sector there is a lot of regulation for quality assurance on the manufacturing processes and the facilities used have to follow a vast amount of control and policies. An example of this are the well known ISO 9001, 17025 and 13485. Another important practice in the pharmaceutical manufacturing processes is to apply GMP (Good Manufacturing

Practices) which are used along the value chain and are included inside the quality guarantee concept. This and other regulations also embrace and boost the optimization and efficiency of the production processes along the supply chain from raw materials arrival to the final product expedition for distribution.

Along the value chain of drugs manufacture there are plenty of crucial steps that need to be handle with the required standards. There are several quality checks, quarantine periods, varied expiration dates, cross contamination risks or even the handling risk for operators, associated to some chemical raw materials that are used in the process. All this need of quality assurance and risk control makes the processes upgrading a complex task for production managers. The modelling and simulating tools applied to different parts of the manufacturing processes can help to understand the variables that describe the process or evaluate different scenarios without the risk of affecting the production. This way bottle-necks, bad stock management policy, misuse of warehouses, inefficient use of the resources or any other production management problem that can be happening in the system can be identified and improved to increase and optimize the production.

Since the investments in the pharmaceutical sector are multiple and of great value, the simulation and modeling of possible future developments or investments can help to handle the financial resources of the companies in a cleverer way. In Figure 1 it is presented a graph with the distribution of investment in Spanish pharmaceutical companies.

This data is extracted from the INE reports [3]. The total value of investments is 468 million Euros being those focused on Machinery and tools, technical facilities, land, building construction and improvements. Specially the new investment in technical facilities involves a substantial investment and involve facility changes which profitability and results are usually hard to measure precisely in advance.

As a conclusion, the simulation models and tools allow the companies to use the vast amount of data they collect from their manufacturing processes to generate knowledge value about the process flow and operations. This digital tools also allow the different managers along the value chain to perform

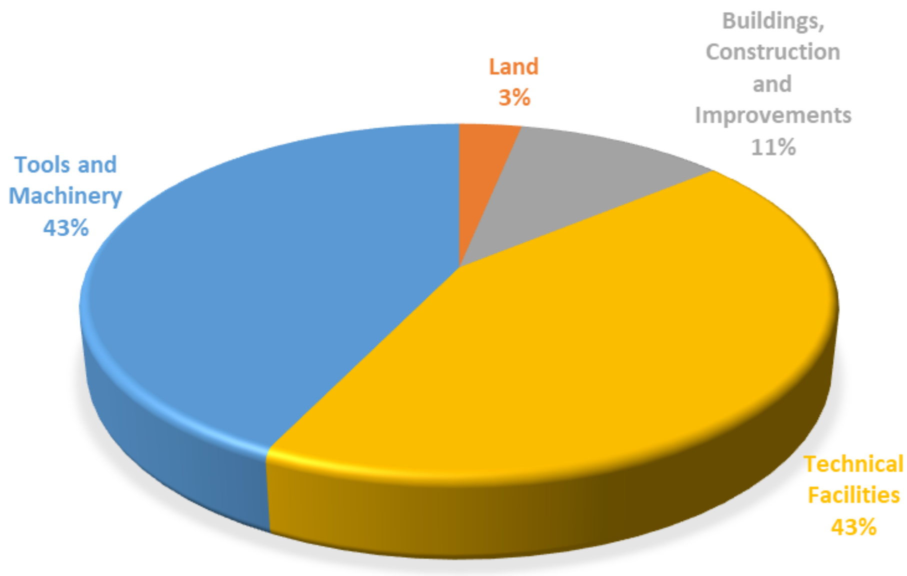


Figure 1. Investments distribution in the Spanish pharmaceutical manufacturing industry [3].

a better management of the available resources either to evaluate the actual systems performance, improve the processes operations or even evaluate different investments.

1.1 State of the Art

The history and evolution of computer simulation has developed parallel to the evolution of the computing systems. The origins of these technique started in the Second World War with two mathematicians J.VNeumann and S.Ulam. Some of the performed experiments during the war were performed by trial and error but this approach was capital expensive and complicated to be addressed by analytic techniques. The simulation has been used since then to imitate and reproduce the behavior of real or complex systems to later perform different experiments with the purpose of understanding the structure behaviors or evaluating different operation strategies for the system in an affordable way.

There are several types of simulation grouped by a wide variety of characteristics. Here are presented the most used ones to define a simulation type.

- **Static or Dynamic:** This classification depends on the role that the time variable plays in the system. If the model is classified as static the passage of time doesn't affect the behaviour of the model. If contrary, the model is dynamic. In case the time shapes the behaviour of the model it can be applied the following classification.
- **Continuous or discrete:** Differences between continuous and discrete dynamic systems arise from whether the changes in the system caused by variable change are in specific instants of time (discrete) or are continuously happening (continuous). The discrete events again can be classified in the next division.
- **Deterministic or Stochastic:** In deterministic systems the events in time are know and constant so the behaviour is predetermined. The stochastic model by contrary are defined by uncertainty where randomness in changing events comes into play. This randomness usually follows statistical functions that have been previously studied as defining the expected variables behaviour.

In this Final Master's Project, the simulation that is going to be carried out is classified as dynamic and discrete. There will be used a deterministic or stochastic approach to simulate depending if is being evaluated the actual system performance or the future capacity limits expectations correspondingly.

Applications of simulation are all across industries as it is one of the most applicable technologies used in the last century. Simulation has been applied in the industry in designing steps, process optimization, problem finding or future expectations analysis. As an example, the European headquarters of the company object of this thesis has carried out various analysis for its different manufacturing plants to optimize and evaluate capacity increases in some production lines. There are other industries that use softwares as Arena, Witness or ExtendSim that are also very intuitive for manufacturing processes. The SIMIO software has been selected for two reasons: the first one is that this software allows an easy introduction of real databases with enormous amount of data to use in the simulation of real time processes, and the second one is that the software has already been used inside the company to perform other studies so this way exist other employees in the company HQ that can help with the development of this project with their previous experience.

The use of modelling simulation has both advantages and disadvantages that are important to know in order to use the tool correctly. Some of the advantages are the following:

- The simulation can be applied in designing phases when the process is still not real in order to evaluate the validity of the design.
- Simulation allows the evaluation of multiple scenarios to find optimal solutions. It is also a valuable tool to evaluate problems in systems' operations.
- It avoids huge investments or fails in design while not interfering with the functioning of processes as the experimentation is carried out of the real system.
- It provides great ease to identify areas that pose a problem in production capacity, either bottlenecks or long periods of inactivity.
- Offers great flexibility to model any type of system no matter how complex it is. The models as well as the obtained results keep improving with the great advances in computer software as well as its processing capacities.

Simulation has also some drawbacks that need to be address in order to make a good use of the tools.

- The simulation does not provide exact solutions, the results it offers are limited estimates within a confidence margin.
- In certain occasions and depending on the complexity of the system, it is not possible to validate the model and thus the results are not verified.
- Modelling the systems need a deep understanding of the processes flow together with a good definition of the scope. When models are too complex is usually needed to do some assumptions to recreate the real systems.

1.2 Problem Description and Motivation

For the studied manufacturing plant, the daily management of the warehouse area is one of the crucial systems in the production process as it is involved in almost any flow of material. In this production site all suppliers arrivals are redirected to the warehouse where the materials are checked, labeled and stored until the production lines make use of it. The production lines are the bottle neck of the entire system so continuous entry flow of materials has to be secured at any moment in time. The expedition rate of finished materials as well as the storage times and the arrivals entries depend also of the warehouse functioning. For all this, an appropriate warehouse performance is needed to maintain the overall production plant functioning continuously in time.

Figure 2. Aereal view of the manufacturing plant in Alcalá de Henares.

Nowadays the warehouse can operate most of the year under normal functioning but has been founded that at some months of the year the needed usage of the short storage areas (located in the warehouse annex area and used for storing the materials after arrival in the warehouse or exiting the automated silo) is above the available capacity. This problem has been overcome until now by using other free spaces or external storage suppliers but as mentioned the plant is expected to experience a production increase, so in the future the situation will get even more complicated. At the same time, the management of the warehouse doesn't have information about the on-time occupation of this areas or how much time do the pallets spend in this area making hard to find root causes of the mentioned problem.

This project, under the explained motivation, is intended to pursue the following objectives:

- **Perform a deep analysis about the short storage areas occupation over time:** The management of the warehouse doesn't have information about the areas occupation curves over the year. Currently information about every pallet movement is contained in SAP but it is not interrelated to extract information in form of a balance scorecard that can help management decisions.
- **Improve the rotation of the short storage areas:** Find possible problems of the actual work-flow that can be improved so occupation of the short storage areas is diminished. This will be translated into a better use of the limited capacity of the areas as well as less use of the external storage supplier usage, meaning less inventory costs.
- **Evaluation of the actual warehouse methods:** An external view of the warehouse processes can find other existing problems in the warehouse than the ones mentioned in the short storage areas, so other aspects can be improved.
- **Gather scientifically information to evaluate production increases:** Is expected that the production plant experiences an increase in production in the following years that will impact the plant needed capacity as well as the annexed warehouse. The annex area is already experiencing some capacity problems and if those cannot be solved the warehouse will suffer more unexpected problems that the ones already experienced. To evaluate this future capacity increase and evaluate if an investment is reasonable needed, the warehouse response to an increase in capacity will be analyzed with the designed SIMIO model.

For the attainment of this objectives the simulation model created will cover the pallet flow for all the material arrival and expedition processes. This two processes will be detail explained later on in this thesis for reader's better understanding. The arrival process covers since the material arrives to the warehouse until the pallet enters the automated silo for long storage or production lines supply. The expedition process covers since picking is done in the automated silo of the plant until the delivery batch is picked by the transportation carrier. Thus, all the pallets classification, labeling, packaging, storage, transfers and load into/from the carrier trucks is considered inside the cited model.

The model will use pallet units instead of product units or weight as the areas space is only occupied by pallets and so it is measured its capacity. In the case of the arrival materials the products some times arrive in barrels or sacks over a wood pallet (the same way they are introduced in the silo) this way are considered stored also in pallet units. The pallets can only contain one type of product so there is not a straight relation between product units and space in pallets. Therefor the pallet unit usage has been selected to measure and evaluate the previous mentioned objectives. The model will be developed with data from a complete year because the plant demand is not linear or seasonal but its cyclical in years. It has also been selected the year 2018 for being the last complete year with flow data and the most recent one that can reflect better the actual functioning of the plant. The used data is real from the warehouse functioning and it is gathered both from digital systems, previous time analysis and employee experience.

1.3 Methodology

As mentioned before this project will cover the design, development and evaluation of a virtualization model to analyze the actual functioning of a production site warehouse. The selected methodology will be problem solving oriented to extract relevant conclusions from the performed analysis that will derive useful conclusions and recommendations to improve the warehouse processes and management. The used methodology to achieve the previous mentioned objectives of this thesis is here presented:

1. **System Study**: Perform a deep understanding of the warehouse system and its flow. This step is really important for the well development of the project. The main flows of materials as well as the areas and resources involved need to be identified. At this step it will be also define the scope of the designed model, the used units and the KPIs needed to take in mind. This established KPIs will be crucial to later evaluate the model by comparison with real results an to analyze and extract relevant results and conclusions.

2. **Data Collection and Conditioning**: This step is one of the most extensive along the project and needs working with the different company departments to extract all needed data. The data needs furthermore extensive conditioning before being introduced in the model to be coherent in variables and share the same units. The needed data will vary from pallets movements, processes times, number of workers, schedules, etc... and will be needed to size the existing resources and unitary processes. To model the in and outs of materials in the different subsystems (silo, short storage areas, deliveries, expeditions...) will be used the SAP and SGA systems that are used to register the material movements along the production plant.

3. **Model Development**: This is an iterative step. It will be used the technical modelling tool SIMIO to design a system that reflects the real functioning of the warehouse work-flow under the selected scope. The model will be first created with imputed real data from a one complete year time frame and then changed to model capacity increases. This way all the area capacity usage peaks will be evaluated to asses bottle-necks and maximum capacity causes as well as the miss-use of resources in scarce periods.

4. **Model Validation**: Once the model is completed it will be tested to evaluate the correct functioning. The extracted results will be compared with the real store-card figures from the company and other main KPIs to see if the model performance meets the previous fixed requirements as well as the expectations for the desired further use of the model. The model is expected to be used further on by the company to introduce new data and parameters when hypothesis about the processes need to be confirmed or tested.

5. **Results Analysis and Recommendations**: After the validation of the designed model the extracted results will be further analyze to extract relevant conclusions about the short storage areas occupation. The root causes of capacity peaks will be also analyzed to present pertinent recommendations that can improve the actual operations of the warehouse. Furthermore it will be evaluated also the overall functioning and performance of the warehouse discussing general process situations that could be optimized.

6. **Capacity Increase Evaluation**: Once the actual problems are evaluated and recommendations to improve the actual situation are proposed, it is also evaluated the future performance of the warehouse. It is expected, as mentioned before, an increase in capacity for the production plant. If the actual problems are not amended the warehouse will have further capacity problems and the designed model can give a hint of how will respond the warehouse to this situation.

Even though the methodology is presented as a sequential process, iteration is needed between some steps, for instance the model development, model validation or even the data conditioning.

1.4 Contents of this Document

After this initial introduction with the motivation, objectives and methodology of this master thesis, a brief description of the following chapters is here presented. Along ***Chapter 2: Facilities Description***, the manufacturing plant object of this thesis is presented to the reader. The overall functioning of the plant as well as the product types and materials used are explained. After this brief introduction about the plant facilities, the warehouse target of this thesis and that will be modelled is detail explained with its actual management, characteristics and work-flow. ***Chapter 3: The SIMIO Tool and Data Sources:*** introduces to the reader the used tool for the modeling of the warehouse. The two different steps for model creation and experimentation or results attainment are presented together with the different type of objects the software uses and the definition of logical constraints or processes. This chapter also contains the model introduced conditioned data and its analysis, the taken assumptions and the model validation.

Moreover the ***Chapter 4: The Warehouse Model Design*** presents the designed logic processes, constraints as schedules and equipment or transport times, the taken assumptions to simplify the modelled system and the model validation process. After that, ***Chapter 5: Experiments and Results*** contains the model extracted results for the 2018 simulation that are presented and analyzed to extract conclusions and find possible problem root causes. The results analysis is divided in three sections, the arrivals and expeditions areas and the overall warehouse functioning. Together with the extracted results are proposed some recommendation guidelines to improve the actual processes. Furthermore in this chapter are discussed different future scenarios for the warehouse increase in capacity needs. The main intention is to asses the future management of the warehouse with the risks and possible impacts of an increase in capacity needs, evaluating the relevance of the external storage usage and a possible area increase investment. To end with, ***Chapter 6: Conclusions*** gathers all key aspects in this thesis to give possible future implementations and controlling strategies that can be the further steps for this company. Also future risks to have in mind that the increase in plant's capacity can bring to the warehouse to prevent future problems are giving to the reader together with future work paths to continue this thesis. To conclude there are some self-thoughts about the development of the project.

Annexed to this document can be also found an user guide that describes how can the created model be re-used for future works or other analysis.

Chapter 2

Facilities Description

THE development of this project has been based on a well-known multinational company that is one of the largest pharmaceuticals manufacturers in the world. The company has competencies in the bio-scientific sectors of agriculture and health obtaining at the end of 2017 revenues of 35.000 billion Euros. Specifically in Spain the company has three manufacturing plants of which the based in Alcalá de Henares, Madrid is the object of this project. This plant is the only soft capsules products manufacturing plant of the pharmaceutical group. The soft capsules accelerate the drugs actuation inside the human body and facilitate the administration of active substances of difficult solubility in water.

2.1 The Production Plant

The manufacturing plant has a constructed surface around 13.000 square meters and it is considered one of the most modern pharmaceutical specialized plants in Europe. Together with the soft gel capsules it produces around 15 million units of liquid pharmaceutical forms for the business group and it is also one of the few plants that manufactures final product for the Asian market. The Alcalá de Henares plant made an investment of more than one million Euros at the end of 2017 to construct a new soft gelatin storage and transfer space. In addition, the expansion of two new production lines was completed the same year to expand the productivity of the plant in order to meet the group's demand increases. All these investment decisions was made with modeling software tools and are of great relevance for the company due to the capital intensity and the need of fully satisfying the demand portfolio once they are implemented and operating. This way, the capacity increase solutions and needed investment decisions are strongly support by the company with simulation and modelling tools that allow evaluating the different alternatives without being those implemented.

The site has three linked buildings that contain the production lines (5.310 m^2), an I&D Pilot Plant (240 m^2), a social building with offices and laboratories (2.730 m^2), services (980 m^2) and the warehouse (1.900 m^2 for the annexed area and 1.600 m^2 for the automated silo). The distribution of the plant is presented in Figure 3. The offices gather the supply management, engineering, production, quality assurance and administration departments. The production area is divided in a weighting area, liquids production (sterile and non sterile liquids), soft gelatin capsules and a secondary package area. The most relevant part of the plant for this project is the warehouse area that will be latter on explained in a subsequent section.

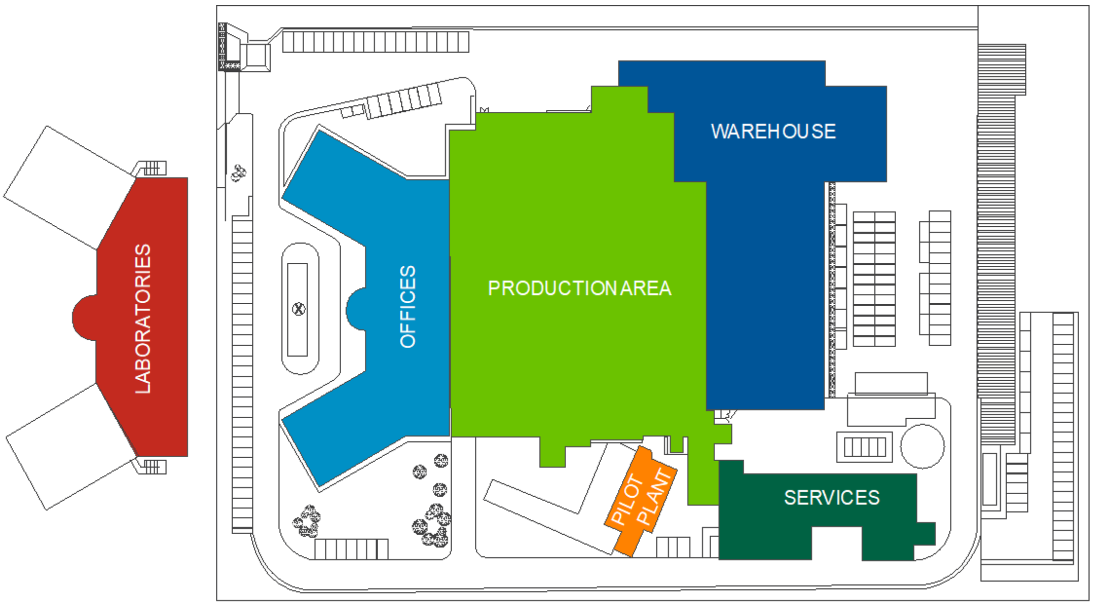


Figure 3. Soft capsules manufacturing plant in Alcalá de Henares.

2.2 Product Typology

It is important to understand the different type of materials that the plant manages in order to understand the work-flows of materials. The plant manufactures only medicinal products for human use that correspond to the following four categories: sterile liquids of small and large volume, sterile liquids for nebulization, non sterile liquids and soft gelatin capsules. The soft gel capsules can be at the same time distributed conditioned or in bulk. If the final product needs to be conditioned there are required: *primary conditioning materials*, which are the containers that are directly in touch with the active product; and *secondary conditioning materials*, which are prospects, product boxes or any other extra packaging materials.

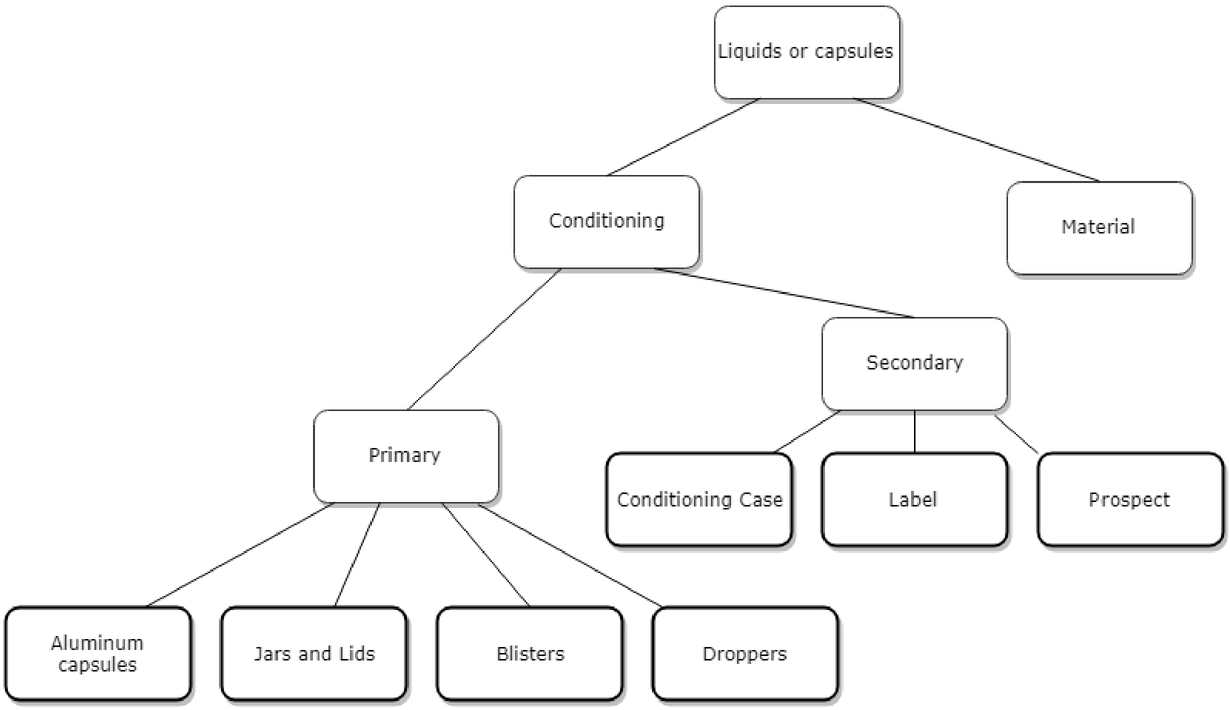


Figure 4. Short-term Storage.

The products can also be classified and labeled depending on the step of the process that are on, for example, sometimes intermediate products are carried out of production for quality checks or quarantine period. Here is a resume of the different product categories and a short explanation of each one:

- **RM: Raw Materials**. The materials needed in the production lines to manufacture the desired different pharmaceutical products brands. This category can vary from chemical products to boxes, plastics, gloves or any other type of material needed.
- **MP: Primary materials**. Used for the conditioning of the pharmaceutical product and that are in direct contact with it. Examples of this are, jars, caps, PVC for blistering or droppers.
- **MS: Secondary materials**. This materials are use for the conditioning of the finished products but are not directly in touch with the pharmaceutical product. In this category are included labels, prospects and cases.
- **RC**. This category is used to classify an specific product that is extracted from production as a waste but is later exploited. As it is a very precious material it is sent to be recycled and extract another raw material that it is used in the production process.
- **Z: Samples and documents**. This category enclose the rest of the products used in the plant site but that are not included in the previous big categories.
- **NI: Non-storage items**. This are products that are not introduced in the automated silo because of its size, shape, weight or typology.
- **IM: Intermediate product**. These are products that are still in the production manufacturing processes. It can be result of quarantine stages, quality checks, etc..
- **TM: Finished products**. The final pharmaceutical product ready to sell. It has been conditioned and packaged for its sale. Inside this category are also included products in bulk even they are not packed for customer sale.

2.3 The Warehouse

The warehouse has an extension of 1.600 m^2 for the automated warehouse (8.000 pallets capacity) and an annex area of 1.900 m^2. It works under a FIFO and FEFO system to ensure the rotation of stock and the minimization of expired products.

The main layout is presented on Figure 5 and consists mainly on an automated silo that is used for the long storage of the products or supply of the production lines and an annex area where the short storage of arrivals and expeditions is perform together with other warehouse activities.

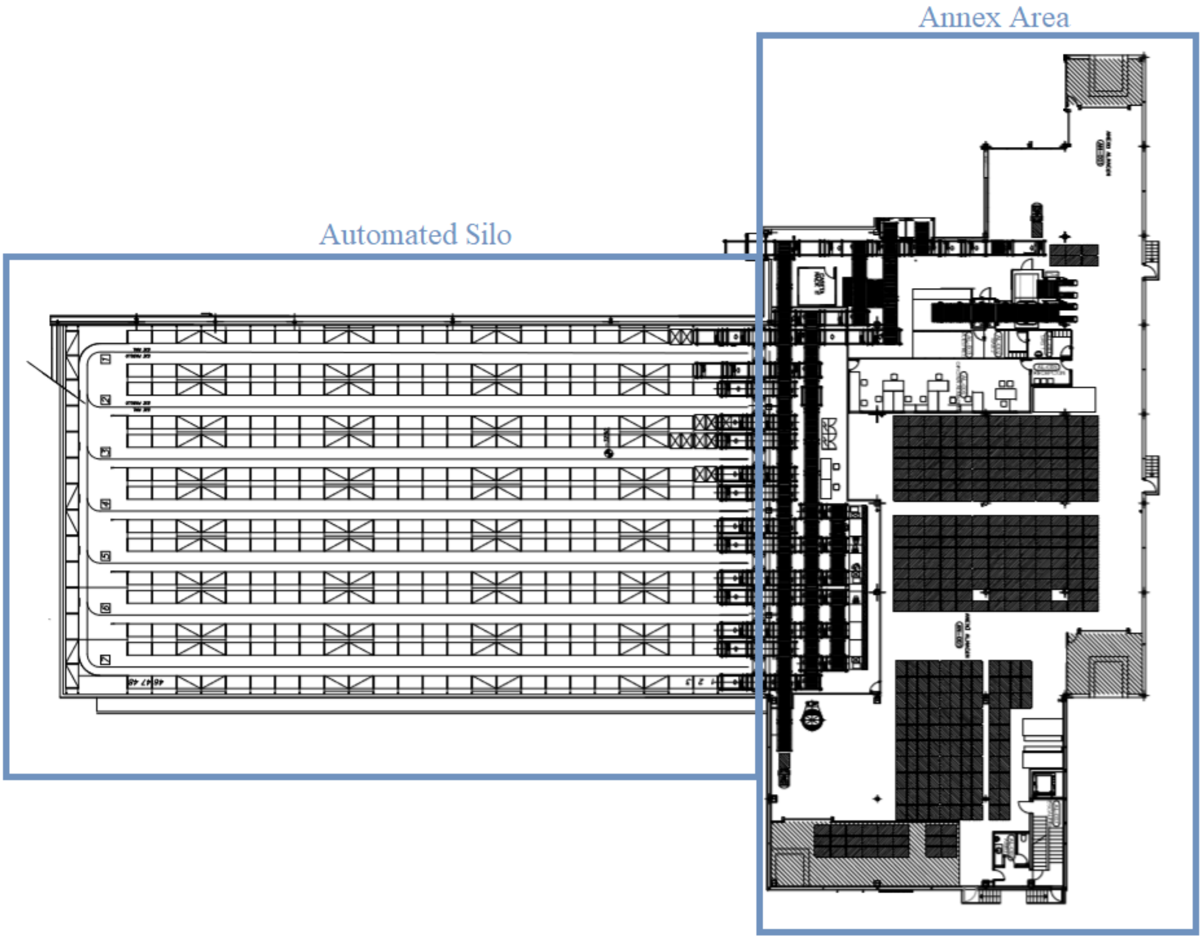


Figure 5. Aerial view of the warehouse.

The warehouse is completely closed and it is necessary a 24h a day control over the interior temperature (maintained between 15-25°C). Figure 6 shows a general outline of the warehouse work-flow that will be further detailed in the upcoming sections, this is only an overview for the reader to understand the warehouse distribution. There are two sources of entry materials in the warehouse, from suppliers and from production. The arrival of materials from suppliers is unloaded from the carrier trucks into the warehouse and stored in a short period storage area inside the warehouse annex. The materials wait in the area until they can be entered in the silo or all the quality checks have been performed. The production arrivals are treated separately and are directly managed by the automated silo.

There are also two exits of materials from the warehouse: the expedition of finished products through carrier transport to other plants or countries, and the production lines supply of raw and conditioning materials from the silo. This way the needed materials for the products manufactured can be directly demanded through the silo software and delivered without any human interaction. In the automated silo there are all kind of materials stored, from finished products and raw materials to documentation or machinery. When the produced final products are ready to distribute, the selected pallets are picked-out of the silo for convenient packaging and stored in a short storage annexed area until the transportation carrier arrives for pick-up. Besides this, there are some specific materials that need to be stored in a refrigerator o freezer, like some acids, to maintain quality conditions. This materials are stored in a separate area and are out of the scope of this thesis.

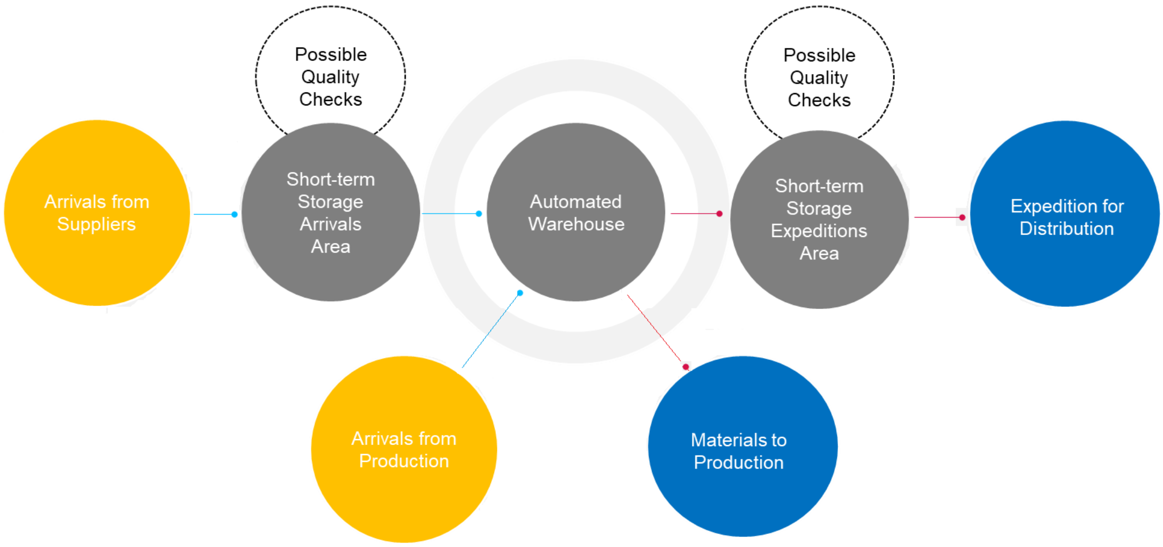


Figure 6. Work-flow overview of the warehouse.

In Figure 7 is shown an overview of the warehouse annex. The arrival materials are stored in the yellow area while they wait for quality checks, repackaging or entering into the silo. Light blue areas represent the short storage areas for

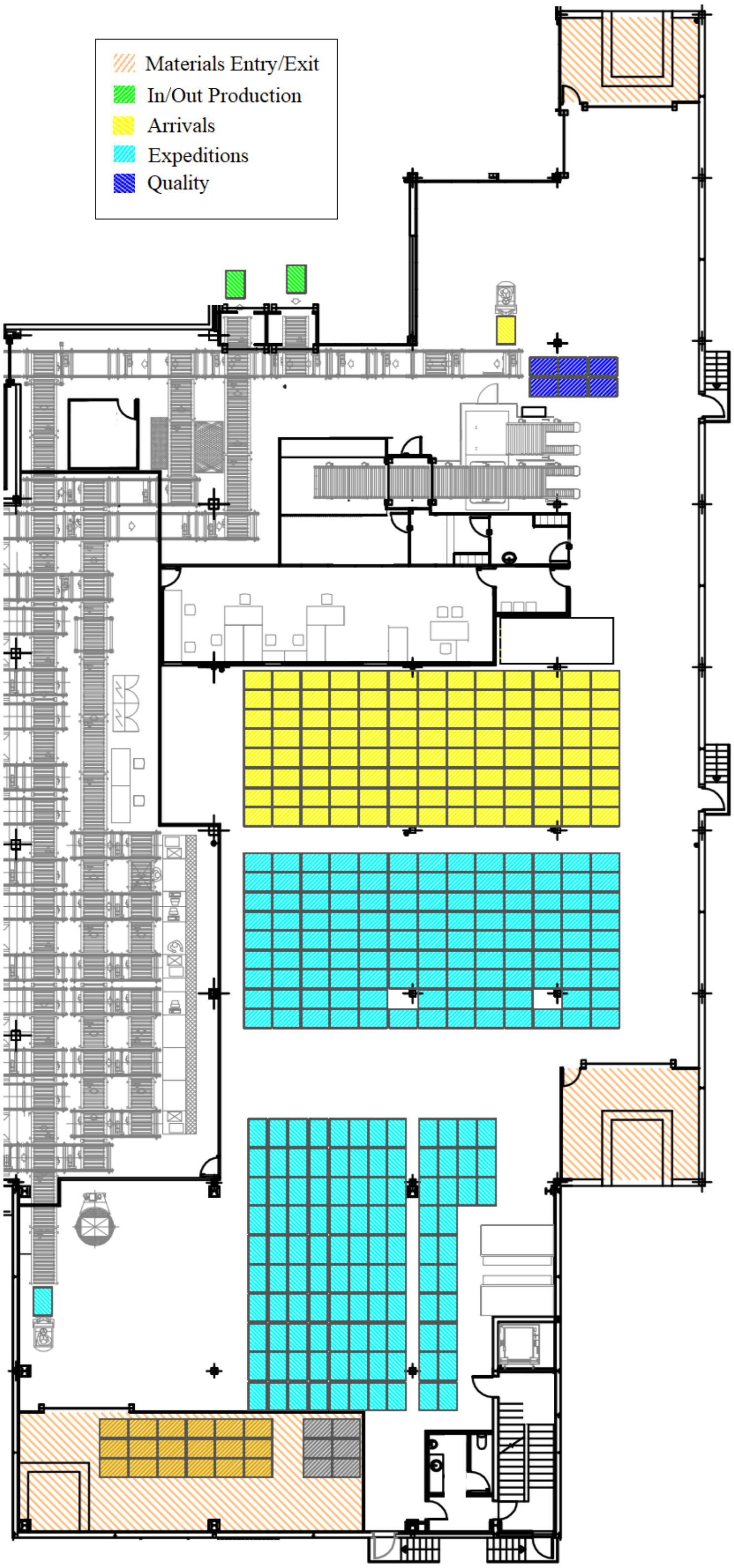


Figure 7. Distribution of storage locations in the warehouse annex.

expedition pallets that are already packaged and prepared for its loading into the carrier truck. The dark blue area is used for the materials that are waiting to be entered in the quality check or are being re-packaged for it. Green areas mark the in and out flow from production lines that are done directly and autonomously from the silo. Light orange areas are entry or exiting points of materials. The two marked zones in the right side indicate the loading/unloading ports and the one located in the lower part marks the exit of waste and scrap pallets. Lastly, the dark orange and grey areas are used as short storage for waste pallets from the production site. In the annex area there are also an office for employees where all transport documentation is managed and prepared.

All the materials under the warehouse responsibility are shown in Figure 8 classified by type of product by the beginning of 2019.

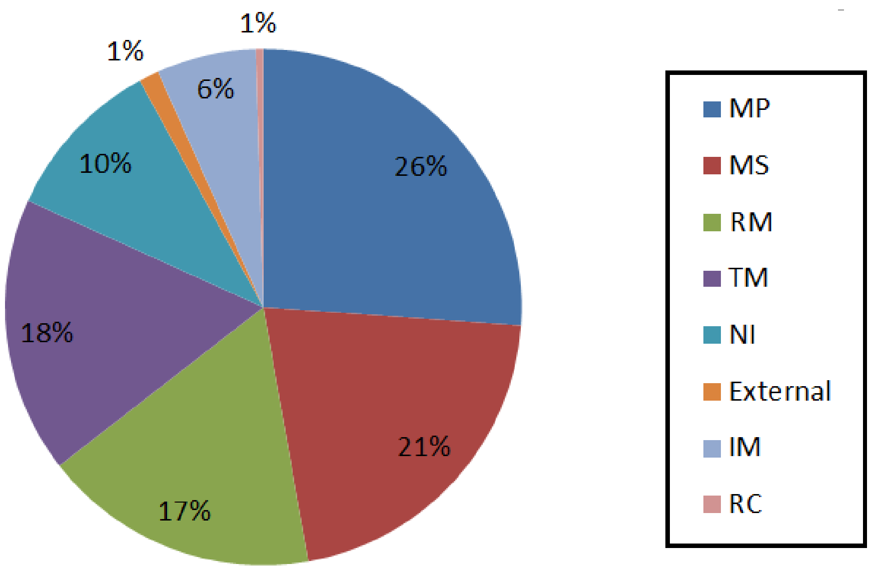


Figure 8. Materials under the warehouse management classified by product type.

This products can either be in the annexed areas, in external storage, special conditions racks or the silo. As it can be seen the goods are a majority of raw material and conditioning products (64%), then it has a 18% of finished products and the rest is documentation, other non inventoriable materials and products that are still in manufacturing process (because of quarantines or other reasons). It is also included the external storage even though is not physically in the warehouse to give a hint of the usage. Note that the production lines are the plant bottleneck so it is important to maintain the continuous income of raw materials and conditioning products creating a buffer for this type of materials. On the other hand the finished products are inventory materials that can already be sold to obtain revenues and liberate space in the silo, this materials are expedited from the warehouse as fast as possible but this percentage is still a big percentage.

The workforce structure used for the warehouse management is shown in Figure 9. There is a manager responsible for all the operations carried in the warehouse: the silo, the annex area, the exterior facilities used for waste and the external storage. Right under the warehouse manager there is two morning and afternoon responsible that supervise the two shifts. There are two secondary managers that are responsible of the most extensive tasks that the warehouse carries: the expeditions or the arrivals from suppliers and the supply to the production lines. Finally there are office employees that carry other task for the well functioning of the warehouse and give also support to the superior managers. Workers are responsible of transporting pallets, downloading/loading trucks, movement of waste and packaging, etc... There are some of this workers that are also responsible of assisting the silo when pallets get stacked or there are any problems with the reading or transport of the pallets.

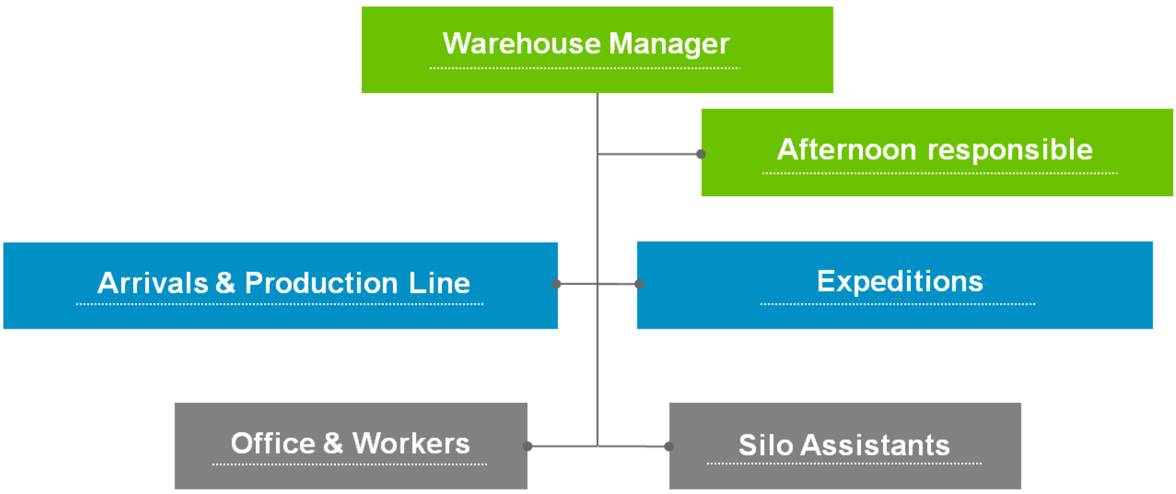


Figure 9. Warehouse workforce structure.

The total workforce of the warehouse is composed by fifteen people although for the simulation will be only used seven workers that will be the only ones moving and transporting pallets. In Figure 10 is presented the workforce needed for each warehouse task (first figure) and the percentage of the total labour time dedicated to the different activities (second figure). In this project there are only inside the scope the arrivals and expeditions which cover also, re-packaging, internal deliveries and other activities (which entails the external storage load/unload). This takes the 57% of the labour force time. In total are needed 9 people working in those task, remaining the office employees.

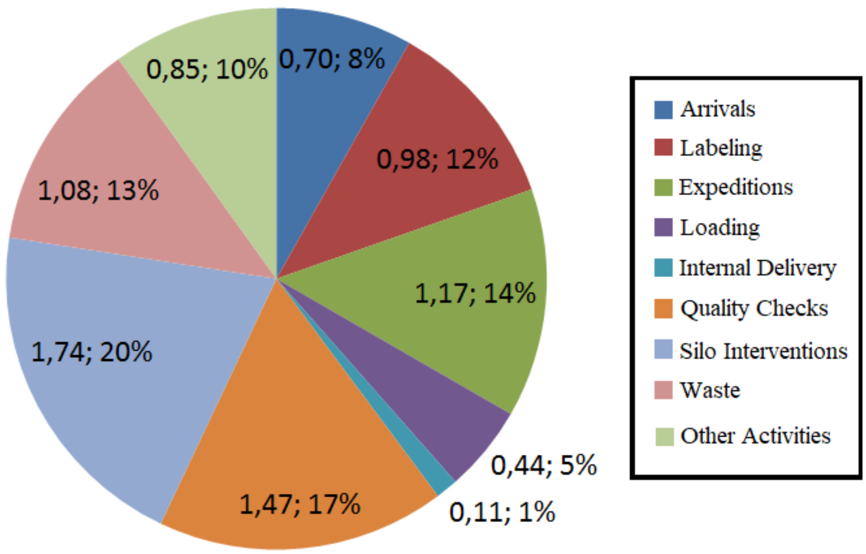


Figure 10. Workforce needed and times.

2.3.1 Work-Flow

The warehouse that is object of this project requires a strict coordination not only with the production departments but also with suppliers and distributors to avoid long finished products turnovers or production material shortages. In the previous section was already presented a brief summary of the work-flow and the most relevant areas of the warehouse that in this section will be further analyzed. The warehouse annex area is presented in Figure 11 containing a more detailed

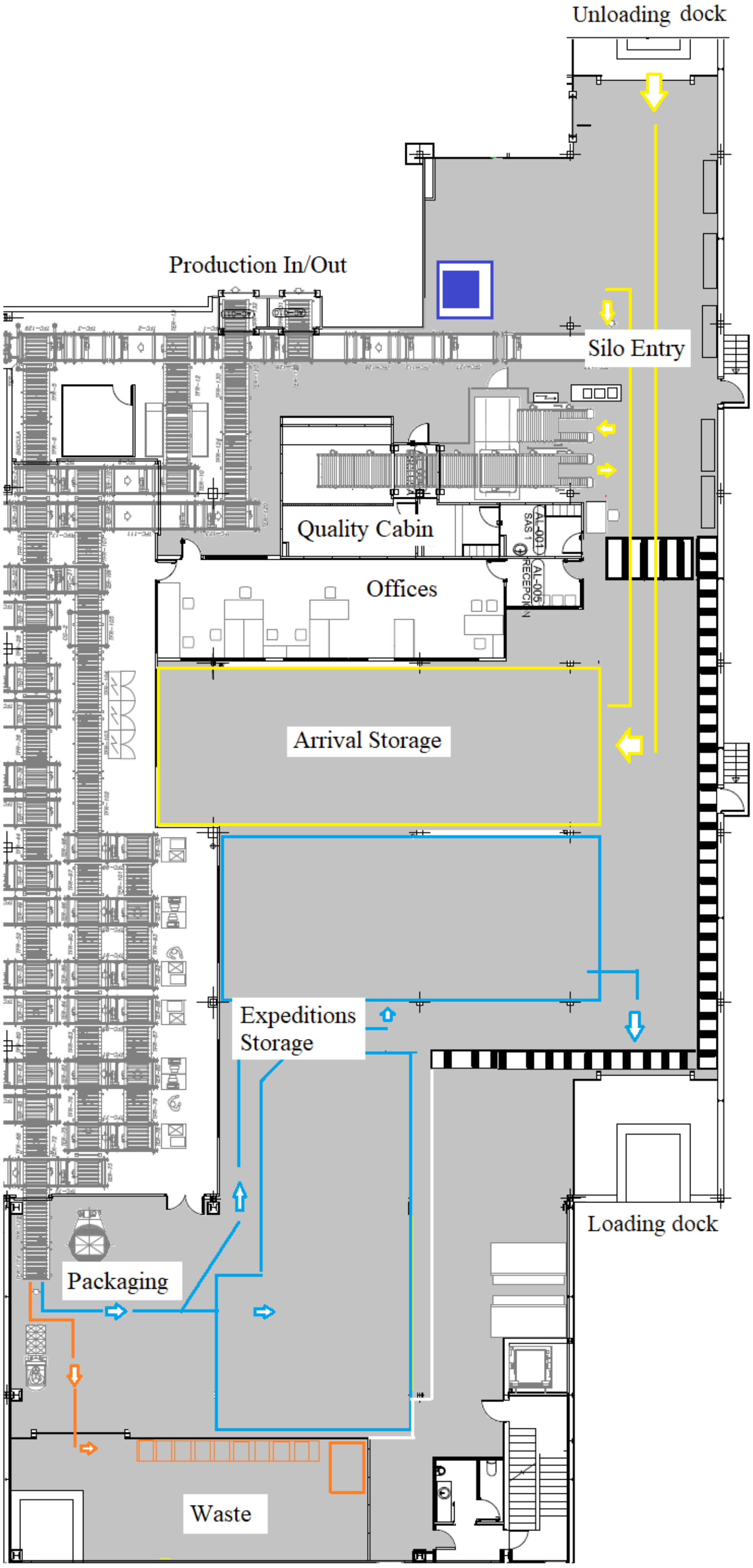


Figure 11. Warehouse annex arrivals and expeditions work-flow.

explanation of the arrivals and expeditions work-flow. The areas previously presented are in this figure together with work-flow arrows indicating the processes in the same colours. The entry materials that arrive to the warehouse are downloaded directly from the distributor's truck and placed in the yellow short storage area. The materials are then re-packaged, labeled and introduced either to the silo or directed to a quality inspection. From the silo, the materials can either exit to the production lines or to the expeditions area by the automated racks. Pallets are picked by the workers at the silo exit that is close to the packaging machinery and again its path depends on if the pallet is for waste pallet or for distribution.

On one hand waste pallets follow the orange line and are storage until they are properly managed in the outside of the warehouse (each kind of waste needs a different treatment or storage, but this is not inside this project scope). On the other hand the rest of the pallets can be either for internal distribution (documentation, machinery, resources...) or for expeditions. The first ones are directly distributed while the second ones are packaged (the packaging processes and times will vary depending on the travelling method: terrestrial, aerial or maritime) and stored in the blue areas until the transport carrier arrives to the warehouse and the batches are loaded

Now that a wide overview of the warehouse work-flow has been given to the reader and the relation between processes has been discerned, each of the mentioned tasks will be detail explained in order to understand better each of the individual operations and the complexity of the warehouse. Mention again that the waste management, silo maintenance and document distribution are here not mentioned as they won't be relevant for the development of this thesis.

2.3.1.1 Arrivals from Suppliers

The company has relations with a vast amount of suppliers that deliver all kind of resources, tools and raw materials (being those sometime really dangerous or fragile). This requires a quality receptions procedure to incorporate each pallet in the warehouse digital systems and conditioned it. When the materials enter the warehouse each batch is examined to check the validity of the products and the deliveries information and legal requirements are introduced in SAP. It is also important to label the batches and each of the packaging units for its later identification. Each pallet is identified with a label containing the following information: short description of the product, quantity of each container, number of containers, batch number, expiration date, item code, order number and the supplier ID. Once the identification has been made, the items received are segregated and conditioned if there is required any quality checks and if not needed they are introduced into the silo for its storage until they are requested by the production lines. When the pallets are entered in the silo they are registered in the silo management software SGA to indicate the number of pallets that are beeing introduced in the silo.

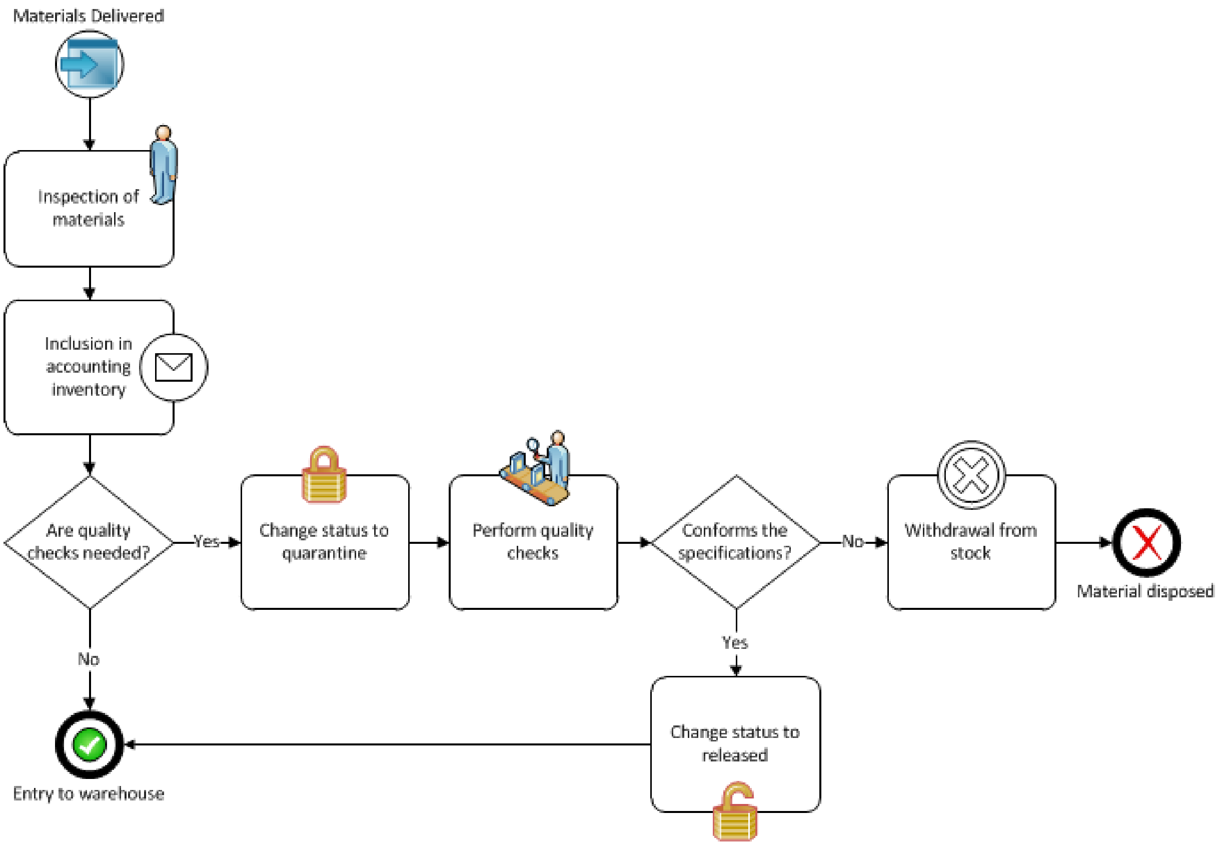


Figure 12. Arrivals flow diagram.

As it has been mentioned before, included in the arrivals work-flow are areas delimited exclusively for download and short term storage of the pallets. This area is used for the downloading of the trucks' delivery and then inspection and labeling of the received materials. After that the materials wait either to perform quality checks or for its storage in the automated warehouse. This area has a floor capacity of ninety-nine pallets. In case the type of material that the pallets contains can be stacked in two levels to save space, the area would have a total capacity of 198 pallets. This is usually the case but there are some products (specially for arrivals) like the raw materials that are delivered in drums or sacks and is risky to pile the pallets.

2.3.1.2 Expeditions

The expedition process as mentioned before embraces the preparation and load of deliveries. This delivery products can vary from finished products (the majority) to samples or intermediate products and it is mainly managed through the SAP system. The delivery products that have been already produced and approved by the technical division of the plant are detected by SAP which automatically generates a delivery order. From this point the workforce in the warehouse is the responsible for managing the delivery to the distributor.

First the picking list is generated, which contains the list of batch pallets that are needed to be extracted from the silo. This list is passed to the operator together with the delivery physical labels and the checking list, while the SGA system extracts the pallets from the silo. This lists is later used to check the uploaded pallets in the carrier truck. The list contains:

- Product description
- Product code in SAP
- Number of pallets
- Batch number
- Delivery number

With the provided information the workforce picks the pallets from the silo expedition dock. It is important to check at this step if there is any quality problem with the pallets like broken blisters or material losses. If everything is correct, each of the pallets are checked in the picking list. Then the information labels are inspected to check the information and placed in the extracted pallet. After that, the pallets are shrink wrapped using double retractable. If it was necessary, corners can be used to protect the lower pallet and this way storage two pallets on top of each other, reducing space. It is also necessary to add thermal blankets to the pallets prepared for areal transport. Once the pallet is packed and prepared it is weighted to confirm the expected weight (allowing a variation margin of +/- 10 kg per pallet). In case this last step is not accomplished it is needed to check the content of the pallet. Finally, the packaged pallet is transported to the expeditions area for its storage until the delivery carrier arrives.

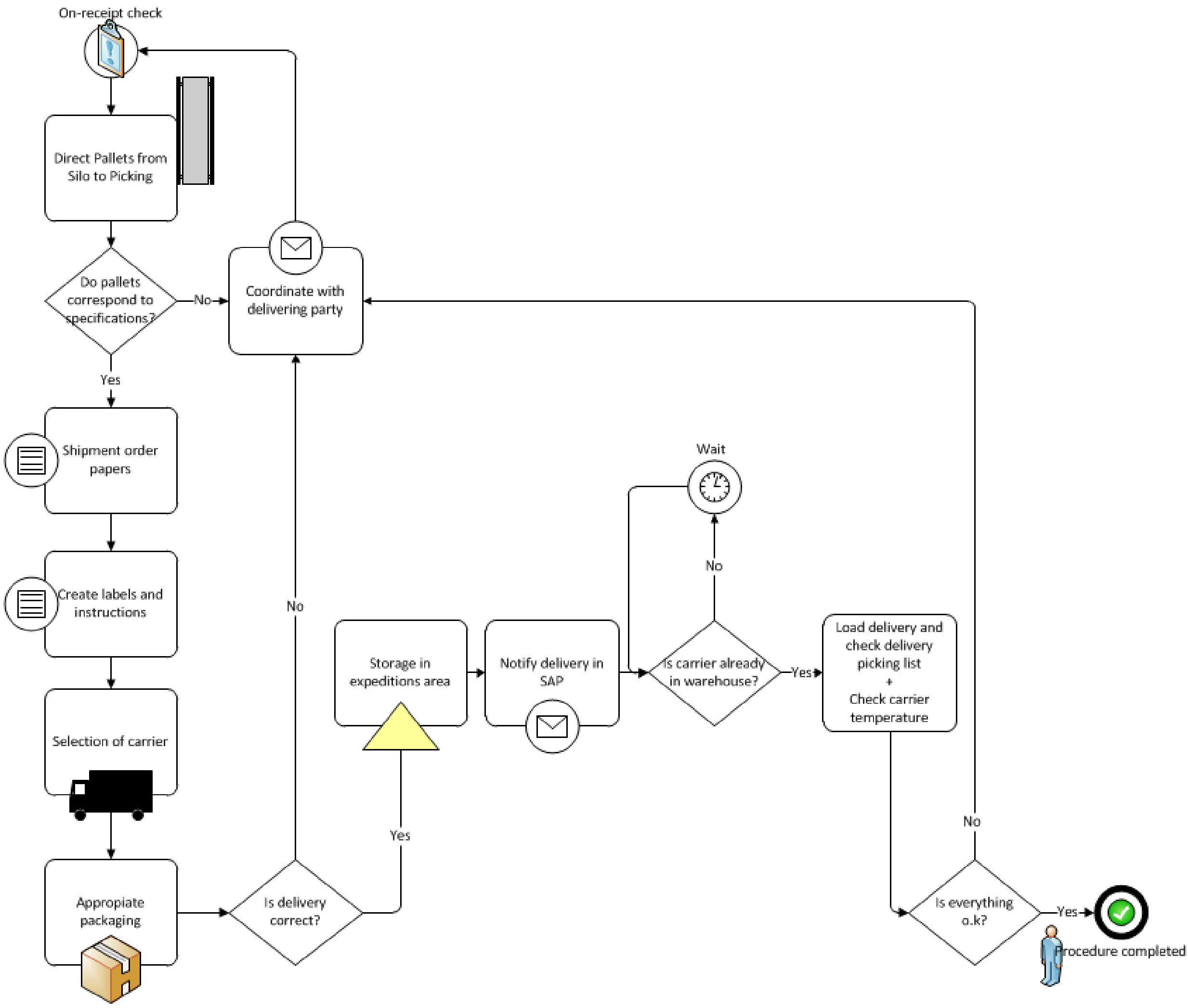


Figure 13. Warehouse expeditions and deliveries flow chart.

After the delivery is packaged and prepared each pallet is digitally changed by the warehouse office of module inside SAP to schedule the transport (this can be done directly from the warehouse, by the clients or by the group HQ). When the delivery carrier arrives to the warehouse it is checked again the number of lumps, batch code, and preparation methods to finally load the delivery into the carriers' truck.

Previously it has been mentioned the existence of a short storage area for the arrivals. There is a similar area for the expeditions, in this case the pallets are stored after its picking from the automated warehouse (and the packaging that applies for each transportation method) and placed until the carrier arrives. This areas have a capacity of 179 pallets, again, 358 if it can be placed in two levels, what it is usually possible for the finished product pallets. In case that a capacity surpass happens for any of the areas, the other one will be used to store the pallets, but this is not the desired way of working and it is only used at moments of unexpected peak flows.

2.3.1.3 Automated Warehouse

The automated warehouse has a capacity space for 8.000 standardized European K7 pallets (1200 x 800 x 145 mm as standardized dimensions) with a maximum height of 1050 mm and a maximum weight of 800kg. Each pallet is filled with only one type of product and batch, containing: finished product, WIP, product in quarantine, raw materials, tools, conditioning and packaging material, documentation, etc... The automated warehouse is fully automated and the needed orders are given either from the warehouse or from production, quality and supply chain departments. It is operated by an SGA software that controls all the automation, but its contents are also regulated by SAP so both systems need to be checked to avoid gaps on information of scraped or no longer available products. There is another difference between both systems, SGA operates with pallet units, related with the silo spaces, and SAP operates with batch quantities.

Apart from the expeditions there are also materials that exit the silo and are needed for the production of finished products or for further quality checks. The

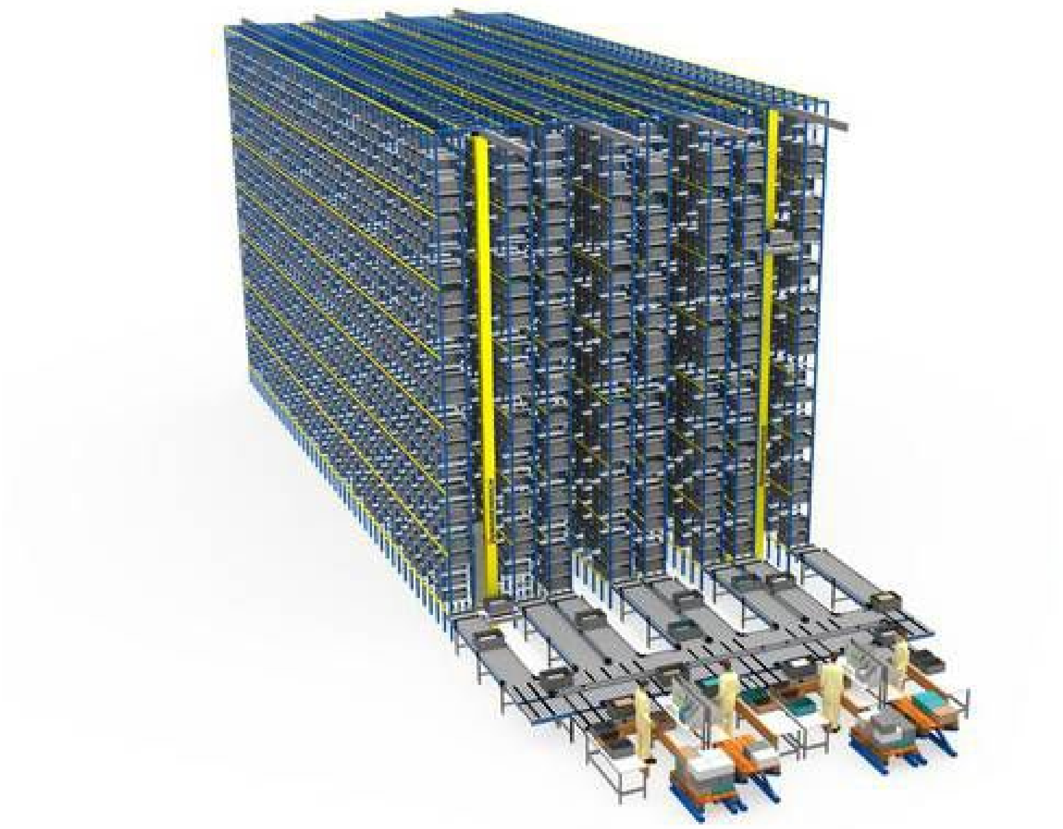


Figure 14. Automated Silo from Mecalux, similar to the existing in the plant warehouse.

warehouse supplies the production lines so when pallets are demanded by the production department, those are directly directed from the automated silo to a floodgate that communicates the warehouse with the production lines. The warehouse also receives materials from the production lines. Those pallets are directly sent from production into a floodgate that communicates the lines with the silo and are automatically placed by the system in an empty placement. It is necessary also when managing the silo not to reach the maximum capacity and leave some empty spaces. This is important to ensure that the production lines do not stop producing because of the finished products cannot be transferred and stored into the silo. Actually, the silo is at its maximum capacity but this silo problem is predicted to be managed in a future increase of the warehouse's capacity (as a consequence of the plant production capacity increase) in the upcoming years so it won't be covered in this thesis.

2.3.1.4 External Storage

The external storage is carried by a logistics service provider that enclose transport, storage and customer needs like temperature stability. The materials that for different reasons (capacity limits reached, special conditions needed, etc) cannot be stored in the automated silo are stored in this external locations. This providers can also serve as an unloading site for suppliers that can't download directly in the plant. Similar process can be made with the deliveries, been directly collected by the distributors in the external provider's warehouse. In this case the main external provider used is UPS although sometimes other providers are contracted. In Figure 8 was previously indicated the percentage of total materials that where stored in the external services, a 1% of the total materials. This type of storage is very expensive as the service provider charges the customer for loads/downloads, transports and storage (it also varies depending on the storaging conditions required). Thus, even if the total quantity stored is only a 1% of the total warehouse materials is important to reduce as much as possible the usage of this service and optimize the capacity usage of the warehouse and its annex.

2.3.1.5 Quality Checks

Even though the quality checks are not inside the objectives of this thesis, they have been introduced in the simulation model to validate the dedication time of the workers. The quality checks can be performed at any stage of the manufacturing process but the most frequent step when quality checks are performed in the warehouse is for the material arrivals. During the year 2018, which is the one represented in the model, there where introduced changes in the quality check processes so a variety of materials where extracted from the silo only to perform quality checks, this is why in the model there will be pallets sometime exiting and reentering the silo after some quality checks. The pallets waiting for the quality inspections to be performed are stored in a small area close to the arrivals dock. The material analysis are performed by schedule during four hours a day and the checked pallets need to be re-packaged for correct evaluation by the quality employees.

Chapter 3

The SIMIO Tool and Data Sources

THIS chapter presents the simulation tool used to design the virtualization model of the warehouse, SIMIO, the logic processes behind the developed model and a brief discussion about the income data, which has been an extensive part of the model creation. The data used as a model input has been extracted from different sources as SAP, SGA, time analysis or processes observation. The chapter is intended to serve as a brief introduction to the used simulation tool to understand how the software can be used and how it has been utilized for this master thesis objectives attainment.

3.1 Introduction to the SIMIO virtualization tool

In order to carry out the modeling of the warehouse operations the simulation software SIMIO, an environment modeling tool, has been used. The software allows the design and 3D visualization of the relationships between the different processes of the modelled system. SIMIO uses intelligent objects, custom made or from libraries, to perform a representation of the different parts of the selected system as well as code to establish the relationships between the intelligent objects. It also allows to model the variability of real processes, to import data from different sources (which can be updated automatically before simulation replicas begin) and to export all types of data in different formats and classifications after performing simulations.

The SIMIO tool consists of two different parts, one for the creation of the model and the other for the experimentation and results visioning. In Figure 15 is shown the main screen of the SIMIO software. At the top of the presented screen there are six tabs that are related either to the model designing or the experimentation and results visioning.

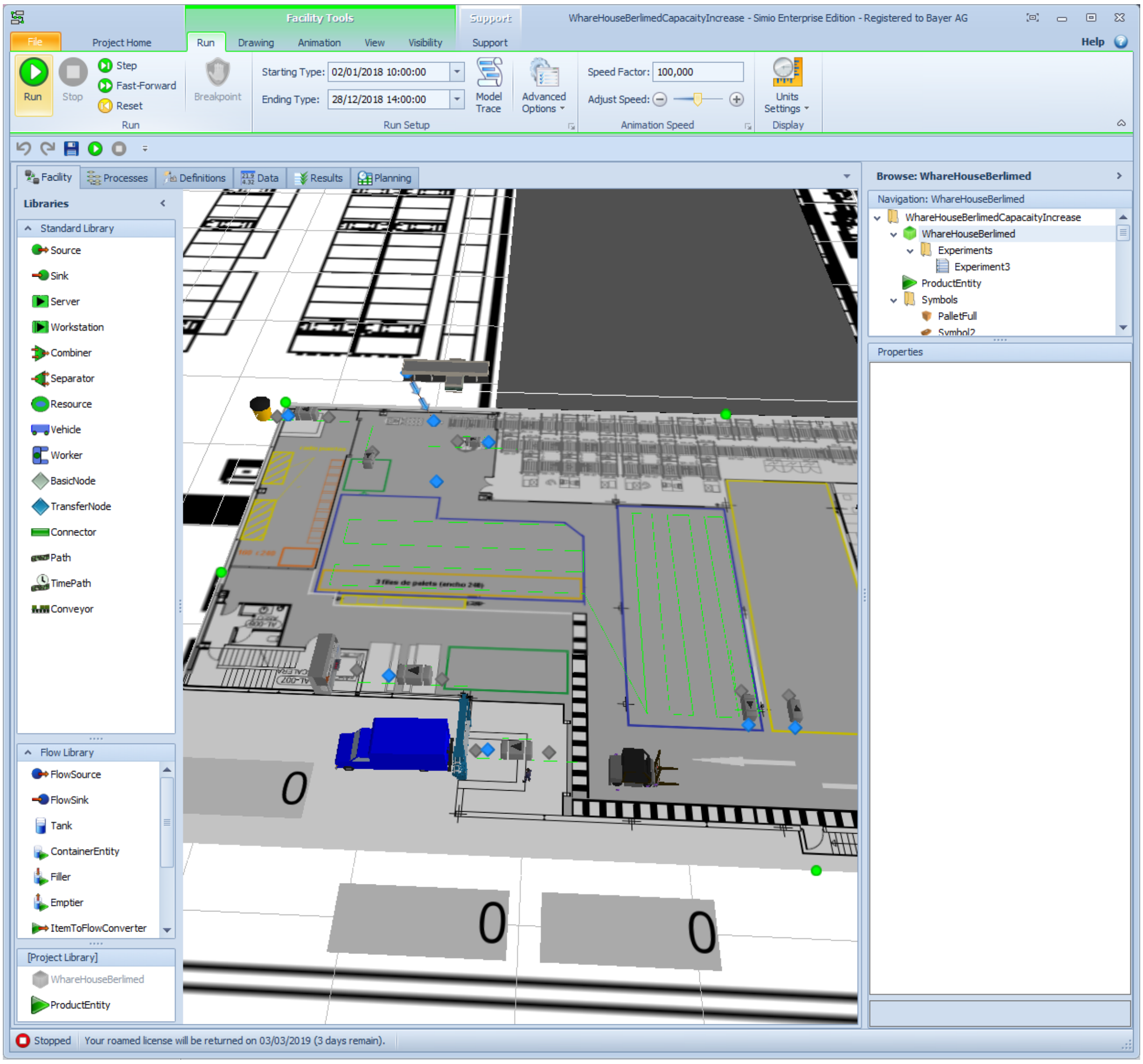


Figure 15. Facility window of the Simio software.

3.1.1 Designing tools

The designing tools allow to create and visualize the designed model creating processes and constraints that reflect the selected system. There are four relevant tabs in the model design: facility, processes, data and definitions. The facility window allows to connect the intelligent objects and visualize the system performance. In the facility window the standard libraries are shown to access quickly to the most used predefined intelligent objects. The objects have the optional ability to be seized, released, or constrained by a predefined schedule. There are four different type of objects that are gonna be used in this model:

- **Fixed:** This components have a fixed location inside the model and are used to represent equipment or work-cells. In this project will be used Sources, Servers and Sinks. Sources create entities and can be related to tables for arrival interval times or quantities. Servers or workstations are used to process the entities and usually contain extra logic that models the desired performance. Workstation can also use resources (that can be transporters, workers or physical resources) that are reserved while the process is ongoing. Finally, Sinks are used to destroy entities that arrive to the final destination location and are no longer needed in the system.

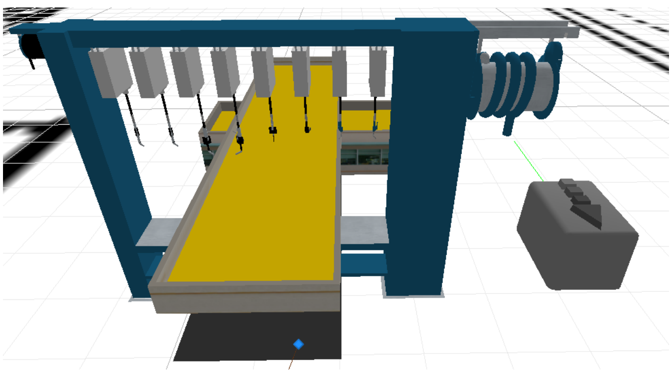
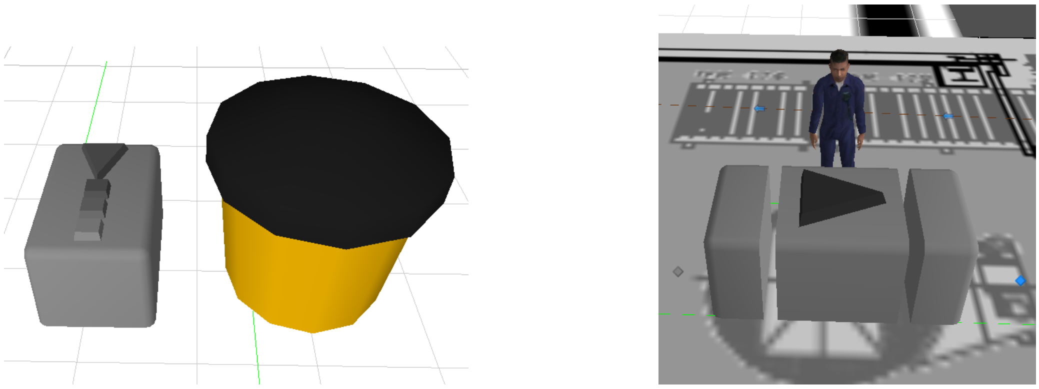


Figure 16. Standard and personalized SIMIO sources.

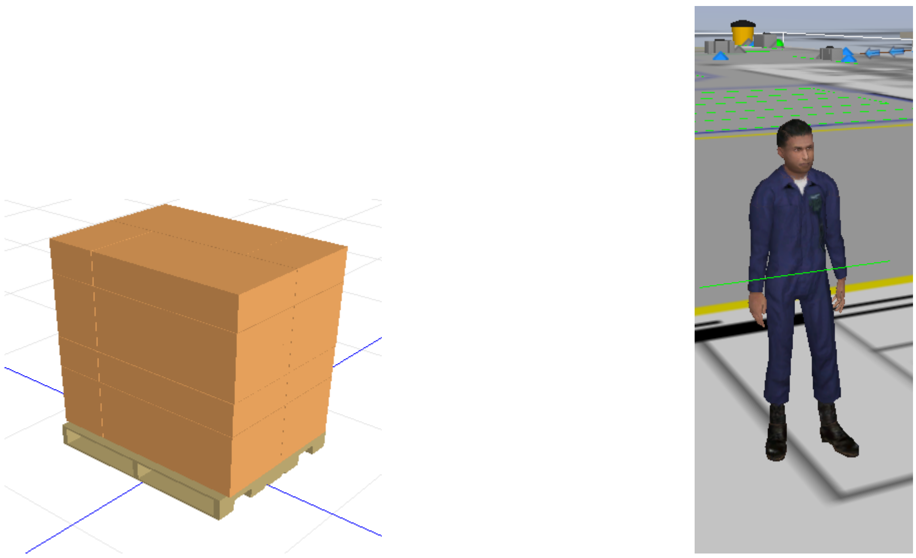
- **Agent:** This objects can be dynamically created and destroyed being able to move inside the model space interacting with other objects. The number of agents created can belong to different categories of which in this project



(a) Standard and personalized SIMIO sinks. **(b)** Standard SIMIO workstation.

Figure 17. Fixed type intelligent objects used in the warehouse modelling.

will be used two, Entities and Transporters. Entities are in this model representing the material's pallets, the units object of warehouse processes used in the simulation. Pallets are grouped under the specific entities called ProductEntity that will be the only ones used in the simulation. On the other hand, Transporters will represent workers in the warehouse that transport and move the pallets between locations or are used as necessary resources for processes like packaging.



(a) Entity symbol that represents the material pallets. **(b)** Transporter being used as a workstation resource.

Figure 18. Agent type intelligent objects used in the warehouse modelling.

- **Node:** Represents intersection points between linked objects or entry/exit points to visit an object. Transporters can also park at a desired node for off shift periods or entities can be picked up/dropped off at nodes by a transporter. There are two types of nodes, BasicNodes and TransferNodes. Basic nodes are only used to support connection between links while transfer nodes support connection to paths as well as ability to transfer or change between paths. TransferNodes are also used by default in predefined objects as sinks and sources as an entry/exit point. BasicNodes are represented as grey points in the model and TransferNodes as blue ones.
- **Link:** This intelligent objects create pathways for entities or transporter movement to follow. Its speed can be defined so a transport conveyor or automatic movements can be defined by the user. The links can be also used to force an specific process flow or destination in a unidirectional or bidirectional movement.

Once the main objects used in the model are defined, the next step is to determine the processes logic that will be contained in the processes tab. Processes are sequences of actions (seize, assign, release, decide...) that change the model behaviour and can be created from pre-designed action blocks. Processes can be fired by objects in the facility window as well as by occurring events or conditions. An example of a process is shown in Figure 19.

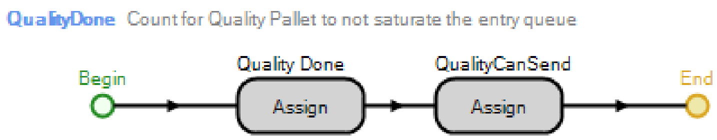


Figure 19. Example of process with two action block steps.

Finally the Definitions tab allows the user to create variables that can be used in the model. Here will be only presented the variable types Elements, Properties and States, as are the ones that are used in the warehouse modelling.

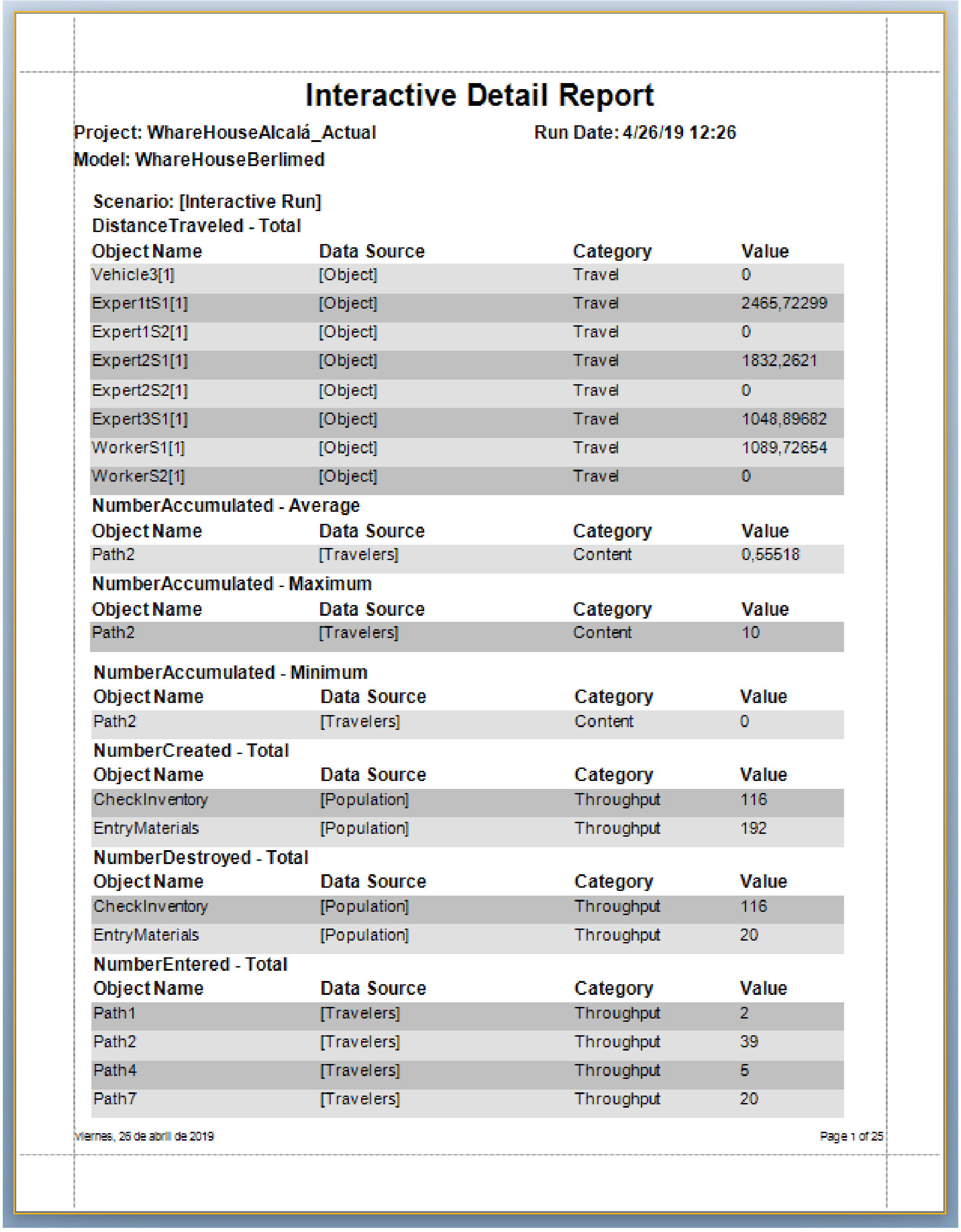
- **Elements:** Represent variables or elements that change its state over time. In the created model are mainly used to model the stations and its capacity. The station elements can be used to define a capacity constrained location for holding entities representing discrete items. This specific elements have been used to represent the arrivals and expeditions short storage areas in form of queues that are filled with pallets until an expedition or liberation date is reached. Other examples of elements are tally elements or timers.

- **Properties:** Are input parameters associated with an object and are variables that doesn't change within the simulation. Properties are key to define parameters that will be later used in the DOE (Design of Experiments) stage for getting relevant results. It can be designed different scenarios that change the value of the properties and see how the model behaves with respect to it.
- **States:** Can be continuous or discrete and are mainly used as variables to assign values or states to entities that change along the simulation runs. The states are also really useful for the debugging of the model as it allow the creation of variables that save problem points or statistics to visualize in the facility window on the run.

3.1.2 Experiments and Results Visioning

The SIMIO software contains aside from the designing appliances a wide variety of tools to perform all kind of experiments and analysis. In this section, again, will only be presented the ones used during the development of the project thesis.

- **Output Tables:** SIMIO allows the user to fill data tables with processes logic outputs. The processes will be referenced to an specific output table and when executed, the software adds a new row in the table that is filled with one assignment of data per column. This data tables can be later exported to csv files to use in excel for the data visualization and analysis. In the User Guide section is presented to the reader the file created to read and plot all the model extracted results in case the reader wants to re-use the model.
- **Logs:** There are multiple usages and applications of logs but in this model only the tally observation ones have been used. The tally log displays the value over time of a Tally Statistic element, in this case the statistics were recorded each hour of the one year span containing the pallet occupation for different areas. This way the occupation of the areas over time can be represented to evaluate peaks and average demand.



Interactive Detail Report

Project: WhareHouseAlcalá_Actual Run Date: 4/26/19 12:26
Model: WhareHouseBerlimed

Scenario: [Interactive Run]

DistanceTraveled - Total

Object Name	Data Source	Category	Value
Vehicle3[1]	[Object]	Travel	0
Exper1tS1[1]	[Object]	Travel	2465,72299
Expert1S2[1]	[Object]	Travel	0
Expert2S1[1]	[Object]	Travel	1832,2621
Expert2S2[1]	[Object]	Travel	0
Expert3S1[1]	[Object]	Travel	1048,89682
WorkerS1[1]	[Object]	Travel	1089,72654
WorkerS2[1]	[Object]	Travel	0

NumberAccumulated - Average

Object Name	Data Source	Category	Value
Path2	[Travelers]	Content	0,55518

NumberAccumulated - Maximum

Object Name	Data Source	Category	Value
Path2	[Travelers]	Content	10

NumberAccumulated - Minimum

Object Name	Data Source	Category	Value
Path2	[Travelers]	Content	0

NumberCreated - Total

Object Name	Data Source	Category	Value
CheckInventory	[Population]	Throughput	116
EntryMaterials	[Population]	Throughput	192

NumberDestroyed - Total

Object Name	Data Source	Category	Value
CheckInventory	[Population]	Throughput	116
EntryMaterials	[Population]	Throughput	20

NumberEntered - Total

Object Name	Data Source	Category	Value
Path1	[Travelers]	Throughput	2
Path2	[Travelers]	Throughput	39
Path4	[Travelers]	Throughput	5
Path7	[Travelers]	Throughput	20

viernes, 26 de abril de 2019 Page 1 of 25

Figure 20. Example of SIMIO results report.

- **Pivot grids and reports:** All the basic results of a simulation run can be easily analyzed in a pivot grid were the results can be filtered and drop as desired. The main use of this reports were the resources percentage usage out of its total schedule and the average behaviour of the system stations, workstations, sources and sinks. In Figure 20 is shown an example page of the generated predefined reports.

3.2 Income Data

Once the model is designed the system income data can be introduced under the data tab. This income data is one of the most important aspects of a virtual model and in this project was decided to introduce real data from the system to simulate it exactly as it is. This means that each iteration of the model will behave exactly the same as data is predetermined. This section presents the introduced data, measured in pallets, that enters or are planned to exit the warehouse: pallets from the silo picking, entry materials from suppliers and the material expeditions.

3.2.1 Pallets exiting the silo

In Figures 21 and 22 are shown the exited pallets from the silo classified in two different categories: destination and material type.

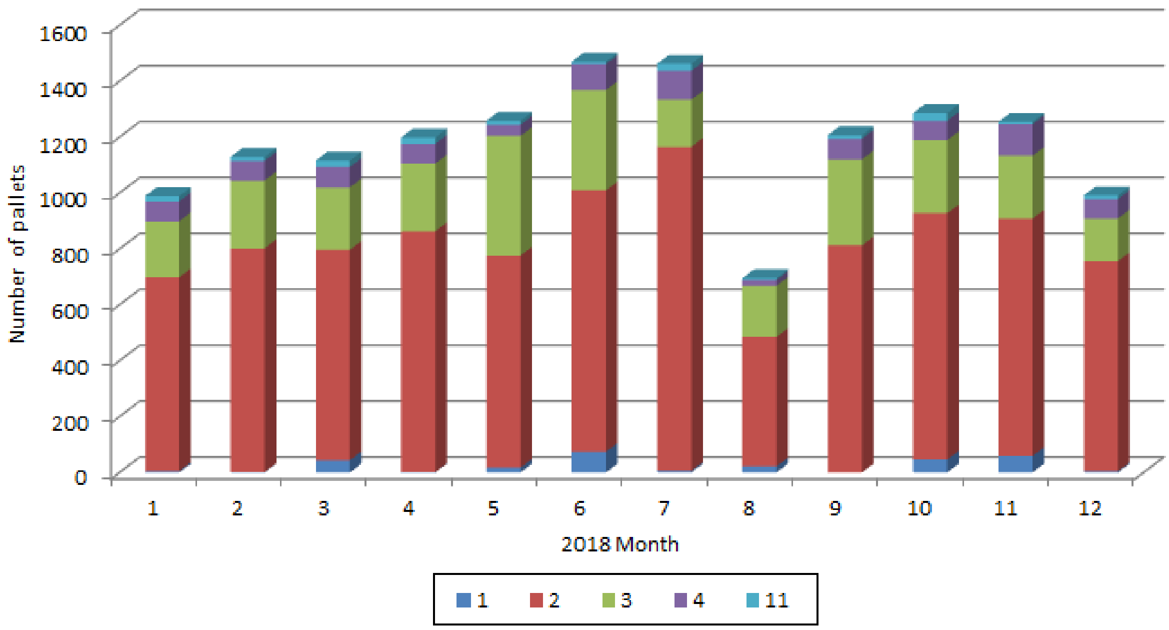


Figure 21. Pallets that exited the silo along the year 2018 classified per destination.

Destination locations are numbered to simplify the logic in SIMIO (1-waste, 2-deliveries, 3-quality, 4-documentation and deliveries, 11-no identified -directed to the same destination as 4-).

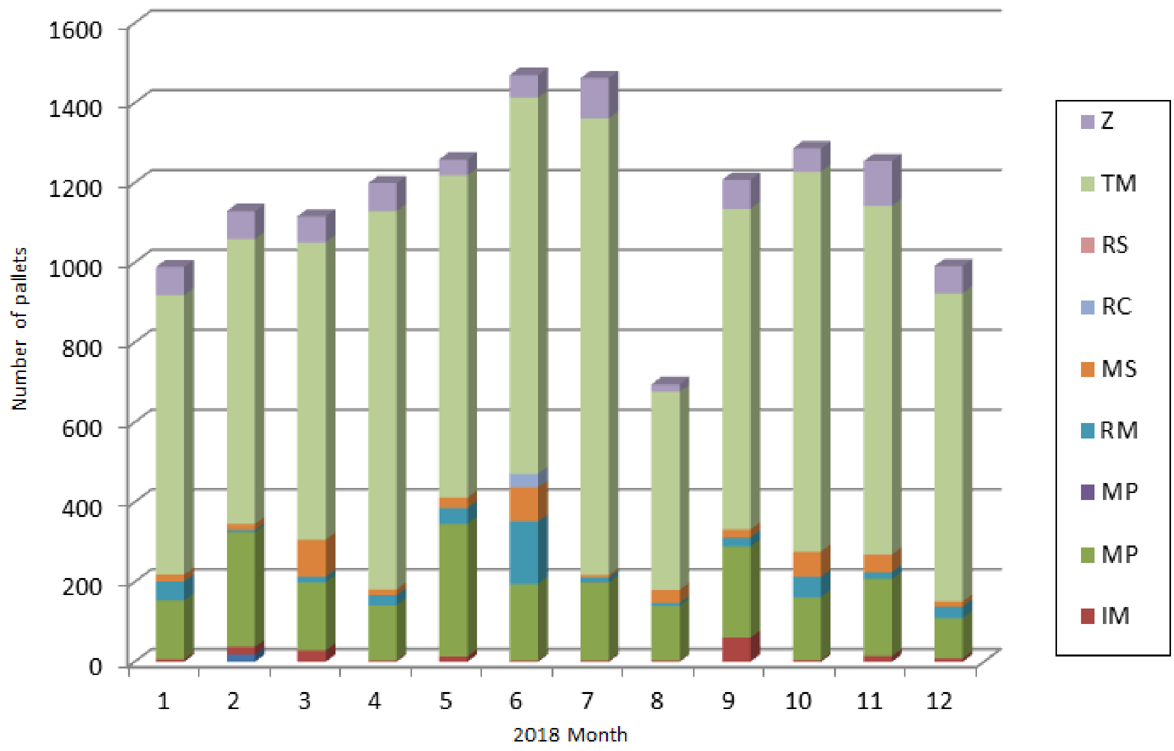


Figure 22. Exited pallets from silo in 2018 classified per material type.

As it can be seen in the mentioned figures, the demand for this plant is not linear, and this is gonna be also reflected in the work-flow of the warehouse and in the expeditions area usage. The outcome from silo reaches its peak during the months June and July. This is because the vacation period approaches forcing the months before to speed up its work-flow to cover the vacation months demand.

Something similar occurs with October and November months before the Christmas season to cover in advance the vacation period demand. Another important fact to highlight is the distribution of pallets that goes to different destinations. By evaluating both graphs together it can be seen that the majority of pallets that exit the silo are transported to the expeditions destination being the finished products the most frequent type of material in this specific destination as expected.

3.2.2 Pallets entering from suppliers

The second important source of entries in the warehouse annex is the arrivals from suppliers. Most of the entries are raw materials as it can be seen in Figure 23.

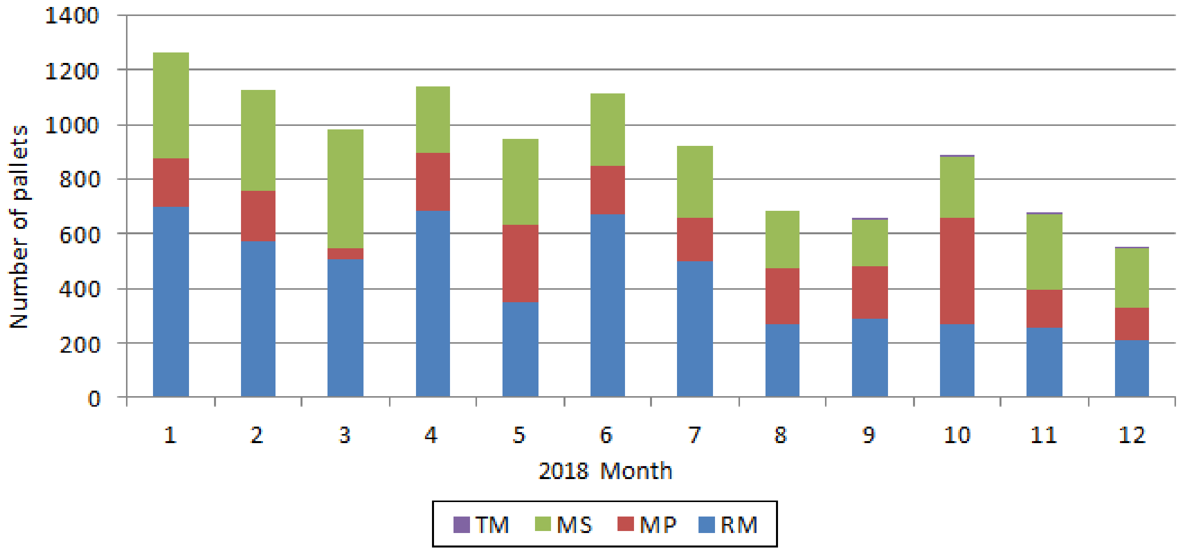


Figure 23. Number of arrival packages per 2018 month classified by material type.

The rest of the materials are for conditioning of the pharmaceutical products and only a small portion is finished product, which corresponds to the previous mentioned cross docking materials. This suppliers' material arrivals curve has a decreasing tendency towards the end of the year. This is caused by adjustments of inventory that are made to prevent from having non used materials stored in the warehouse. For this the production lines consume the already received materials and less supplier deliveries are scheduled. Another highlight is that this curve has similar shape to the production curve but delayed in time. This is really important as by checking the production curve the warehouse can have an overview in advance of how it would be an approximation of its demand.

Finally is presented in Figure 24 a similar curve to the previous one, but this time for the entry of materials in the silo. The two curves are really similar in materials proportion but there are more pallets entering the silo than the ones

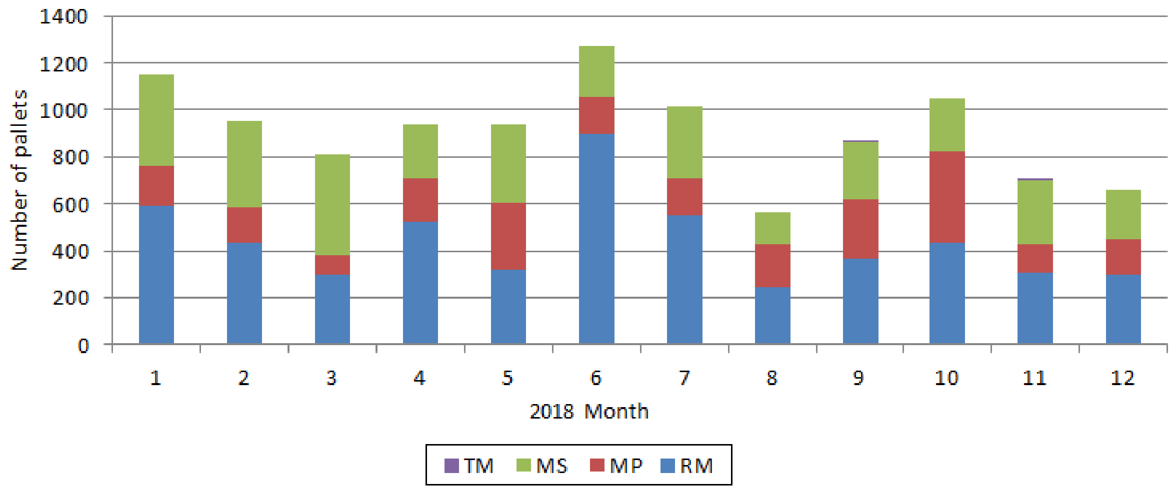


Figure 24. Number of packages that enter the silo per 2018 month classified by material type.

entering the warehouse. This means that there are pallets exiting and re-entering the silo probably caused by quality checks.

3.2.3 Expeditions

The income data used for the pallets expedition is the warehouse delivery lists. It contains the date of delivery, the material included, the number of pallets and the specific batch. In Figure 25 is shown the distribution of expeditions along 2018 months. The products X have been created to name an specific type of products that usually are treated as cross-docking materials being directly transported to the expeditions area. But last year there was an exception where a number of those pallets exited the silo. The rest of acronyms where described in Chapter 2 and are as expected for deliveries, a majority of finished products. It is important also to mention that there is WIP which are exits from the silo that where done before the beginning of the 2018 and thus, where already in the expeditions area when the simulation started. It can be seen that the WIP stays for two months in the expedition area until all pallets are picked as a delivery. Also the months quite vary in number of expeditions as the carrier's pickup are not much predictable (even though they are programmed in advance).

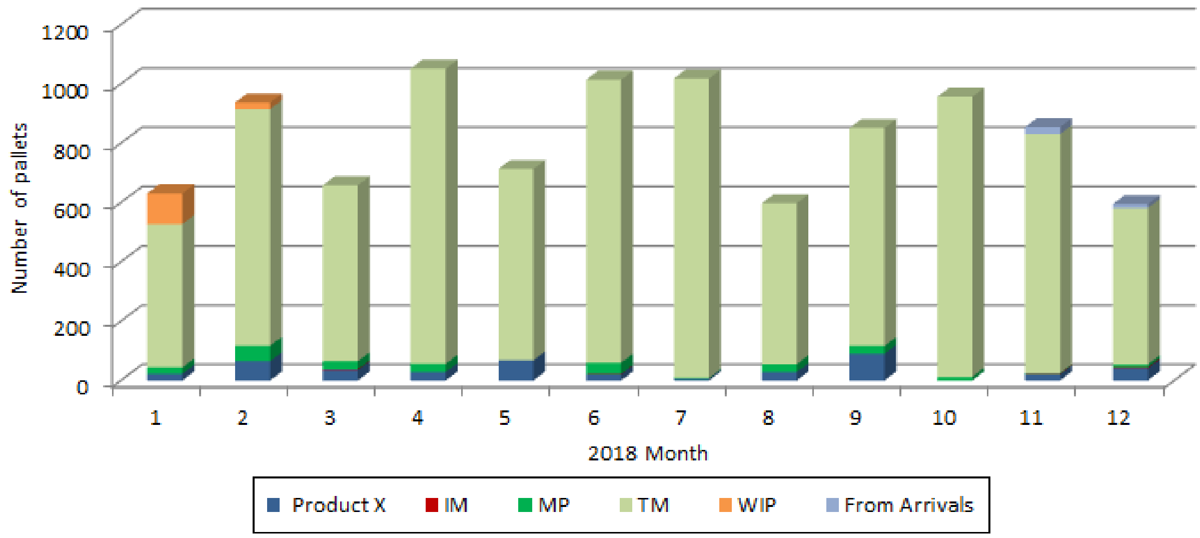


Figure 25. Expedited pallets from the warehouse in 2018 classified by month.

Chapter 4

The Warehouse Model Design

AFTER presenting the warehouse object of this thesis and the software that it is going to be used for the virtualization model design, in this chapter is presented all the logic behind the model, the main assumptions and the model validation process. The created warehouse model will represent the performance of the annex warehouse area during the year 2018, although the income data can be changed to represent any other year. Together with the programmed logic are also introduced in the model other variable definition like the equipment, transport times and working schedules. Finally, the assumptions and simplifications about the model are presented for the reader to understand how far the developed model can extract relevant data as well as the methodology used to validate the final designed model.

4.1 Model Logic Processes

Processes in SIMIO are a sequence of actions that may span time or change the model state. The logic processes can be created from basic predefined blocks containing conditioning statements or other programming logic being the most important part of the simulation model as it contains the constraints and conditions that represents the real system. An example of this processes blocks are: assign states, delays, creates, searches, seizes, decides, etc... Processes can be also fired by events, like the entry of an entity in a workstation or any other discrete condition. In this section are presented all the processes programmed in this project classified in different logic groups.

4.1.1 Entries of Pallets

In order to simulate the entries of pallets into the warehouse annex there have been used sources intelligent objects that contain logic processes. The entries of pallets in the warehouse, as mentioned before, can either come from suppliers arrivals or from silo exits. For the suppliers material arrivals there exists two sources. The first one follows an annexed table containing real warehouse data related with the introduced received materials in the same order and moment in time that in reality. This materials are transported to the arrival expedition area until further steps are decided. The second source placed in the suppliers entry represents the entries from arrival distributors that use the plant warehouse as cross-docking location. This second source creates less entities and all of them are directed to the expedition area to wait until the transport service arrives to pick up the delivery.

On the other hand related with the expeditions from the silo there is placed a source that models the pick-up of materials for its latter re-packaging and queuing until the delivery carrier arrives. Pallets exiting the sources exit one by one, then are picked by a transporter and moved to its next destination. When entities are created by the mentioned sources the logic processes shown related to them and shown in Figure 26 are fired. This processes define the pallets destination in case of the pallets exiting the silo and also assigns to the entity the material code, the packaging time, the expedition date and the batch code. All this assignments are done to later identify each different pallet and be able to distinguish the products and delivery dates to identify root causes later on in the results discussion. In case of the arrivals from suppliers it is also indicated the date the pallets entered the silo and, if the external storage is used for that specific material, the dates for this movement are also indicated.

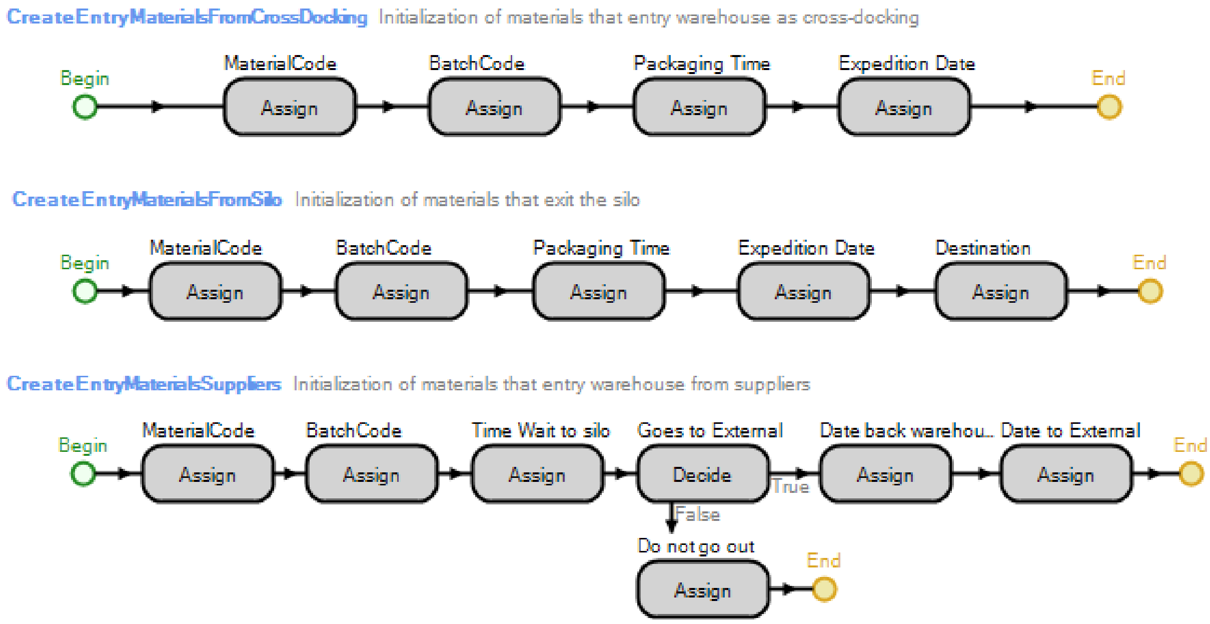


Figure 26. Creation of pallets entering the silo through the model sources.

4.1.2 Destinations

When the pallets are exiting sources or stations different destinations can be assigned depending on the pallet classification. For this specific logic have been created logic processes that filter this pallets differences and assign the correct pallet destination. In this model there are two key nodes when the destination of the pallets is selected: when exiting the silo and when finishing the quality check process. The pallets exiting the silo have been classified as waste, delivery, quality check and others having each one a destination related. The waste pallets are directed to a waste sink together with the disposals of obsolete or inadequate materials. The delivery pallets are the ones ready to deliver and are directed through a packaging process for its conditioning to the transportation method and then to the expedition storage area. There is also documentation or additional material that needs to be filled or distributed which is directed to the others sink. Finally the pallets can also belong to a batch that needs quality checks and are directed to the quality storage area.

The second key point where destination is decided and used is after exiting the quality check's workstation to evaluate whether the pallets are stored in the arrivals area or directly entered in the silo. In Figure 27 both decision processes are shown. Note that Decision 3 in the *NodeDestination_ExitingSILO* logic process,

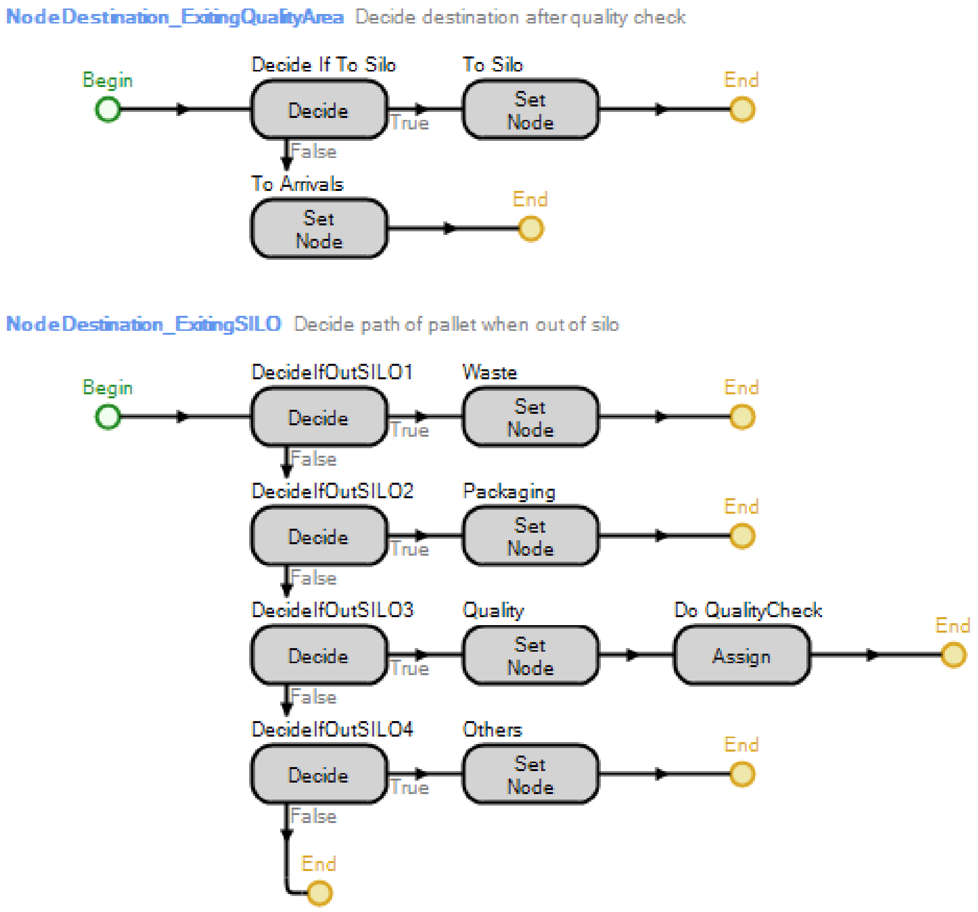


Figure 27. Destination selection processes when exiting the silo and quality inspections.

which is the quality check destination, has an extra logic step after assigning the expeditions area destination to the entity. This step activates a variable to indicate that the pallet needs a quality check and it is ready for it. The quality check server represents the functioning of the quality department which has an specific schedule to perform the quality checks. Only when the quality employees are on shift and there is no pallets waiting outside the cabin the pallets will be moved to the quality queue. For this, the logic process shown before as an example in Figure 19 and the *SearchQuality* process in Figure 29 are used together to handle the quality entry queue. When pallets finally enter the quality queue the previous mentioned variable is incremented and later diminish when exiting the quality check.

4.1.3 Repackaging and Quality

The repackaging and packaging workstations model the change of packaging for the pallets, either to adapt them to the transportation method in case of the deliveries of to prepare the materials for the quality checks. This processes take some time and use specific equipment to rotate the pallets, change the container, create new labels and seal or protect the exterior. Thus, this machines need the presence of an operator to manipulate the material and the equipment. In the workstation that model this machines, workers will be used as a resource to reserve them while the activity is performed. This logic is directly implemented in the workstation intelligent objects and it is fired when those are being used. The reserved transporter to perform the workstation activity will be different each time as transporter resource is selected by the smallest distance.

4.1.4 Storage Areas

The short term storage areas, as mentioned before, are modelled as stations where pallets are stored until an specific event occurs. To introduce pallets into stations, workstations are used as well as transfer steps. The workstations logic include the transferring processes together with the uploading/downloading times that the operators take to place the pallets in the correct locations. During all the workstation processes the worker is reserved to prevent them to perform other activities. The transfer steps move the entity pallets in the simulation from the 3D facility to the infinite space and converts them to an item inside the station. Complementary to this transfer step is needed an end transfer step to indicate that the material has already arrived to the transfer destination. This prevents the model from trying to move entities twice and screen entering errors or warnings.

In Figure 28 it is shown a simple logic for this station transportation that it is used for the downloading/uploading of materials into the expeditions area.

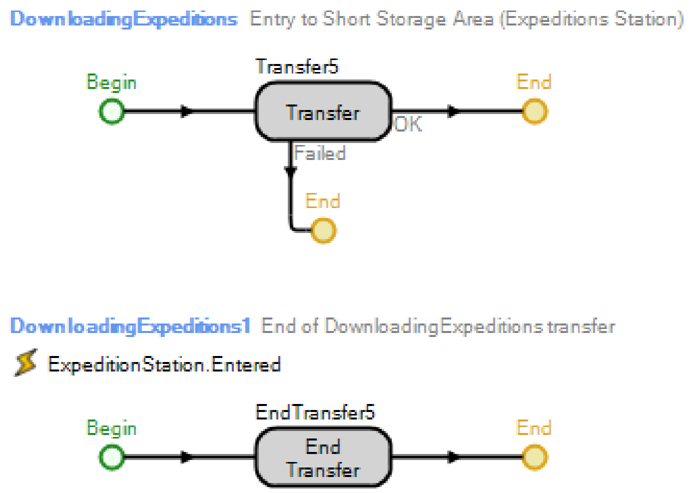


Figure 28. Loading and downloading pallets process.

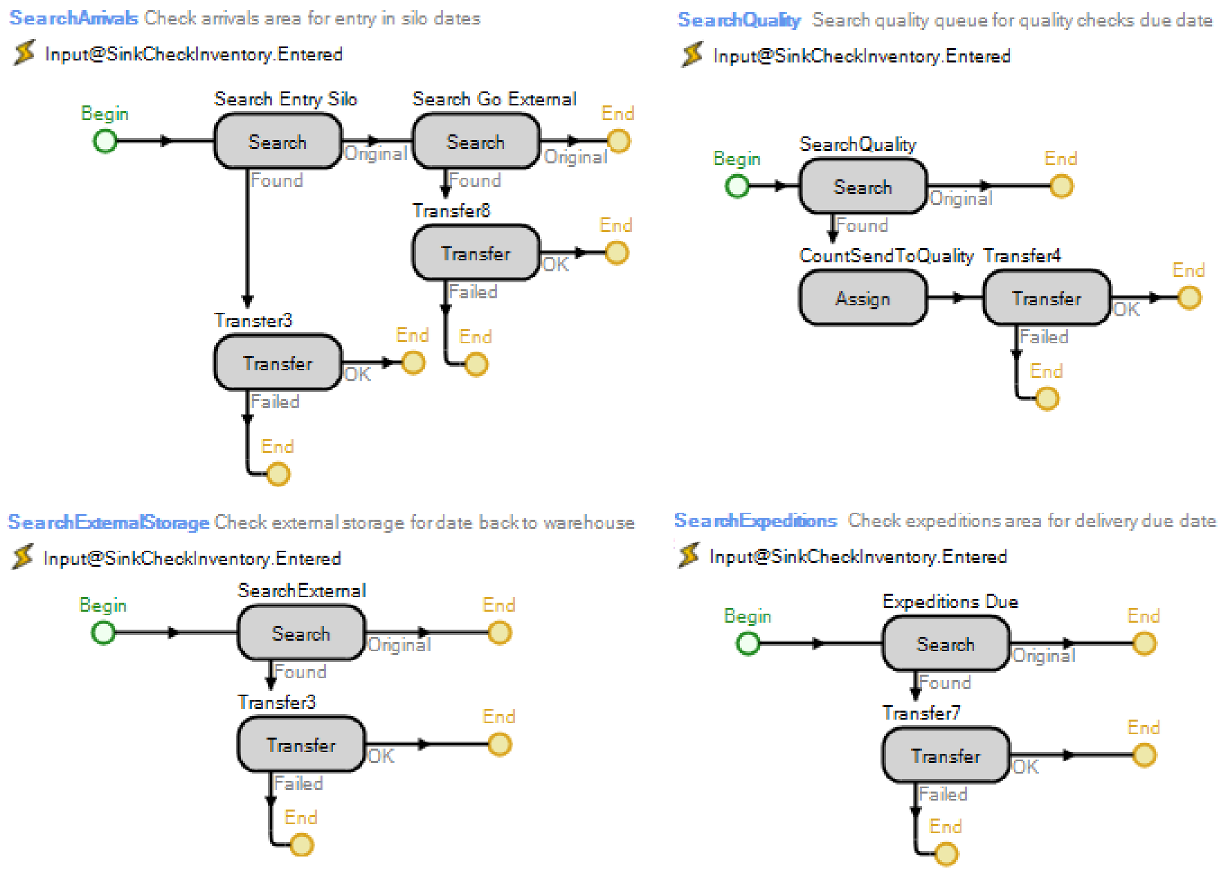


Figure 29. Searches in model stations to search for delivery order or transport date.

Another important step performed in the station areas is to check whether the material is ready to exit the station. The arrivals station is checked to identify whether the pallets have to be moved into the silo, the quality station or to external storage. The expeditions and external storage searches have similar logic. They verify that the due date has passed and transfer the materials out of the queue. Note that all this processes are fired by the same event. This event refers to a timer created to perform the searches every two minutes like in a for loop. This loop has been modeled with a source and a sink that send entities to each other every two minutes, then the creation of entities event is used to fire the searches in the station queues.

In Figure 29 are shown the four previous mentioned searches. All the transfers have an exclusion expression that will prevent for transferring materials out of the areas in non-labour days. They are associated with the workstation schedule so when they are off shift (same schedule as workers) the exclusion expression is activated. There is another process related with the short storage areas that is shown in Figure 30.

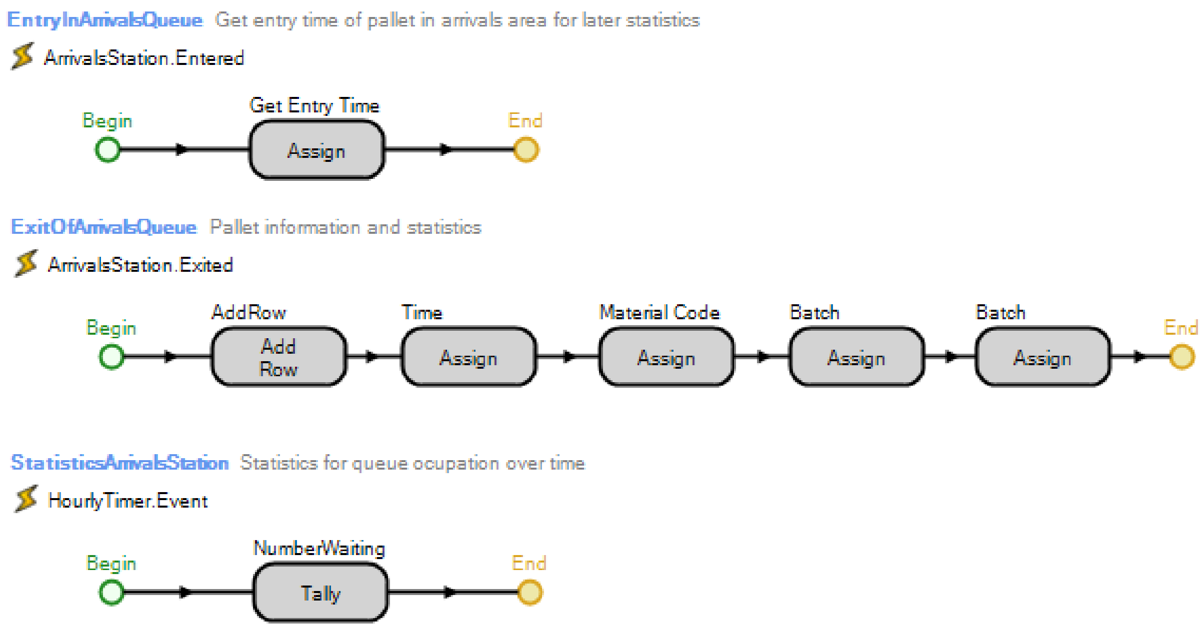


Figure 30. Statistic processes for pallets staying-time evaluation in the short storage areas.

It is used to record the time that each pallet has stayed in the area to later perform statistics about the area occupation. First when the pallet enters the area the date is saved in a variable. After the pallet is transported out of the station a new row in an output data table is created and the time span computed and record in it. It is also saved the batch and material code for its later use in excel to extract relevant information about trends and causes in the pallet's staying time and its rotation.

4.1.5 Initial WIP

This last process category contains the initialization of the model logic. The process is shown in Figure 31 and has two different branches for the arrivals and expedition areas respectively.

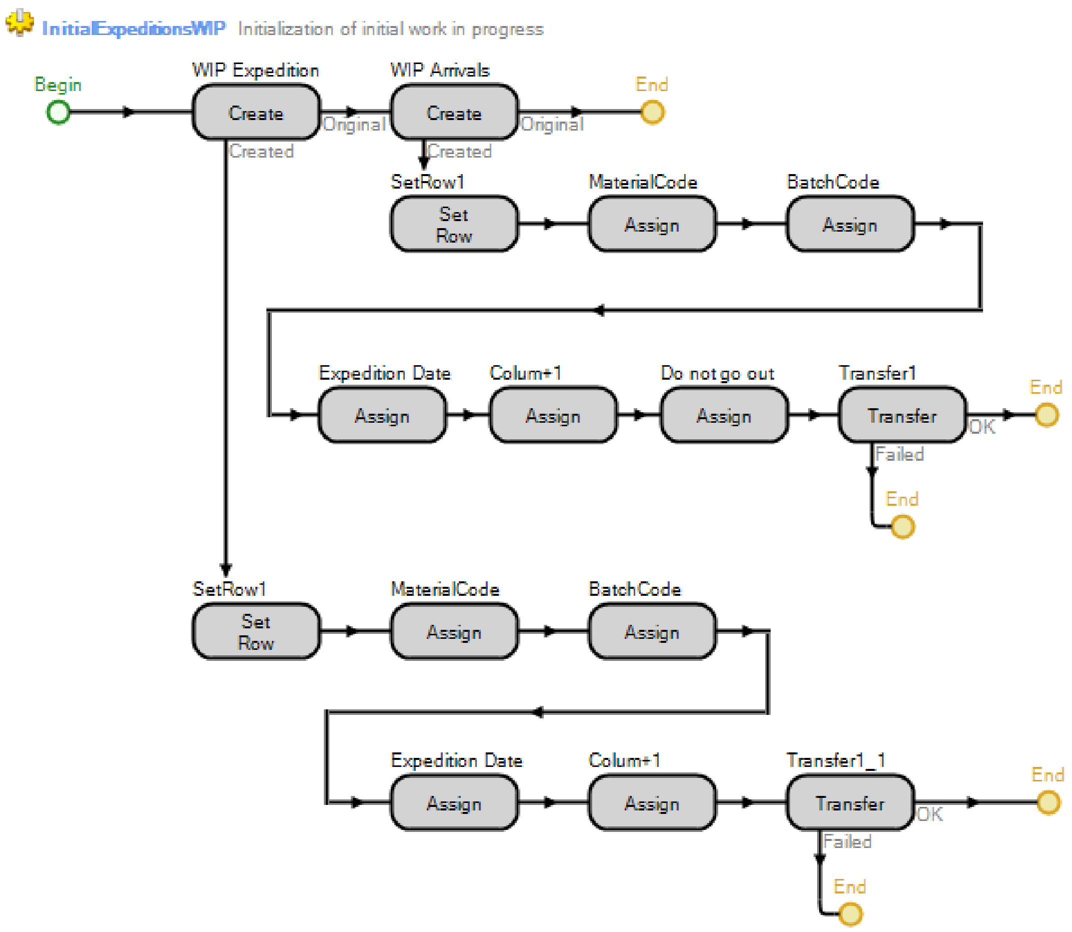


Figure 31. Initialization process for WIP creation.

In this case it is used to create the entities that constitute the WIP in the short storage areas. This process is different from the previous mentioned ones as it will only be executed once at the beginning of the simulation. The branches start with a creation step that generates a pre-defined number of entities. Each of this entities are matched with a row in an external data table containing all the WIP pallets. Then, the material code, the batch code and the expedition date are assigned to the entity before transferring it into the storage station. In the case of the arrivals WIP there is an extra step. This step assigns a value to the variable that contains information about if the pallet goes to external storage or not.

4.2 Equipment and transport times

In the created model there are three workstations that require a processing time: the packaging for expeditions, the conditioning for the quality inspection and the quality checks. In Chart 1 is shown the processing times for each of the workstations as well as the number of pallets that go through it. The re-packaging station time also varies depending on the transportation method that is going to be selected for the delivery. The times shown for the re-packaging time are an average of the all the used ones. The real processing times where used in the model as there was original data for each of the pallets re-packaged. The pallets that go by air take more time that the ones by boat or truck as they need to be covered with thermal protection, need more labels or special documentation and are weighted. There is also special preparation for the samples that makes its preparation close to an hour but this is not so relevant as there are only 70 pallets.

Station		**Min**	**Batch Size**
Re-packaging	Air	16,26	2.009
	Air-samples	49,24	70
	Sea	9,36	2.374
	Truck	7,16	5.433
Conditioning		4	2.993
Quality Check		6	2.993

Chart 1. Warehouse workstation processing times and quantity processed.

There are also times associated with the transport of pallets, specially for the uploading/downloading tasks that have been mentioned before. For this uploading/downloading times have been created workstation with processing times of half a minute. Additionally, the workers that move the pallets can carry two pallets at the same time as they use trolleys for the transport.

4.3 Working Schedules

There are two types of working schedules. The first one is for the quality checks. This task is performed by the quality department which only dedicate five days a week (from Monday to Friday) with two shifts of two hours duration (from 9:00 to 11:00 and from 16:00 to 18:00). The second schedule type corresponds to the operators in the warehouse. During the week there are two shifts every day of eight hours. As mentioned before in the warehouse there are employed seven workers that are distributed in the two shifts. The two sifts go from 6:30 to 14:30 and from 14:30 to 22:30. The total worker numbers are divided in four employees for the morning shift and three for the afternoon shift.

4.4 Assumptions

There are different assumption that have been taken about the model in order to simplify the design. In this section those are mentioned to the reader in order to understand the extent and validity of this project.

- **Transporter Speed:** As it is unknown the percentage of time that the transporter use the trolleys to move the materials and this speed is faster than the normal walk, it has been assumed an average speed between the two movements that has been assigned to all workers. Also there are not specific paths for the workers to move so the trajectories that the workers will follow will be the optimal to the destination location, not representing the real variability of routes. But it has been observed that changes in trajectories doesn't introduce relevant changes in the obtained results so this trajectories complexity can be simplified without almost affecting the desired results.

- **Capacity of the storage areas:** Most of the pallets can be pilled in two levels (specifically a 79% of the total income pallets). This assumption has not been taken in mind in the model design but will be evaluated in the results analysis to extract relevant conclusions.
- **Quality Checks:** The quality checks processing time has been estimated as an average. Not in all batches are inspected the same quantity of pallets as there are different quality procedures and there are different quality inspection that also vary in time. Despite this, the quality check doesn't affect the utilization of the expedition areas as it has another area for its storage. It just have been modeled to give some information to the company management that is not going to be covered in this thesis.
- **Transporters capacity:** There are some arrivals that cannot be transported pilled in two levels by the trolleys, this haven't be taken in mind as those kind of pallets are only around a 20% of the arrivals. This will mean that the worker would have to perform two transports instead of one, but again, this transport time is not so relevant so it has been simplified.

4.5 Model Validation

Once the entire model has been designed it has been simulated along a year span to compare the extracted data with the one gathered from the warehouse and this way validate the created model. The compared data to check the validity of the model has been the following:

- **Man hours needed:** The man hours used in the model simulation have been compared with the times from a previous warehouse timing analysis. This man hours expended in the different processes has been extracted from physical documents and it stands for the whole expedition processes: picking from silo, packaging, labeling and loading/unloading. In the following Chart are summarized together the warehouse timing analysis and the model timing results. The results from the model are smaller than the obtained in the warehouse analysis but are inside the variability limits. This can be caused by the model routing optimization and unexpected stops or productivity variance between different experienced and beginner workers.

	Daily	2018	Warehouse Analysis
Arrivals	**Total man hours**	4.26	
	Man needed	0.53	0.7
Expeditions	**Total man hours**	15.82	
	Man needed	1.98	2.18

Chart 2. Man hours validation.

- **Packaging times:** The obtained packaging average times from the model data where compared with another analysis performed during last year in the warehouse. This analysis was a sample time of the packaging times for the different transportation methods (air, sea and truck). The data was extracted from the physical documents that are filled along the expeditions process. The difference is that the created model uses data from the digital systems instead of the physical documentation. It is also important to highlight that the packaging time analysis performed in the warehouse was done only over a four month period and the simulation model covers a year time span.

	Total Pallets	Simulation Minutes/Pallet	Time Keeping Minutes/Pallet	Time Keeping Deviation
Air	2.009	16,203	19,09	6,82
Air-Sample	70	49,24	-	-
Truck	5.433	7,16	8,92	5,07
Sea	2.374	10,67	9,12	4,43

Chart 3. Model packaging times per transportation method vs the warehouse packaging times analysis.

Note that the data used in the model is inside the ranges of the warehouse analysis excluding the air samples which where not covered by the physical documentation. The analysis conducted by the warehouse doesn't distinguish between air deliveries and sample capsules and those where treated as the same category. This latter ones take much more time and are a unique pallet that requires fragile packaging and specific documentation.

- **Arrivals:** The daily reception of materials in the warehouse is planned by the supply department around one complete truck delivery per day. This is translated in 50 pallets as a daily average. Even thought, the amount of packages received each day in reality will vary caused by carrier delays, this is only an indicative average to plan the arrivals as balanced as possible. In Figure 32 is shown the number of arrivals per day along the 2018 and as it can be seen the average of pallets is really close to 50 pallets for the working days.

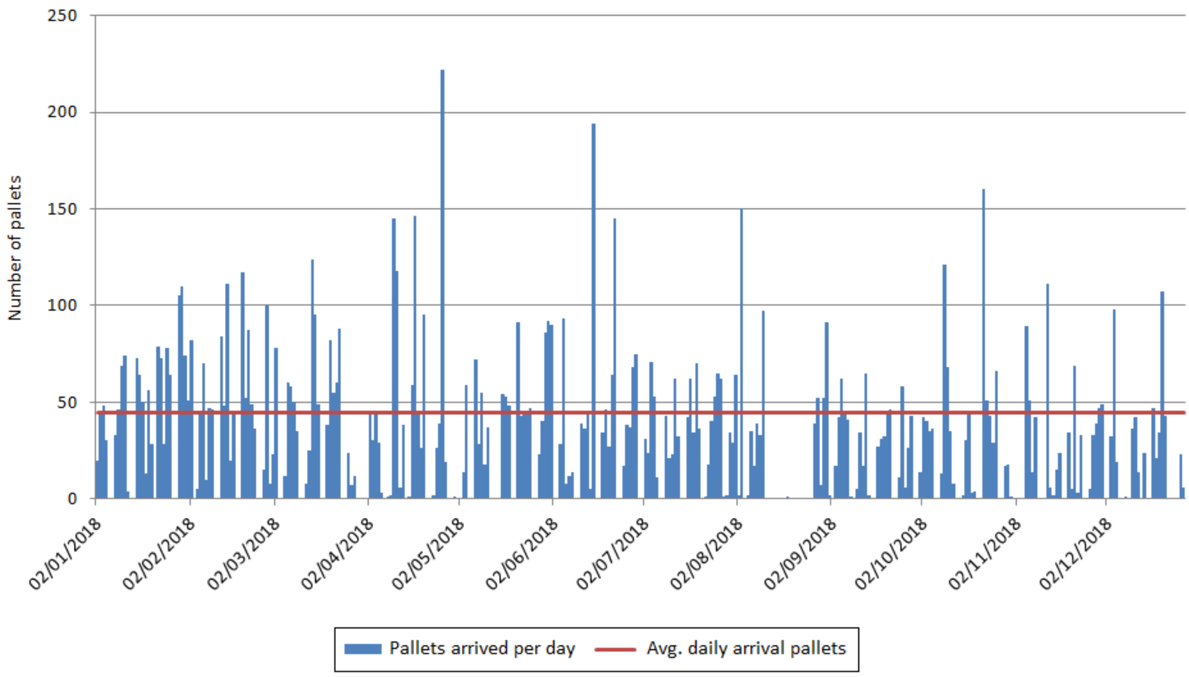


Figure 32. Number of arrival packages per day to the warehouse.

Other way to check the validity of the arrivals input data has been done by comparing the entry of arrival materials in the warehouse with the production rhythm. The arrival materials entry in the warehouse has a similar distribution to the production but shifted some months in advance. There is also a diminish in the entry of materials by the last months of the year related to inventory adjustments that are done to close successfully the production year and use all the inventory materials available.

- **Areas occupation:** This last verification is not quantitative. The occupation curve for the expedition area over time was checked with the warehouse manager to see if the average occupation and the peaks extracted from the simulation matched with their working experience over the last year. This curve will be latter on discussed in the results chapter.

Chapter 5

Experiments and Results

ALONG this chapter are presented and discussed the results extracted from the performed SIMIO experiments. First, it is discussed the actual situation of the warehouse in order to understand the functioning and performance along the year 2018. This initial evaluation is intended to realize the work-flow problematic points and possible enhancements that can be implemented in the warehouse. Each of the presented problematic steps will be accompanied of a cause discussion and recommended solution that can be implemented in the studied system. After the evaluation of the actual performance it will be analyzed how a future demand increase will affect the studied system and individual processes. This capacity increase will be done with real expected demand figures along the year 2023 and the extracted results will be used to evaluate different alternatives (investments, changes in processes, new tasks...) to face the mentioned situation.

5.1 Actual Work-flow Discussion

The 2018 year simulation's result discussion will be focused first on the warehouse annexed area and then, on the overall functioning of the warehouse. The two short storage areas located in the warehouse annex are discussed separately as their work-flows are completely different and involve different processes and tasks. The presented results include the areas' occupation over time as well as other relevant

KPIs to further on find the root causes of the actual occupation curves shape. After each of the areas is understood, the total annex area occupancy is discussed under different scenarios in the Warehouse Results, Section 5.1.3. Finally, to end this actual work-flow discussion are presented recommended solutions for each of the three previous mentioned section founded problems that can be implemented in the studied warehouse.

5.1.1 Arrivals Results

In this section are presented the main data results for the arrivals short storage area extracted from the model simulation. Each of the here presented results will be analyzed and explained to guide the reader from the detected problem or process that can be optimized to the root causes that are motivating those situations. The results presentation and discussion here presented evaluate the area occupancy over the year 2018 to understand the actual area usage. Then, different underlying analysis are also presented to identify the main causes of the the capacity actual situation.

In Figure 33 is shown the occupation curve of the arrivals area over the year 2018 represented by the green curve. There are also included in the graph two dotted lines that represent the capacity limits of the area. There are two of them because the arrival pallets have a singularity, for instance the bags and petrol drums cannot be stored in two levels as the containers and materials could be damaged. This singularity has been evaluated and around the 80% of the arriving pallets can be stored in two levels so actually this doesn't entail a great augment in capacity. Nevertheless, in the mentioned graph, the two different capacity levels are indicated to have a sight of the worst and optimal scenarios possible.
There are two moments in time where the occupation is for sure overcome and these peaks can be found in the months of April and June. This peaks are not expected in the arrivals planning as the entry of materials is tried to be aligned around 50 pallets. But as it was shown in Figure 32 this is not the reality. In the mentioned real entry curve it is shown that even the entry pallet average is around 50 as expected from the planning, there are some days that the warehouse actually

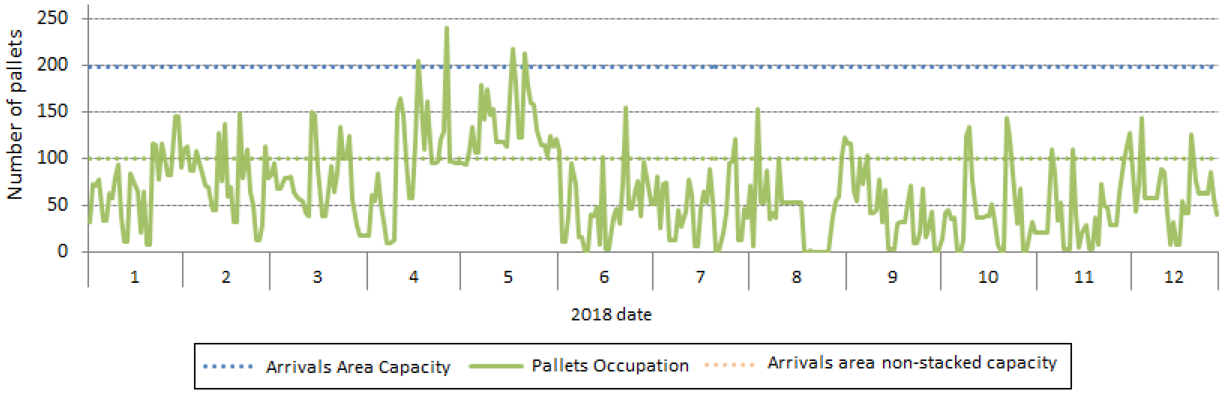


Figure 33. Arrivals short storage area occupation over time.

receives way more materials that it should. Some peaks match with the occupation curve peaks causing an instantaneous increase in the occupation that is removed after some hours by using the external storage.

Apart from this peaks the average occupation of the curve is between 23,61% (for the non-stacked scenario) and a 47,22% (for the optimal scenario). In the maximum occupation peak is being used a 12.57% of the expeditions area in order to download this pallets. It can happen that over this peak times the expedition area is also at maximum capacity but this will be analyzed further on by presenting the total annex area and occupation curve. A final highlighted fact is that the occupation of the area shows a descendant behaviour along the year of around 50 pallets. This makes sense as the entry of materials tendency, as it was explained before, presents a similar behaviour to adjust and minimize the inventories at the end of the year.

	Pallets	**Occupation**	**Expeditions Usage**
Max. in queue	243	122.73%	12.57%
Avg. in queue	46.75	23.61-47.22%	

	Days
Max. rotation	92.34
Avg. rotation	1.15

Chart 4. Number of pallets and time rotation in the arrivals area for 2018 most realistic scenario.

There have also been extracted some indicative KPIs that evaluate on a big picture the time the pallets stay in the arrivals area. This KPIs are shown in Chart 4 with an average rotation of pallets of 1,15 days and a maximum staying time of 92.34

days. The maximum time in the arrivals area is a significant big figure but after the study of those specific pallets it was seen that there was a problem with a damaged delivery that was detected after its download. This carried a problem of spilling risk and because of security needs and negotiations with the supplier the situation ended in the affected pallets staying for a long time in the arrivals area.

Nevertheless, the rotation of the pallets is quite suitable as the figure means that the day after the materials arrive and are download the pallets are either entered in the silo or carried to the external storage supplier, leaving the area empty for new truck downloads. Actually as this KPI is an average between all pallets, and non-labour days are covered in the model, the vast majority of pallets will be spending less than a day in the arrivals area. In Figure 34 is presented the number of pallets that stay between zero and six days showing that there is not much variability in the arrivals rotation.

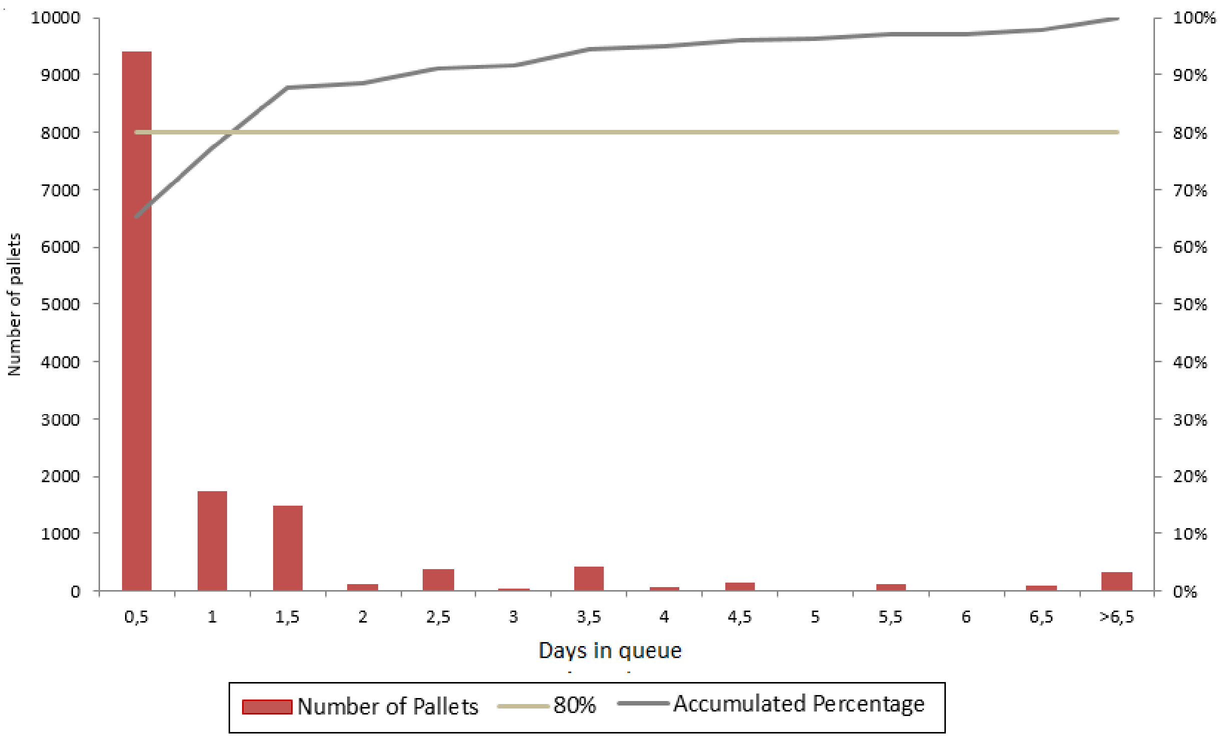


Figure 34. Pareto graph for the number of days pallets stay in the arrivals area.

To improve this actual occupancy situation there are three different alternatives, the first one is the investment in an area increase making the total capacity bigger, the second one is to find the reasons of the occupancy peaks in order to smooth them, and the third one is to use the external storage on a higher level than is done right now. In this results discussion is evaluated the second alternative as it will be the most beneficial on the long term and the other two can be implemented without further need of research.

The entry materials can be classified in type of product (as it has been seen before RM, MS, etc...), brand category or by product family. This product families gather all the brand products with the same pharmaceutical characteristics and allow a higher overview of the production plant products. Figures 35, 36 and 37 show this three different classification together with the number of pallets that enter the arrivals area and the average of time they spend in the queue.

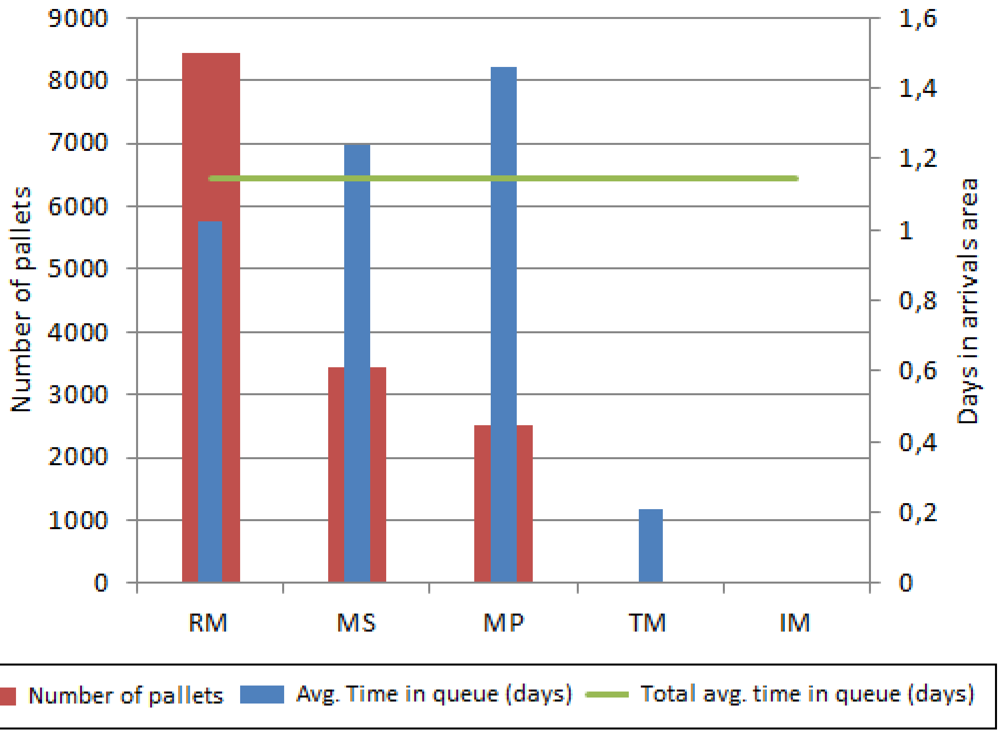


Figure 35. Average time pallets stay in the arrivals area depending on the product type.

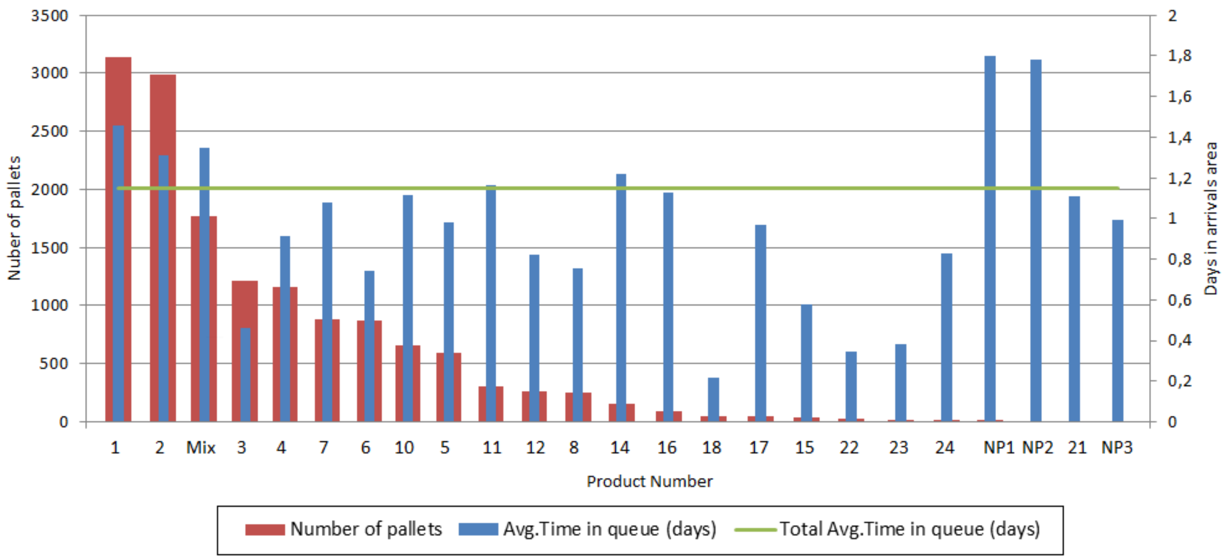


Figure 36. Average time pallets stay in the arrivals area depending on the product brand.

As it can be observed, conditioning products take longer to enter the silo just as the liquids, common materials and product families 1 and 2. Along the results analysis of this master thesis it have not been founded the causes or reasons to explain this differences in the mentioned products rotation time, but it can be further performed an extensive analysis to identify specific problems with this materials.

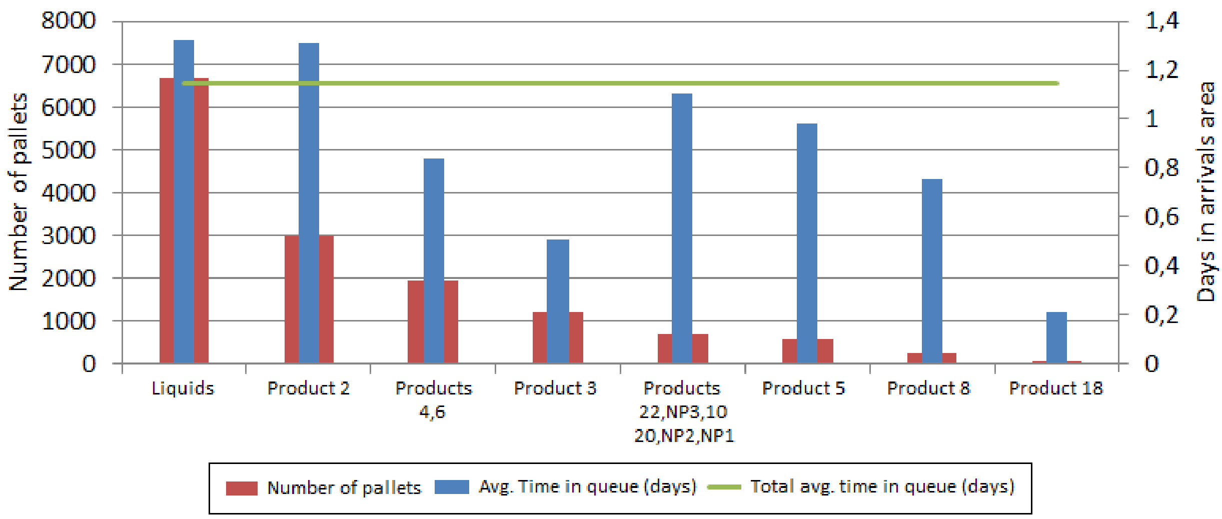


Figure 37. Average time pallets stay in the arrivals area depending on the product family.

The most relevant conclusions extracted from the arrivals area analysis is that the rotation of pallets and the area average occupancy are in good conditions but there is variability introduced by not respecting the arrivals plan. There is also in the arrivals area an occupation capacity that is not being used due to the unavailability of two level storage for all type of pallets.

5.1.2 Expeditions Results

After the results from the arrivals area simulation have been evaluated, in this section are presented the main results and data extracted from the conducted simulation experiments of the expeditions area. To begin with the results discussion, first, the curve over time for the expeditions area is presented in Figure 38. Note that the reference taken as the area capacity limit is the blue dotted line.

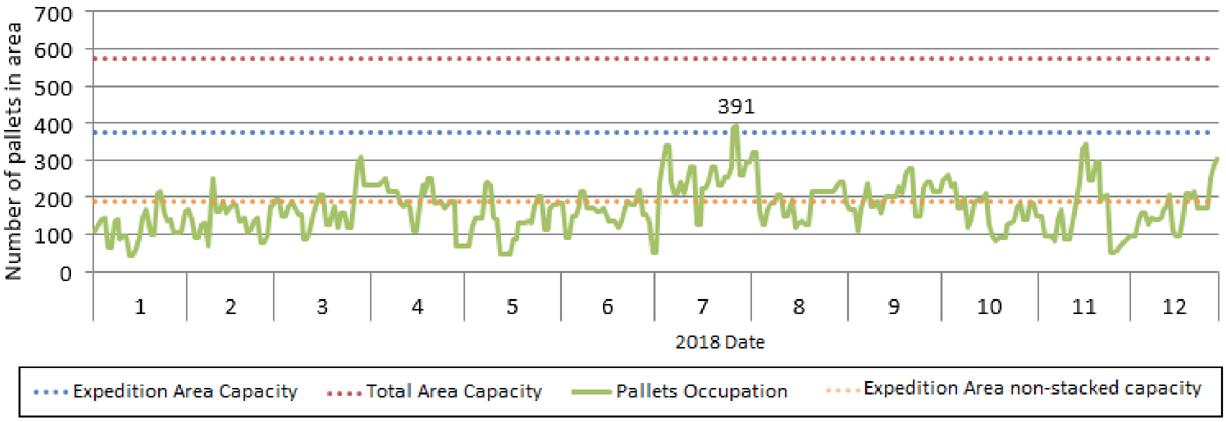


Figure 38. Expeditions short storage area occupation over time.

This line represents the capacity of two level stored pallets. The vast majority of expeditions, as mentioned before, can be piled for storage, hence this situation is taken as the evaluated scenario. As it can be observed the expeditions area occupation is very unsteady and most of the time it is bellow the capacity limit. There are only two points in time when the needed occupation surpasses the area capacity, by the end of July and at the end of December. This is because in August the capacity of the production lines decreases, caused by vacations periods and thus there are needed more material movements and transports beforehand to have the holiday's deliveries covered. The same happens with the month of December when there are Christmas vacations and the plants shuts down completely. As shown in Chart 5 the maximum number of pallets in the queue in year 2018 is 391 (being the limit of capacity 358 pallets which means a 109.22% occupation) which requires and instantaneous use of the arrivals area of 16.67%. This is a risky situation because if the arrival area is also full at the same point in time it would be no place for the entering pallets and extra measures should be taken that increase the storing costs.

Despite the two peak occasions the average occupation of the expeditions area is of 150 pallets which means a 41.92% of occupation. This number reveals that there is no urging need of increasing the expeditions area as it was initially thought for the motivation of this project. As long as the peaks of occupation are smothered the expedition area is extensive enough to cover the demanded storage. Furthermore, following the tendency curve of the expedition area occupation it can be seen that the occupation increased over the year an average of 50 pallets, but it is not proved that this is caused by the increase in production and not because of cyclical behaviours. This will be further discussed in Section 5.2, where an increasing demand scenario for 2023 is evaluated.

	Pallets	**Occupation**	**Arrivals area usage**
Max. in queue	391	109.22%	16.67%
Avg. in queue	150	41.92%	

	Days
Max. rotation	138.13
Avg. rotation	5.06

Chart 5. Maximum or average number of pallets and time in expeditions area for the year 2018.

The average of pallets that are stored in the expeditions area stays in the queue for an average time of 5,06 days (counting with non-labour days) a figure that can be reduced as the maximum non-labour days are the two days weekends. There are some pallets that stay in the area for more than 138 which means more than four months. This long period pallets can be also easily seen in Figure 25 shown in a previous chapter, as part of the WIP extracted from the Silo in 2017 that stays in the area until March to be removed. This two figures give an initial sight of the area situation. There are several batches that experienced storage time outliers, this, together with a rotation that can be diminished, makes the area occupation really unsteady and unpredictable. Furthermore, in Figure 39 is shown a Pareto graph which exhibits that the 80% of the area occupancy stays less than six days, the rest of the pallets are outliers.

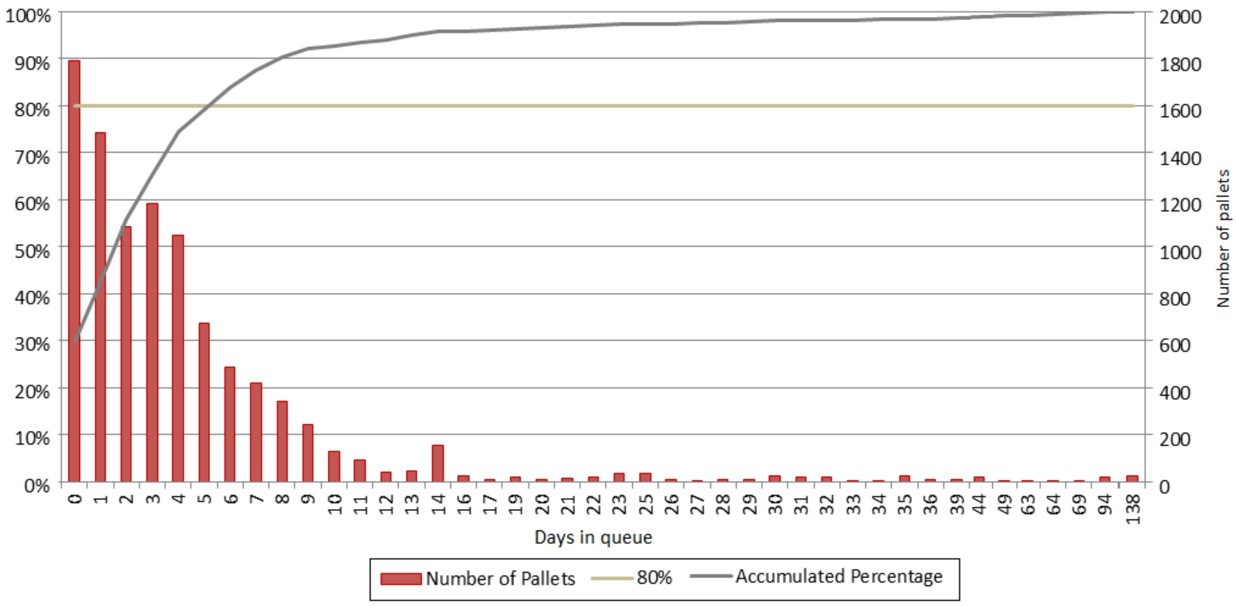


Figure 39. Pareto graph for the number of days pallets stay in the expeditions area.

Another important result extracted from the simulation is that neither the workforce or the machinery capacity are creating bottle-necks or are at the moment close to their maximum capacity. It is important to add that not all the workforce's tasks have been added to the simulation but the percentage of occupation time is small and close to the real experience results. Until this point it can be established the conclusion that the human labour is enough, the machinery usage has enough capacity but the expedition area is creating a bottle-neck at some points in time. To improve or solve this problem there can be selected two different options. The first one is to do an investment and reform the area of the warehouse to increase the area capacity and the second option is two reduce or smooth the occupation level of the areas by removing inefficiencies in the processes. In this thesis we are gonna evaluate different solutions for the improvement of the area occupation as this will be useful even if the area is later expanded. It would probably also be a less expensive alternative that would not affect so much the daily functioning of the warehouse.

To detect which variables affect most the expedition area there has been assessed three graphs that evaluate three different variables currently conditioning the time the pallets stay in the area. This three variables are the transportation method (even thought all the pallets are picked up by truck from the warehouse the majority of the trip can be done by other transportation method), the delivery destination and the pharmacy product brand.

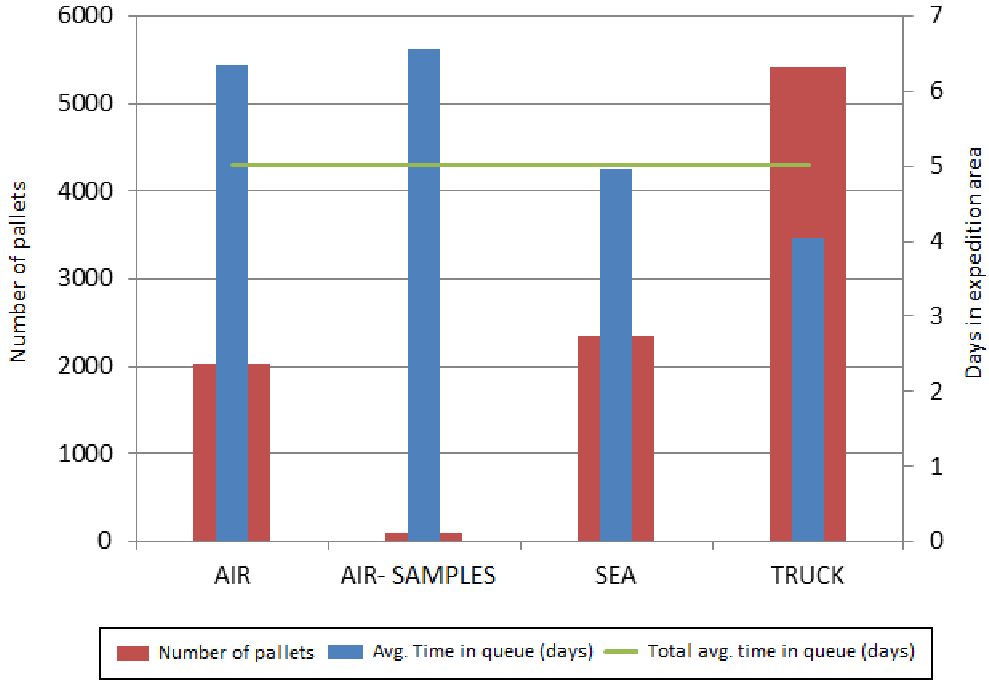


Figure 40. Average time pallets stay in the expedition area for each transportation method.

In Figure 40 can be seen that the usage of different transportation methods entails a notorious difference in the time that pallets wait in the expeditions area. It can also be observed which transportation methods are the most used and which entail longer times in the expeditions area. The presented figure is representing only the time that pallets stay in expeditions area and not the packaging times so the variability of the different packaging methods timing is removed. For truck transportation, the most used transportation method, the pallets waiting time is below the general average mentioned before, while for aerial methods is almost two days longer. The areal transportation method and the air samples are both deliveries carried by plain, the only difference is that the samples are unitary pallets prepared under special conditions that require more documentation (that is why those pallets stay a bit longer in the expeditions area). At this point it is also important to mention that after a complete delivery is placed in the expeditions area it has to wait until there is fixed a date for a carrier transportation. This is made to prevent that carriers cannot be loaded because batch damages. This actual process is the main cause creating the mentioned noticeable delays in the average rotation time and is a process that ads no value if the damage risk is not real or the overall expenses are not well evaluated.

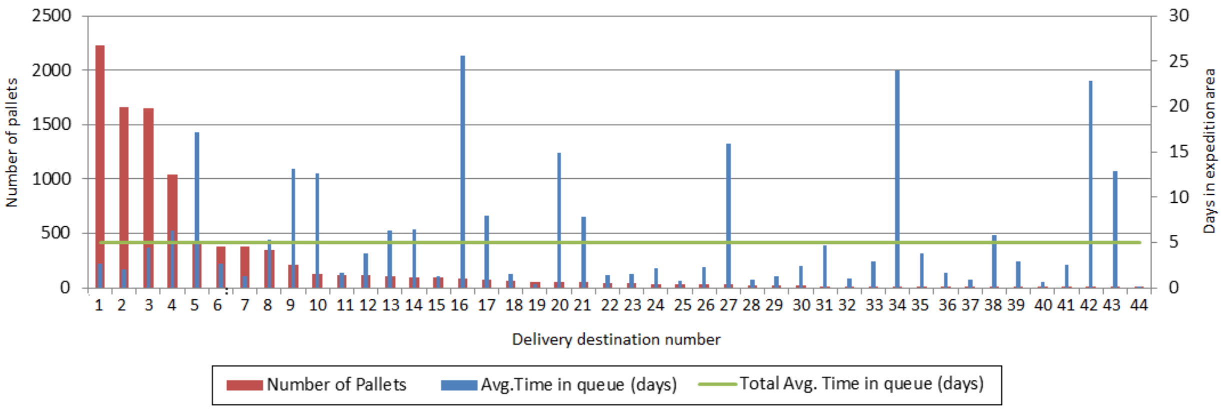


Figure 41. Average time pallets stay in the expedition area depending on the delivery destination.

The mentioned second variable, the delivery destination, is shown in Figure 41. This is an important and relevant variable as each destination is negotiated with an specific particular party, so if negotiations are improved the times can be reduced. For example, Leverkusen, where are the company's headquarters, is one of the destinations with more pallets from deliveries that, at the same time, takes more time to pick-up the expedition batches. This situation and the pick-up delays can be managed to be reduced or eliminated by penalties or discounts in the transportation negotiation.

Finally, Figure 42 classifies the pallets by product brand. The order in brand quantity of pallets is the same as in arrivals for the 80% of the total pallets (the first fourth brands without taking in mind the mix products which make no sense for the finished products). As it can be seen there is main differences in the rotation times. In the expeditions area the fourth product brand is above the average waiting time entailing this product a considerable amount of delivery pallets. There are also some brand outliers like the 23 and 24 that stayed in the areas for too many days, but this is probably because of some important problem that couldn't be fixed in a short time (there are involved only a few pallets).

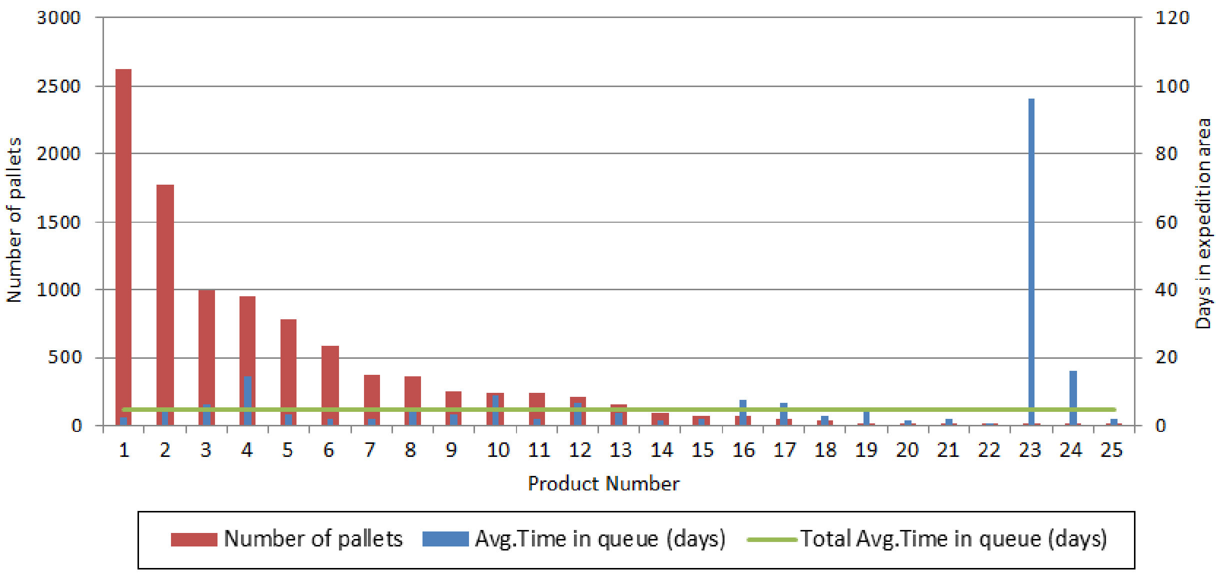


Figure 42. Average time pallets stay in the expedition area depending on the brand category.

Product 4 is gonna be further studied to find delaying root causes. This product is relevant as it is one of the main delivered products and has a staying time in the area above the average. First, is evaluated which transport method is more used to carry this batches. This distribution is shown in Figure 43. There is

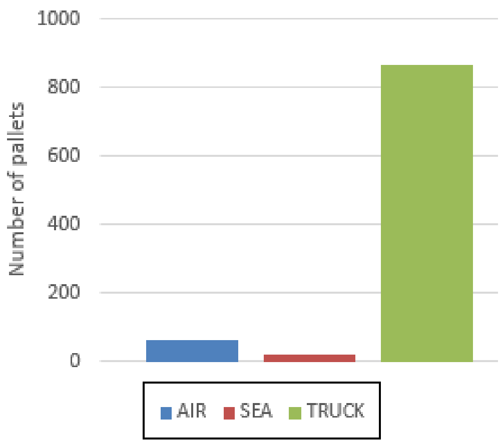


Figure 43. Product 4 number of pallets by transportation method.

not any noticeable problem with the transportation method that could be delaying so much the specific product as the majority of transports are made by truck, the fastest transportation method, so this variable is discarded as cause of the Product 4 delays. The next step is to check which destinations are being delivered. Figure 44 shows that half of the delivered Product 4 pallets go to the destinations with the previous observed in Figure 41 higher pick-up times.

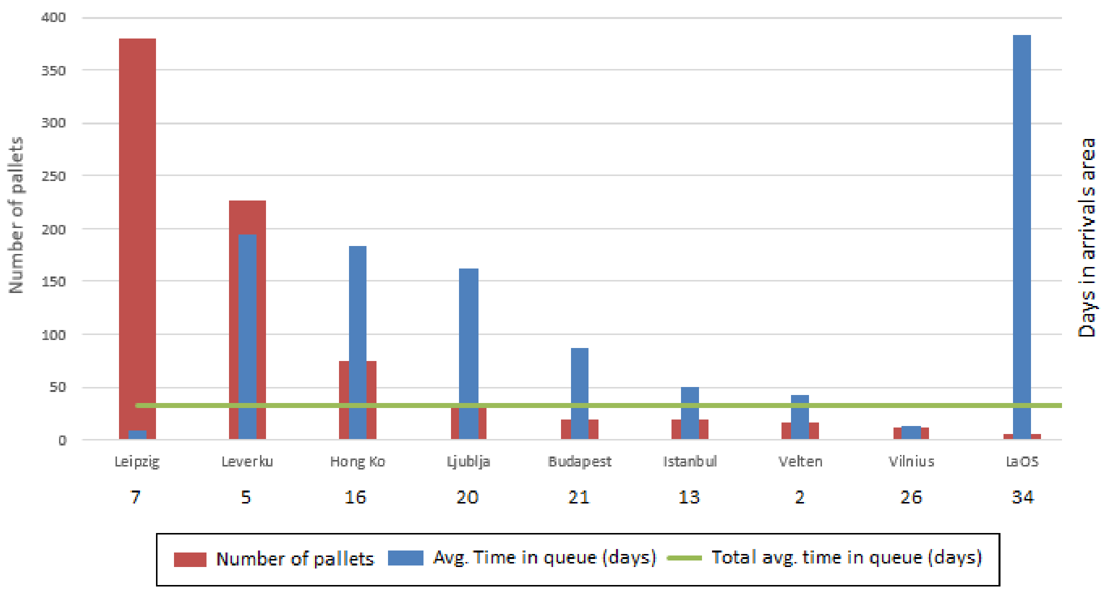


Figure 44. Product number 4 delivery destinations.

It can be shown how product 4 destinations are causing the enormous delay in the brand average. Thus from this analysis can be concluded that the destination (and thus carrier selection) is the real critical variable that causes noticeable delivery delays. Negotiations with this destinations should be made in order to improve the batches pick-up or absenteeism rate.

After the previous results analysis it has been understood the importance of smoothing the occupation curves as much as possible, but having no carrier delays is a really difficult situation to achieve in a warehouse with so many carrier partners. Next, it will be presented a performed simulation experiment that evaluates the differences between removing the variability of expeditions with the actual rotation and the total removal of the occupation variability. The first mentioned scenario represents the case in which the warehouse is able to remove the variations for the expeditions waiting time to the actual average rotation of five days. The second scenario evaluates re-entering in the silo all deliveries that are not delivered by plane and are expected to be waiting in the expeditions area for more than one week. The first scenario expeditions area occupation curve is presented in Figure 45. This scenario shows the case in which the outliers are removed. For this all pallets are expedited in less than five days, forcing all deliveries that wait longer to be picked up by the carrier in a maximum time frame of five days. Even the average occupation is lowered in this scenario to a 31% (a 11% less), the curve variations are not smothered so much, meaning this that the variability in the area occupation is not solved by only removing by the variability in pick-up times.

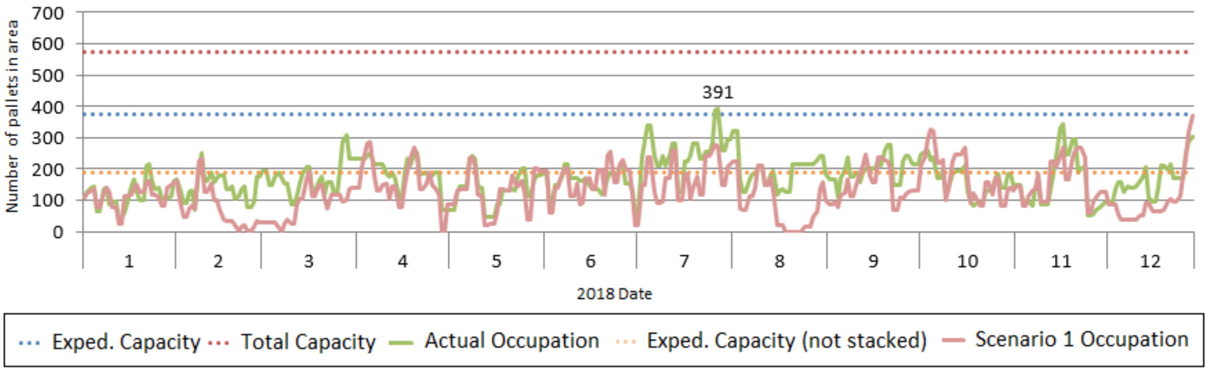


Figure 45. Expedition area occupation over the year 2018 for scenario 1.

The second scenario occupation is shown in Figure 46. In this scenario each delivery that is expected to be in the expedition area longer than seven days is re-entered in the silo until the final and real delivery date. There is an exception in this scenario and is that the pallets that have already been packaged for areal distribution are covered in thermal blankets, making them unable to re-enter the silo (labels cannot be longer read by the automated silo) , so those are not considered and will stay in the expedition area as expected. This areal pallets are the ones that, as seen in Figure 40, stay longer in the expeditions area but, despite it, the occupation in this scenario is reduced to a 27% (a 15% less) and the curve is smothered. In this scenario is removed the non-adding value steps of the expedition process reducing this way the occupation average as well as the variability. This solution would be the optimal one but in reality the silo is at its capacity limit and cannot be implemented until this bottle neck is reduced.

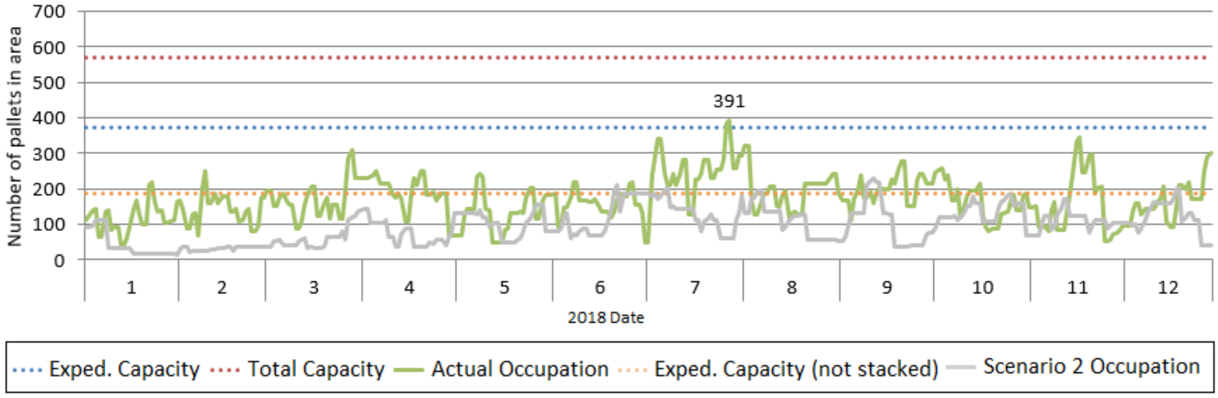


Figure 46. Expedition area occupation over the year 2018 for scenario 2.

Finally a summary with the KPIs evaluated for the original situation are presented with the two discussed scenarios in Figure 47.

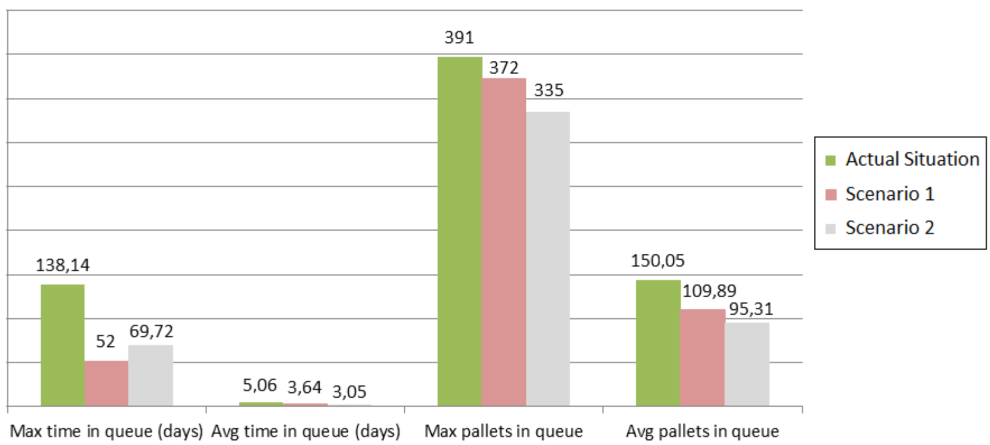


Figure 47. Main KPI variation for the two evaluated scenarios

The most relevant conclusions extracted from the expedition area analysis are that is crucial to reduce the uncertainty of the carrier pick-up date and the rotation time of the pallets. The uncertainty of carrier pick-ups creates occupancy peaks that collapse the storage area and even if the area capacity is increased by investment this peaks will keep happening as the cause situation is not solved. On the other hand the average occupancy is already below the 50% but can be further improved by changing the actual expedition process and thus, reducing the deliveries rotation time.

5.1.3 Warehouse Results

This final section of the actual warehouse performance evaluates the total annex area together with some general work-flow processes. In Figure 48 is presented the occupation of the total available area in the warehouse annex for short storage. The area is evaluated as there was no division between entries and expeditions to see if the overall area is sufficient for the total capacity demand. Similar to the previous occupation curves Figure 48 presents three dotted lines. This lines represent the total area capacity (as all pallets could be stacked in two levels), the capacity with non-pallet stacked (this would be the most pessimistic scenario and is not likely to happen as expeditions can be stacked) and the total capacity with only arrivals non-stacked (this would be the most conservative situation and the area between this line and the red one would be the most realistic scenario).

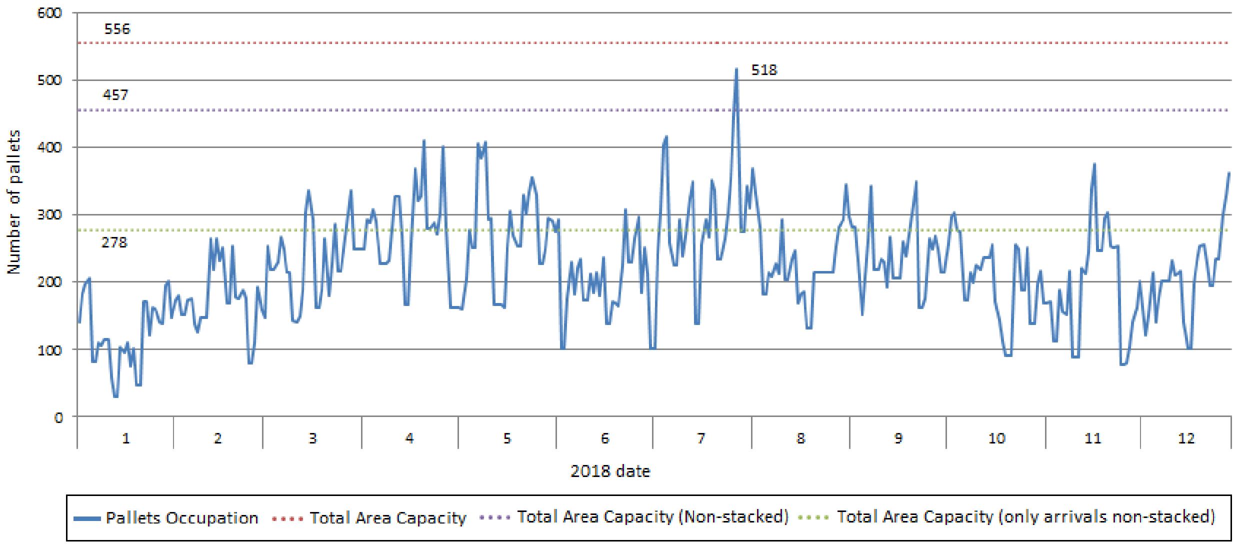


Figure 48. Total warehouse annex storage areas occupation over the year 2018.

In Chart 6 are indicated the average occupation and the peaks for the overall annex area. As a conclusion the overall annex area is apparently sufficient for the total necessities of the warehouse and the capacity peaks in one of the areas can be covered by using the other one. Nevertheless if there is an extraordinary percentage of the arrivals that cannot be stacked the actual area can be overcome.

The conclusions are similar to the ones described in the arrivals and expedition sections to minimize the volatility.

All stacked	
Average	35,42%
Maximum	92,09%

Arrivals non-stacked	
Average	43,10%
Maximum	112,04%

Nothing stacked	
Average	70.84%
Maximum	184,17%

Chart 6. Average and peak occupation scenarios for total annexed area in 2018.

5.1.4 Recommendations

In this final section are presented the recommendations for each of the discussed work-flow founded problems or parts of the processes that leave room for improving. It has been leaved out of the scope the economical evaluation of the recommendation implementation.

- **Use code readers:** The actual reception of materials in the warehouse involves a lot of filled forms and manual tasks that introduce non-value time delays and possible errors. For this is recommended to implement a system of code bars with digital readers together with the suppliers to avoid the mentioned problems and the need to print new labels for all the received pallets and materials. This would reduce one of the main tasks of two office employees.
- **Industrial structures to stack the pallets:** There can be bought portable industrial structures or implement dynamic racks that are weight resistance and allow the storage of materials in two levels even if the containers are sacs or drums. This way all the available warehouse area is exploited and the average occupancy reduced. The decrease in the average area occupation by implementing this measure could be between a 24% and 12%.

- **Reduce the silo occupancy:** There are pallets that are being pushed to the short storage areas for the need of liberating the silo capacity. External storage or an investment in a new warehouse extension can be done to liberate the silo capacity and facilitate the warehouse material rotation. Another solution for this is to move from the silo the slower rotation SKU's to an external storing party and use the silo for the fastest rotation pallets. This has the advantage that the external storing party charges for upload/download of inventory so costs would be reduced if the less rotated materials are destined to the external warehouse instead of the silo and the rotation of the warehouse materials becomes faster. There is also an industrial plant close to the studied warehouse that can be invested to expand the long term storage and release silo capacity.

- **Negotiate better agreements to anticipate better the expedition dates:** Develop further the relation with some destination parties, this way waiting times for carrier pick-ups can be lowered down. As explained by the warehouse managers even though sometimes there is a proper pick-up date fixed, this date is not respected or postponed several times. There are specific destinations that need to be handled, it can be established discounts or penalties in the transportation price to encourage the carriers to deliver or pick-up on the expected date. By reducing only the variability and not the process, as seen in Scenario 1 the capacity can be reduced an 11% and the peaks only an average of 20 pallets.

- **Change the picking process:** The warehouse extracts from the silo the finished products when ready to deliver to then create a delivery order and select a transportation method. This is done to eliminate the probability of having any pallet in bad state and not filling an arrived truck. This working methodology can be changed to lower the non adding value part of the lead time. It should be evaluated in detail why pallets are sometimes in bad state or which kind of products tend to suffer more to remove this problem and this way be able to extract the pallets after carrier transportation is settled without almost risk. It should be also evaluated in the analysis if the mentioned risk is not real or doesn't cover the overall costs of area occupancy being this way better to suffer the risk than having the pallets waiting in the expeditions area.

- **Re-storing the pallets expected to stay in the area for more than a week:** This is a way of reducing the area occupation by taking away pallets that are going to be occupying space for a long time. The best approach for this would be to use the warehouse silo (because of distance and cost interest) to re-stored the pallets. If this method is going to be used is important to notice that the pallets prepared for airplane transport cannot be re-entered as the silo photocells are unable to read the label information. This solution has another major throwback that is the high occupancy of the silo that if not reduced this recommendation cannot be implemented. As it has been evaluated in the Scenario 2 analysis the occupation can be reduced a 15% making the expedition rotation two days lower and decreasing the peak occupation in more than 50 pallets.

- **Smoothing the peak seasons:** By knowing that the pre-vacation periods result in the area occupation peaks its important to smooth as much as possible this season workload. This can be done by planning in advance this peak deliveries or by designating an operators team over the vacation periods to solve this deliveries.

- **Reduce the areal deliveries:** The areal deliveries contracted by the warehouse can be booked with other transportation methods to reduce the waiting times for the carriers to come. This way there is also reduced the packaging time as this transportation method is the one that has the longest preparation process, saving time and workforce needs. Furthermore, by removing the areal deliveries all the packaged pallets could be re-entered in the silo in case the carrier suffers a delay. This way the aerial transports would be only use for urges or necessary deliveries making this transportation method extraordinary to use.

The expeditions and arrivals processes are very independent between them as task needed to keep the material flows are different. The previous recommendations were specific for this areas and their processes and tasks. But some more recommendations can be done that affect the warehouse as a whole and can contribute to lighten the workload and optimize the overall processes.

- **Introduce changes in the data bases:** The data needed to analyze the different warehouse processes where founded in different software and data systems. For example SAP is an ERP system used all along the company that contains information about all materials and deliveries information in weight, but SGA is the software used by the automated silo and contains information in number of pallets. This disagreement in units makes analysis of materials flow harder. Also both softwares can have errors that lead to differences in total inventory quantities and that have to be checked by the warehouse employees on an usual basis. The compatibility between software systems would save office employees and also management time by saving time in performing KPIs and reports.

- **Digitize the processes:** to make them faster and more accurate. Right now the arrival of materials has to be introduced with the delivery note manually by the office warehouse employees. This leads to errors and time consumption of human capital that can be used to add greater value to the processes. An initial implementation of this could be to introduce bar code readers as mentioned before that check each of the arrivals pallets that a batch contains and uploads the pallets status automatically in the data base. This can also be used to complete checking lists after loading the carriers.

- **Change the external usage:** to apply an ABC SKUs storing system. This can lead to a cost reduction as the external storage suppliers charge the company with each material rotation done. This common rotations also take warehouse operators and employees time as loads/unloads as well as planning and form fill-in take part of their working time. This way C SKUS (that have the lower level of consumption rotation) can be stored in the external warehouse optimizing the transportation travels and thus the warehouse costs. Together with this can be created an optimizing tool to decide the most optimal transports and material moves between the warehouse and the external storage so better cost focus decisions can be made.

- **Initiate an evaluation project:** to evaluate if the K7 boxes with wood pallets are the best storage/transport unit in terms of costs and space. Sometimes the K7 boxes are not completely full by materials and this way some of the storing space are not optimized. This has special importance in the management of the automated silo as it has limited spaces.

- **Try to implement a balance planning of expeditions:** as it is done with the arrivals in the warehouse. It is of great importance and would reduce substantially the warehouse occupation that carriers get the finished products on time or the transport method is correctly selected to reduce the overall costs for the company and not only the transportation ones. This is a delicate solution as this is mainly managed by the HQ of the company and the silo is almost at its full capacity so is important that finished materials get as soon as possible out of the silo. Nevertheless this can be communicated on a higher level to indicate the problem and find global solutions that optimize the general costs.

- **Implement an outliers detection plan:** This recommendation is related with the previous one and the recommended plan would be focused on the detection and evaluation of batches and materials that stay in the storage areas longer than the KPIs detected. After that, reports and analysis can be made in order to find the root causes and consequences being able to order the impact, risks and necessity of change to propose adequate solution plans to correct this actions or at least minimize its impact.

When presenting the recommendations it is also important to create implementation plans to evaluate and control the measures development. Some recommendations to establish a control plan is to upscale the responsibilities and make the management involved in the implementation motivation. Also make specific teams and employees responsible of the implementation development establishing objectives that are SMART. It is also important to establish major milestones to evaluate the performance and reformulate if necessary the implementation strategy.

5.2 Plant Capacity Increase

In this section is evaluated the expected capacity increase during the following five years based on a real expected demand increase of a 50%. The income demand data has been given for each pharmacy product family and has been assumed the same for arrivals and expeditions. This is a shallow analysis to evaluate on a first sight the overall impact in the warehouse of a capacity increase in the plant. In case of more specific data or more realistic results requirements it would be needed further income data and more realistic assumptions. This evaluation is also result of SIMIO model experimentation, there has been created other model varying from the one created for 2018 to introduce the new expected demands, but the logic behind it will not be included in this document as it does not add much different programming from the explained before. In Figure 49 is shown the total annex occupation curve in the years 2018 and 2023 respectively.

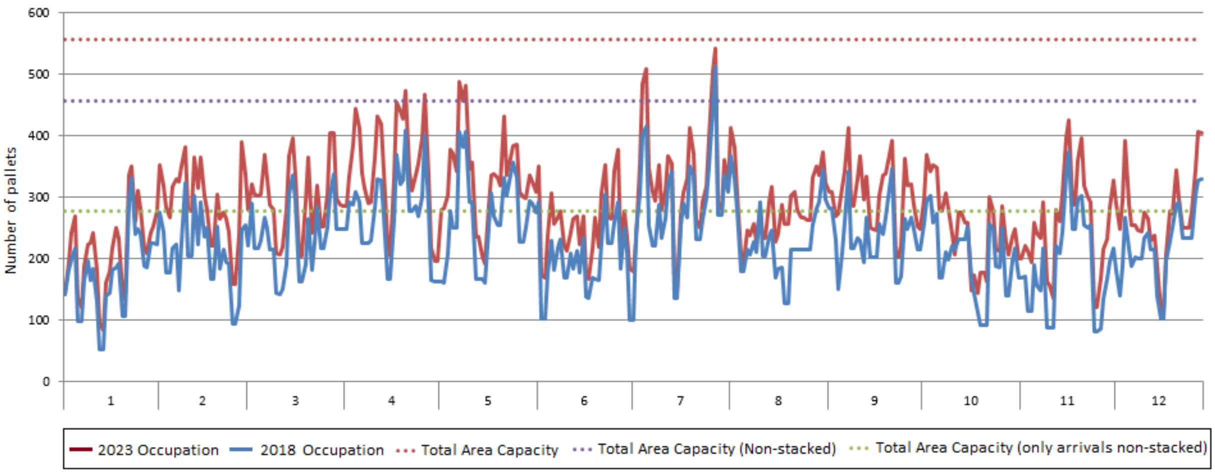


Figure 49. Occupation increase from year 2018 to year 2023 in all the annexed area.

In the previous section it was briefly discussed that the expeditions area experienced an average occupation increase along the year of 50 pallets. In the capacity increase figure it can be observed that this experienced increase is a cyclical annual effect as the increase in the average demand over the five years span is only a 15%. In the Chart 7 is shown the expected average and peak capacity of the areas for all the possible scenarios if the processes in the warehouse are kept the same, in other words as if no recommendations were implemented.

All stacked	
Average	48.03%
Maximum	101.26%

Arrivals non-stacked	
Average	58.44%
Maximum	123.19%

Nothing stacked	
Average	96.07%
Maximum	202.52%

Chart 7. Scenarios for total annex area in 2023.

Average Variation	15.34%
Maximum Variation	11.16%

Chart 8. Variations in occupation for the most probable scenario from year 2018 to year 2023.

The occupation of the annex increases, experiencing even more peak points as the variability is not removed. This means that the management of the annex area will be more complex and that even more external storage that the one expected by the capacity growth will be needed to remove the new peaks. There is even more variability in year 2023 that the one experienced along the year 2018. There are also included in Figures 50 and 51 the occupation increase curves for the expeditions and arrivals areas separately. The expeditions curve has a similar shape in 2023 although the peaks are larger and more frequent, an increase in the process variability.

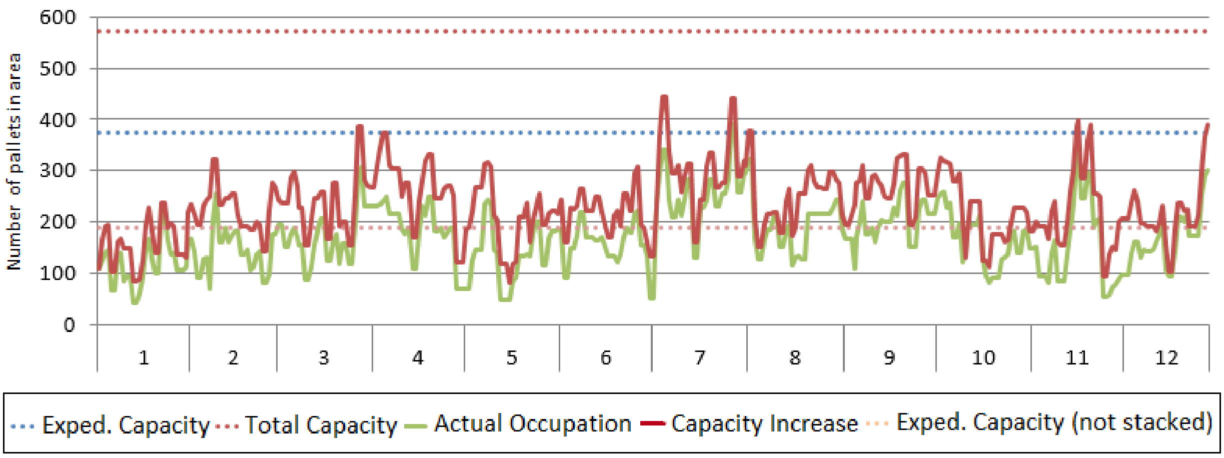


Figure 50. Occupation increase from year 2018 to year 2023 for the expeditions area.

Average Variation	16.71%
Maximum Variation	11.16%

Chart 9. Variations in occupation for the expeditions area from year 2018 to year 2023.

For the materials entry the situation is a bit different. The variability increases enormously and the shape of the curve changes gently but again increasing the average occupation.

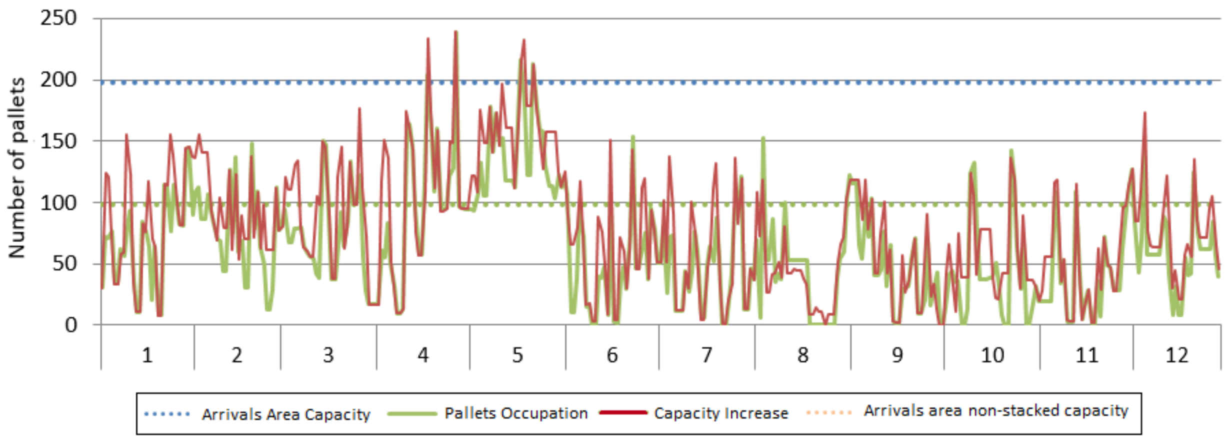


Figure 51. Occupation increase from year 2018 to year 2023 for the arrivals area.

Average Variation	5.86%-11.71%
Maximum Variation	0.51%

Chart 10. Variations in occupation for the arrivals area from year 2018 to year 2023.

Is important to highlight that this capacity increase simulation was performed over the supply chain department expected figures of 2023 demand. This figures were given over the family products and simplifications were made to be able to evaluate a future situation. For example, the fact that the raw materials increased at the same rate that the finished products that belong to the same category was assumed. It was also simplified the point that the mixed products used in different family brand production grew with the average rate of all the resulted finished products. The transportation methods, arrival dates and transportation times probabilities were extrapolated for the 2018 obtained results following the same distributions.

Finally, it is also included the change in the workforce occupancy. In Chart 11 is shown the variation in the workforce needed. In the capacity increase analysis was also found that there was also necessary to perform the expeditions packaging in parallel (this means either two machines or making the process possible with two people using the same machinery doing two pallets packaging at the same time) otherwise the packaging process becomes a bottle-neck for the warehouse expedition process.

	Daily	**2018**	**2023**
Arrivals	**Total man hours**	4.26	4,62
	Man needed	0.53	0.58
Expeditions	**Total man hours**	15.82	17,49
	Man needed	1.98	2.18

Chart 11. Man hours variation from 2018 to 2023.

Chapter 6

Conclusions

THIS master thesis aimed at evaluating the management of a pharmaceutical production plant warehouse. For that purpose, a virtualization model in SIMIO software has been designed that revealed relevant data about the system and has been used to extract conclusions and recommendations. The main objectives presented at the beginning of this document where attained: it was performed a deep analysis about the short storage areas occupation over time, there were find root causes for the detected problems in rotation of pallets for the annex area and proposed suitable recommendations that improve the actual situation and warehouse methods; and it was also performed an increase capacity analysis to assess possible future impacts of production changes in the plant warehouse that can be prevented with some upfront investments. To reach this objectives was followed a problem solving oriented methodology with the following steps: studding the warehouse system to understand the processes and work-flow, gather the relevant data and condition it to use it as the model income, develop the SIMIO model in an iterative process together with some validation steps that verify the extent and reliability of the created tool, and finally, perform a critical analysis and results discussion to recommend potential guidelines.

After introducing the warehouse to the reader and explaining in detail the plant manufactured products, the work-flow, employees structure and task distribution; the SIMIO tool is presented as it is not a common used software. This software was the base for this thesis development and it allowed different variable and parameters impact analysis. The logic behind the created model was detail introduced together with the income data that was gather and conditioned to introduce in the SIMIO model. The model logic has been divided in five logic shells including the entries of pallets, the destination selection, the repackaging and quality processes, the storage areas and the model initialization. Together with this logic structures are presented other important variables for the equipment and transportation times as well as the working schedules.

To end this model designing phase were selected some KPIs that helped to verify the created model. Those selected criteria were met with some confident and entail: the man hours needed, the packaging times, arrivals to the warehouse distribution and the areas occupation curve distribution. Once the model has been verified it can be used to experiment, create different scenarios and evaluate the impact in the system of the different variables. The final part of this master thesis was dedicated to present and critically discuss the extracted results, performing different simulation scenarios to evaluate the variables impact and to evaluate future changes in demand that can affect the warehouse system.

The results discussion was partitioned in four sections: the arrivals area, the expeditions area, the overall warehouse functioning and a capacity increase evaluation. For the arrivals area it was observed that the average occupation is below half the total capacity, but the variability in occupation is steeped. The peaks in occupation are related to the entry quantity of arrivals, so when the average handing materials is above the 50 pallets average planned the peaks are reflected in the occupation curve for a small time, until the pallets are transported to the external storage or entered in the silo. The rotation is adequate, for the majority of deliveries below a day, but this can be reduced if the registering processes are digitized with bar code readers that register automatically the information is SAP software. There is also an additional problem that causes the non optimized usage of the arrivals area and it is that there are some arrival pallets that cannot be stacked in two levels. For this is recommended that there are used dynamic or mountable industrial racks that can be used at peak occupation situations and disassembled when there is no need of this structures.

For the expeditions the occupation curve has a similar shape to the arrivals, it has variability and the average occupation is below the 50% of the total area capacity. But in this case the rotation time of the pallets is quite longer as it takes an average of five days for the pallets to exit the expeditions area. This long time is caused by three main motives. The first one is the expeditions process itself. The finished product pallets are extracted from the silo, packaged for the specific selected transportation method and placed in the expeditions area. Is at this final step when the delivery is notified to the carriers and a pick-up date is arranged. This work-flow introduces non-adding value time to avoid risks of wasted pallets that results in nonexistent truck shipments. This risk should be deeply evaluated to assess if this process flow is really the optimal one in global terms and the costs are minimized. The second cause for large rotation times is that the carriers are usually delayed or do not arrive in the arranged date, making a longer stay in the expeditions area for the pallets. This situation can be arranged by improving the pick-up systems to apply penalties or discounts in the carrier invoices if the shipment dates are not respected. The final third motive is related with the previous one, but this time for the delivery destinations. There have been detected some specific locations that hold the pallets longer in the expedition area, varying this pick-up dates sometimes more than twenty days.

There have also been perform two different scenarios in SIMIO to evaluate how the detected variables affect the expedition occupation curve. The first scenario evaluates removing the maximum delivery delays to the average rotation of five days. The results show a reduction in the occupation average and rotation time but not a diminish in the occupation variability. The second scenario evaluates re-entering all the pallets that are placed in the expedition area that are expected to stay in the area for longer than a week. The results shows that the reduction in average occupation and rotation time is similar to the previous scenario but the occupation variability is reduced. To end this actual warehouse evaluation is presented the total occupation of the warehouse annex without taking in mind the division between arrivals and expeditions. There are also evaluated different scenarios depending on the availability of entry pallets that can be stacked in two levels.

To end the evaluation of the warehouse it has been performed a primary analysis to evaluate a capacity plant increase effects in the warehouse. This analysis has been conducted from expected demand figures and extrapolated following the 2018 year distribution for all variables. It was also assumed that the demand growing rate is similar to the expeditions and arrivals volume rates. The obtained results show an average variation in the occupation of 15% but create more sharped curves and peaks. The impact of the capacity increase can be easily noticed in the expedition areas that experiences a larger average capacity increase.

6.1 Experience and Further Work

The development of this thesis had a great final impact on my university education as I was able to see a variety of concepts studied along the studies in an interrelated way. This previous knowledge of theoretical concepts helped me to easier understand the situations and processes, classify them and make a useful analysis of it. It is also necessary to highlight the great difference between theoretical knowledge and the real systems as it is the warehouse object of this study. The concepts, processes and implications are really interrelated and each proposed solution has to be detail evaluated to assist its future real impact and success.

Due to time limitations this project had a predefined scope that was used for its development, nevertheless this project can be further developed in different ways to keep adding value to the production processes. This project can be further developed to introduce the automated silo definition and evaluate this part of the warehouse, either as a separate entity or relating it with the already developed warehouse model. Other parts of the warehouse can follow kind of the same procedures as the waste management or the external storage. This way the total use of operators can be assessed and changes in employees schedules and quantity can be evaluated. There has also been inside the company object of this thesis a previous model performed to evaluate an investment in a capsule production line that was finally implemented inside the production area. The production processes can be further developed and then linked to the warehouse to evaluate and optimize its interaction.

Furthermore, this same model can be adapted to other warehouses of the company group to assist their work-flow and operations. Evaluating different warehouses can lead to extract further conclusions and also to get ideas of better management situations that can be applied in other group warehouses. Besides, knowledge of bad practices or unsuccessful situations can be shared between warehouses to prevent problematic situations or in order to do not experience the same mistakes.

Not only the model but the filtered data bases created and results extracted that contain information across the warehouse can be used to evaluate different future investments either in changes of processes or capacity increases.

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DOCUMENT II

USER'S GUIDE

ALONG this user guide section is described step by step how to use the created model in case it is wanted to be reused for other purpose or further implemented to cover more objectives. All the needed files and the different created models are also listed for the reader to understand the created documents. The here mentioned resources are divided in two SIMIO models that even though have similar functioning they differ in some of the logic.

The first model reflects the actual functioning of the warehouse which was used to extract relevant data about the warehouse functioning. The second model was designed to evaluate future capacity increases that affect the volume of materials processed by the warehouse. The models represent the real operation of the warehouse with specific and real time data that is included in the excel files called *Data*. The created models are deterministic and are only needed to be run once to obtain valuable results. There are also additional excel files called *DataGraphs* that contain the graphical information of the imported and obtained data to easily have an overview of the results obtained in SIMIO.

Actual Model

The needed files to run this model are:

- *WhareHouseAlcala_Actual.spfx*: is the SIMIO model file.
- *Data_Actual.xlsx*: contains the income data needed for the SIMIO model
- *DataGraphs.xlsx*: Contains data analysis and representation graphs.

To start the model open a SIMIO window and select the *WhareHouseAlcal_Actual.spfx* file. This model already contain data for all the needed variables but in case the reader wants to modify the model it can refer to Chapter 4 to understand the different parameters introduced. If the input data tables of the SIMIO model want to be refreshed, the file *Datos_Actual.xlsx* is required. It is important to properly prepare the file before importing it in SIMIO when chaining the data. There are six different tables in the excel file *Datos_Actual.xlsx* that are needed, three related to the expeditions area and three to the arrivals. This excel tabs have to be linked to the SIMIO tables as follows:

- *TE Expeditions* - Expeditions
- *TEWIP* - WIP Expedit
- *TA OutOfSilo* - OutOfSilo
- *TE ExpeditNotSilo* - Expedit Not Silo
- *TA Arrivals* - Arrivals
- *TA WIP* - WIP Arrivals

Each of the excel tab contains the material codes, the number of pallets that is referring to , the batch code and other information as packaging times, transportation method, type of material, family classification and country destination. The process to import correctly the tabs is the following:

1. Fill the model starting date in the *Date* tab of the *Data_Actual.xlsx* file so it is the same as the starting date to start running the model in SIMIO
2. Change the *SimulationTime* column in the *Expeditions* tab so it is the *ExpeditionDate* column minus the introduced date and change it for all the deliveries.
3. Copy and paste the values as numbers so they are not detected by SIMIO as a formula, that could introduce errors of data format.
4. Perform steps 2 and 3 again for: the columns in the tabs *Arrivals*, *OutOfSilo*, *WIP Expeditions* and *WIP Arrivals* that are called *EntryinSiloSimulationTime*; the column *SimulationTime* of *ExpeditNotSilo* tab ; and the columns *ToExternalSimulationTime* and *BackExternalSimulationTime* in the *Arrivals* tab.

5. Change the *ExpeditionDate* columns of *ExpeditNotSilo*, *WIP Expedit* and *OutOfSilo* tabs. For this use *vlookup* command and search the cell under *Searches* column, in the *Expeditions* tab and return the sixth column, which corresponds to the expedition date related to that exact product and batch. For the tab *OutOfSilo* is important to first filter the expeditions by destination two and apply the formula only for those pallets.

6. Again copy and paste as numbers all the columns that have been changed to upload in SIMIO so those are not recognized as formulas.

7. Make sure the tabs *OutOfSilo*, *ExpeditNotSilo*, *Expeditions* and *WIP Arrivals* are ordered by date (from oldest to most recent) and are not filtered in any way. The file *Arrivals* file is also important to be ordered by date but in this case two different dates appear in the tab. Make sure to select the *Entryinwarehouse* column to order the data.

8. Go to SIMIO data tables and add a binding for each of the Tables that corresponds to the same excel data tab in the order mentioned before. Then when running the model the excel data will be transferred to SIMIO tables. If the data is not correctly imported delete the table and create it again with the same name.

After the income data is imported the bindings can be removed to let SIMIO run faster and not import each running time the tables. Also if the importing data is too big and it blocks the model the tables can be imported one by one to use less computer memory.

There are also some data that needs to be checked if the income data in the excel file has been changed. The state variable for Arrivals and Expeditions *InitialWIP* has to have a value that is the number of material rows that the *WIP* excel tabs have. It is also needed to change the simulation end date so it is the same date in which the *OutOfSilo* tab ends and no more pallets are extracted from the silo. There is also another tab in the excel file, *OutOfSiloScenarios* that can be used to change the real constraints of the expeditions (days of the week deliveries are allowed, maximum time pallets can stay in the expedition area, or any other variable that want to be changed).

Finally, is used also the file *DataGraphs.xlsx* to plot all the data analysis and the outcomes from the model tallies and output tables in an easy way. There are three tab used for a quick overview of the model, either as a whole or separated by expeditions and arrivals (*MainGraphs*, *ExpGraphs* and *ArrvGraphs*). This graphs contain all the performed graphs and display the main KPIs to understand the results.

In this document will be only introduced the relevant data graphs creation although in the file the user can find other data analysis and graphs. The graphic creation tabs are duplicated to create similar graphs for both arrivals and expedition areas. Along all the *DataGraphs.xlsx* file the columns that have data to replace from the model outcomes are marked in grey. After changing this cells with the needed model results the dynamic tables and the graphs can be actualized to display the new results.

The tabs *Queue Times* are used to include the outcomes from the SIMIO table *Queue Output* selecting Arrivals or Expedition tagged results to include only the corresponding values. Once this data has been added there are dynamic tables that group the results. But if the results want to be presented in an organized way the tables on the right order the results by its relevance of number of pallets. Another relevant tab is *KPIS* which contains the main model results and workforce times. This tabs also contain main KPIs used in the results discussion section and that are extracted from the SIMIO results. Again the grey cells are the ones needed to be filled to change the results representation. The last essential tabs are the *Area Occupation* that include the SIMIO tally outcome for the short storage areas hourly occupation. As well as in the other tabs there is only needed to replace the grey columns and then actualize the dynamic tables and graphs. In the graphs file there are also included some classification tables that relate material SKUs with product brand, family, stacked availability, or material type.

Capacity Increase

This model is similar to the previous presented one. The needed files to run this model are:

- *WareHouseAlcala_CapacityIncrease.spfx*: is the SIMIO model file.
- *Data_*2023*.xlsx* : contains the income data needed for the SIMIO model together with the demand increase planning.
- *DataGraphs*2023*.xlsx*: contains the data analysis and representation graphs to easy visualize the obtained results.

The *Data_*2023*.xlsx* file is similar to the one used for the 2018 warehouse evaluation. The differences is that it contains two more tabs, marked in orange, containing the pallet increase introduced into the model. This pallets have been calculated in the *Capacity Increase Plan* either for arrivals or expeditions. The plans are based on expected sales growth data from the supply chain department in million capsules units. Those have been related to pallet units and extrapolated to 2023 using the calculated growth in pallets and the distribution curves per months, transport methods, etc... If the income data is changed the grey table needs to be refreshed as indicated from the dynamic tables in the excel file. Also the violet tables are the ones containing the final planning schedule by pallets. This table has to be manually reflected into the *Arrivals*2023, *OutOfSilo*2023 and *OutOfSilo* either to include the new pallets or remove the ones that are not longer being supplied.

Furthermore in the *DataGraphs*2023*.xlsx* file can be founded the same results analysis and data graphs but now those include the results for the year 2023, as well as comparison tables and graphs between the two years.