Product development process 4.0: Optimization of material flow in the digital age

Produktentwicklungsprozess: Herausforderungen des Materialflusses im digitalen Zeitalter

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Preface

The present thesis was written under the scientific and content-related guidance of Maximillian Wünnenberg B.Sc, research associate at the Chair of Materials Handling, Material Flow, Logistics at the Technical University of Munich.

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Abstract

The main purpose of smart warehousing is to enhance the productivity and efficiency along the supply chain in a warehouse and reducing considerably the damages and errors. Recently, a huge growth in the development of automated warehousing can be seen for instance in the high number of papers and studies about the main important benefits and its drawbacks. However, the research in the field of small and medium-sized companies with industry 4.0 is still scarce. These companies have limited resources and need to decide whether to integrate or not and select which technologies are more suitable to its company. The aim of this thesis is to provide some knowledge about RFID, stacker cranes, conveyor belts and roller racks and how they can influence some parameters that are relevant for SME's efficiency.

Contents

Abstract III

Contents V

1 Introduction 1

1.1 Introduction and chapter objectives 1

1.2 Research Objective 2

2 State of the Art 5

2.1 Industry 4.0 5

2.1.1 Origins 5

2.1.2 Involved technologies 6

2.1.3 Main challenges 7

2.1.4 Future scope 8

3 Research questions 9

4 Simulation-based optimization of material flow systems 11

4.1 Requirements 11

4.2 Validation method 12

4.3 Measurements 13

4.4 Approach implementation 14

5 Review of relevant optimization potentials 17

5.1.1 Radio frequency identification (RFID) 18

5.1.2 Conveyor belt 19

5.1.3 Stacker crane 20

5.1.4 Roller Rack 21

6 Application and exemplary implementation 23

6.1 Specific approach 23

6.2 Analyzing implementations results 24

6.2.1 Integration of a stacker crane 24

6.2.2 Roller racks in small racks 25

6.2.3 Picking process in big racks with conveyor belt 27

6.2.4 Picking and packing process in small racks with the conveyor belt and RFID 29

6.2.5 Add one pack stations per two roller racks 30

6.2.6 Add two more big racks 31

6.3 Final Layout 32

7 Discussion 33

8 Conclusion 35

9 References 37

1 Introduction

1.1 Introduction and chapter objectives

Industry is considered a crucial part of world economy due to the production of materials, goods, and services. Thus, the implementation of new technologies is vital for companies in order to be competitive in the market. [Fis-2018, S. 438] Nowadays, due to the high amount of customized and sophisticated products, industry has been forced to change part of its supply chain's structure to be more flexible in the material flow systems (MFSs).

Presently, logistics is one of the most important drivers of economy growth. In fact, the principal objective of warehouse managers is to reach the highest possible performance of the supply chain. However, in real life, some shortcomings are within the industry that reduce the efficiency of the material flow system, thereby many investigators are continuously searching this field to overcome those problems.

Nevertheless, the investment required to automate the warehouse processes and its payback period are critical factors that determine the integration or the rejection of innovative technology. In this thesis, four implementations with Industry 4.0 technologies are described as well as its impact are analysed. The four implementations are compared individually to the previous technology. The integration of a stacker crane and its effects in the process efficiency is compared with the use of a forklift, additionally, the integration of conveyor belts and push back racks instead of classic racks are simulated in a software called FlexSim.

Overall, Industry 4.0 embraces the implementation and the development of Information Communication Technologies (ICT) within the industry. The main objective is to interconnect products and services along the supply chain for not only making a more efficient use of the processes, but also creating modern services and products for the customer. The main objective of Industry 4.0 is the establishment of digital manufacturing in the factories, which encompasses smart networking, mobility, flexibility of most industrial operations and their integration in the value chain. The digital manufacturing also can be named as "smart factory". [Bar-2017]

When this fourth revolution started, the most important countries around the world began founding projects, start-ups and helping to re-industrialize the companies. Germany started the movement in 2010 investing 1 € billion in projects and start-ups while helped with reduced taxes to those who began in this area. In recent years, United Kingdom, France, and Italy also supported enterprises with 0,8 £ billion in research, 10 € billion in subsidized loans to promoting the implementation of new technologies and 13 € billion to foster R&D in companies, respectively. The aim behind these investments is the development of a technological environment in factories, specifically, creating what is called "Smart factories". One of the key points of these factories is the flexibility of their systems when it comes to customized products whether belongs to a batch or an exclusive product. [Bor-2017]

1.2 Research Objective

The approach of this thesis is to provide a systematic methodology for Small Medium Enterprises (SME) of smart warehousing. One objective of this thesis is providing a general method for automating some processes, because most of the warehouses shares the approximately the same layout. It is also true that each warehouse works different depending on its demand, its suppliers, its flexibility, or others, therefore some assumptions are needed.

Another objective is investigating the actual challenges, specifically in logistics, that Industry 4.0 could benefit part of the supply chain, its current development, and its impact. In chapter 5, some specific literature of the main technologies is explained with examples of recent studies for understanding better the possible future scope. Following that, the six simulations of the processes previously briefly described are widely explained and some critical metrics as well as the accounting of that technology, lead us to final conclusions about their main benefits but also their shortcomings.

Generally, the thesis provides to logistics companies, insights about the integration of new systems along its supply chain, such as radio frequency identification (RFID), conveyor belts, stacker cranes or roller racks. Additionally, some standard problems of companies such as storing in the wrong place, the material flow inside a warehouse and how to be more dynamic and efficient, among others, can be solved with that technologies.[Pan-2019]

Firstly, the topic of the thesis is introduced as well as the research objectives. The context about Industry 4.0 and the State of the Art is important due to the huge evolvement of industry technologies since the first industrial revolution. Afterwards, the actual context of the industry and the technologies that involved industry 4.0 are briefly described and also the scope for the next years. Chapter 3 is the main important part of the thesis, as the research questions lead to the following literature, more focused to the logistics and warehousing systems. Thus, some requirements for the approach of Industry 4.0 are described with also the methodology for validating some implementations in FlexSim software. At the end, the simulation results are analysed and discussed, followed by a final conclusion of the thesis.

The main approach is to focus on the following five stages within a general supply chain in a warehouse. Some inefficiencies are currently known and the objective of the use of Industry 4.0 technologies is to obtain the maximum efficiency on each stage with the lowest investment possible. The processes to improve are:

- Product receiving
- Storage
- Picking
- Packing
- Delivering

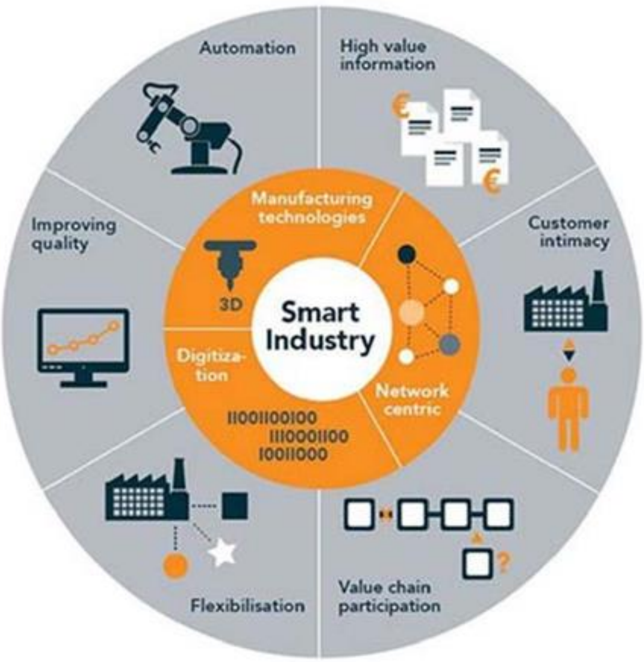

Figure 1. Smart industry benefits' illustration [Bar-2017]

2 State of the Art

2.1 Industry 4.0

2.1.1 Origins

Industry was, is and will be one of the most important areas of worldwide economy. Since many centuries ago, the human being has been improving the processes and developing new technology that are used for the production of materials and goods. Those important changes are called “Industrial Revolutions”. [Kes-2016]

During the last years, the world has experienced an unimaginable evolution in regard to modern technologies. *These innovations in industry can be named as “Industry 4.0”, the new industrial revolution. Industry 4.0 will change and improve traditional logistics and its self-perception. Logistics has become a core pillar in the value chain for suppliers, manufacturers, and retailers. It is crucial for them to have the Right good with the Right quantity and Right quality at the Right time at the Right place and in the Right condition and at Right price (7R), – these are the well-known requirements for logistics, and otherwise they cannot be competitive in the market*. [Kes-2016] .

Horenberg points out that all Industry 4.0 applications within the logistics industry are known such as Logistics 4.0. [Nav-2019]. Overall, logistics means the management of the flow of people, animals and goods between an origin and the point of consumption to fulfil the requirements of the customer. Traditional operations are e. g. collection, transportation, storage and distribution. [Gli-2019]

This new industry revolution is creating new jobs, new ways of communication and improving the efficiency of the whole supply chain of industry. Industry 4.0 is changing the term logistics as we know. Logistics has been during a lot of decades the crux of the value chain for each and every stakeholder.

1784	1870	1969	2011
First Industrial Revolution	Second Industrial Revolution	Third Industrial Revolution	Fourth Industrial Revolution
Mechanical production using water and steam	Mass production using electricity.	Development of electronics and automation.	Development of cyber-physical systems.

Figure 2. Four industrial revolutions along history adapted to this study [Kra-2021].

2.1.2 Involved technologies

The massive amount of internet applications, principally caused by the outgrowth of IoT, cloud-computing systems and Big Data, have provoked several changes when it comes to business models and its way of organizing. The competitiveness of which company develops and/or offers a novel technological service with the lowest cost is high, therefore the competitive advantage is also significant.

This digital ecosystem covers leading-edge technologies that enable the material and information flow along the whole supply chain. The use of cyber-physical systems (CPS) together with the internet of things (IoT) enables virtual networks coming out in smart factories, although it also needs a huge interconnected infrastructure for ensure the correct connectivity along the value chain as well as communicating between partners, supporting decision making, among others. [Cug-2021]

The “Internet of Things” (IoT) has enhanced the previous technologies utilization into the different systems and processes also promoting a way of communication never seen before. Industry 4.0 is remodelling logistics, services, production, and Resource Planning (RP) being more and more flexible and efficient. For instance, decades ago, the automation of processes as maintenance, prediction of orders and include customer requirement instantaneously, could not be imagined. [Bar-2017]

CPS, are devices with some electronic elements that are connected, monitored, and coordinated by a central computer system that allows intercommunication between the machines. CPS are the intermediate of the digital world and the physical one. Some of them are sensors, actuators, control processing units and devices that communicate the information processed internally to the physical world. [Liu-2016]

2.1.3 Main challenges

Although there are widely known benefits that Industry 4.0 can provide to the different processes along the supply chain, there are also some obstacles that can hinder partially or completely its implementation in the production organizations. The following barriers have been detected through some literature review.

Cybersecurity has become mandatory in each and every company that wants to digitalize at some level for carrying on a profitable business model. It is very challenging, and it is necessary that organizations provide information security to their consumers due to the high number of risks that digitalization entails. Currently, data is even more important than whatever product due to its consequences on business' strategics, like analysing customer requirements, or predicting future customer movements. Additionally, on-line transactions and the lack of computer security awareness are potentiating exploring the vulnerabilities of systems. [Bar-2017]

Inadequate information of the potential offered by Industry 4.0 technologies, insufficient knowhow within companies, few skills in the labour market, scarcity of external financing, insufficient infrastructure, legal uncertainties, lack of clear standards, organizational resistance, among others, are the principal barriers to not integrate innovative technologies according to the study "*Openness to Industry 4.0 and performance: The impact of barriers and incentives*". [Cug-2021]

Moreover, some companies do not even try to make studies whether integrate or not because of the lack of information of its technology. It is well known that Industry 4.0 brings a lot of new requirements for workers such as manage the information flow, continuous improvement, and creativity, can be difficult skills that may usually not be in the market. In fact, specifically in SME's, the lack of these skills is creating a barrier for this companies. As the rapid evolvement of these technologies, companies cannot make huge investments due to the variable context and uncertainty. Another two important barriers are the organizational resistance, due to the lack of willingness to integrate new technologies from employees. This issue can be associated with lack of knowledge of the technology and its consequences because workers often feel their job is being replaced by a machine. The second one is the big infrastructure required to enable interconnections along the whole supply chain. [Cug-2021]

Thereby, the digitalization of a factory is expensive, risky, and new skills of workers are required. However, apart from the fact that in order to successfully conduct the integration, the previous barriers should be mitigated at some level, if not fully removed, organizations and the government should collaborate and create together a technological environment to promote the last advances in factories. Including some skills development programs at universities like: "*business intelligence, collaborative robotics, CPS, IoT, etc*. " can be a good proposal according to a recent study titled "*Analysis of Barriers to Industry 4.0 adoption in Manufacturing*". [Kum-2021].

2.1.4 Future scope

In years to come, it is likely that companies will be forced to implement the technology that they are currently denying for lack of knowledge or other barriers we have commented before. This is because the product life cycle is reducing and the product complexity is being increased, and in order to be as competent as the others, they have to be faster, cheaper, and more flexible.

This new industrial revolution will create new jobs with more flexibility and will help humans to be more efficient than ever in history. However, many other jobs will no longer be necessary in factories due to computing systems interconnected with machines will be automated for decision making. The typical human workforce will be replaced by organizational tasks and managerial positions, as "*machine coordinators*". [Hol-2021]

Although it is not likely that RFID replaces the barcodes, along the thesis it is provided some benefits from this technology in comparison with barcodes. In fact, it is just matter of time before barcodes and RFID were both equally in terms of market price. The payback period after investing in an RFID system can be minimal, therefore may be very attractive for logistics companies in the future. [Pat-2017]

A recent study shows the trend of conveyor belt systems in the short-term globally is significantly increasing. It is also evident that the trend depends generally on its application, the type of conveyor and the location, but the prediction reflects that the demand of this technology will increase from 5.008,5 Million US$ to 7.169,0 Million US$, in 2018 and 2026 respectively. [For-2019]

3 Research questions

During the entire thesis, the following four questions arose and were the basis for the systematic literature and the following scientific investigation. Firstly, the main research question was: Which future technologies are likely to be implemented by the majority sooner or later in the logistics supply chain? According to the information gathered, finally the use of RFID, conveyor belts, roller racks and stacker cranes were the elected ones that fit more in the context of a SME.

The investigation across all these technologies previously mentioned was conducted, provoking immediately the second question: To what extent these technologies help the efficiency of processes in a warehouse supply chain? For that question, it is necessary to simulate the possible consequences, drawbacks, and benefits of the implementation of those innovations into the supply chain. Therefore, the following hypotheses to assess by a simulation software are:

- ***Conveyor belt Hyp. 1*:** The use of a conveyor belt in the picking process reduces the number of pickers significantly for the same output
- ***Conveyor belt Hyp. 2:*** Integrating one conveyor belt between two pack stations can be faster than the traditional picking and packing
- ***RFID Hyp. 1:*** Combining RFID with roller racks instead of bar codes and steadily product place, increases the throughput
- ***Stacker crane Hyp. 1:*** The implementation of a stacker crane generates not only a more dynamic environment with less errors but also more efficiency.
- ***Stacker crane Hyp. 2:*** Due to the use of a stacker crane, the space required is much less, creating more storage level

The core criteria of these technologies are to provide to SME a trade-off among its investment and its efficiency. The hypotheses as well as the research questions are the origin of the thesis, and the following simulations are based on finding some conclusions. Consequently, the last two research questions were proposed to also contribute the main challenges and possible drawbacks of these innovative technologies. The first one is: Which requirements must be fulfilled so that a simulation can help the warehouse manager to implement an automated process or not? And the last, : What are the main problems of automating?

4 Simulation-based optimization of material flow systems

4.1 Requirements

One of the main objectives of this thesis is to assess those warehouses whether integrate or not automation technology as well as selecting which implementations are more suitable in a SME. A company is considered as a SME'S according to the definition of the German institute of SME research, when it has a maximum of 500 employees and a maximum annual turnover of 50 million of euros. [Mül-2017]. In this kind of warehouse systems, the core processes to consider are the most typical ones of a supply chain in a warehouse: inverse picking, storing, picking, packing, and delivering. The difference between the performance of these processes is compared in a simulation model explained afterwards in chapter 5 and analysed in chapter 6.

Industry 4.0 provides new ways of developing products, with the use of Big Data, Machine Learning, Cloud Computing, among others, more data is analysed, thereby more automated decisions can be made. Thus, some machine and plant manufacturers' strengths are a requirement for this industry as well as continuous research on automation and CPS systems for increasing process efficiency.

In order to securely implement the technology of Industry 4.0 that enables the intercommunication among machines and databases, it is necessary to build some infrastructure for good quality data exchange. Moreover, other specific requirements to be met for the integration of these technologies are:

- Low lead time
- High demand
- Low waiting time
- Low distance by operator
- Low machine down time
- Reliability: likelihood of a system working correctly
- Affordability
- Cyber-security, protection of data

4.2 Validation method

The validation of the hypotheses as well as the research questions mentioned in chapter 3, becomes decisive to achieve the most similar model to the reality. To validate them, three different options are proposed:

- Analysis of data in some database
- Simulation of the processes in a simulation software
- Interview some companies that implement the corresponding technologies

Among these options, it is challenging to find any database on Internet that contains the four implementations of my own approach, hence the first option is immediately refused. Secondly, due to the coronavirus pandemic in addition to the lack of network in the logistics field in Germany, modelling the layout and the different processes in a simulation software is the selected one to verify the hypotheses as well as answer the research questions.

The simulation easily provides high amount of data that can be assumed and analyzed in detail always considering some assumptions. To reach the maximum number of possible companies that could benefit from the thesis, the simulation is focused on general processes and standard layout. Additionally, to simulate each process in a realistic way "*FlexSim* software" is the preferred for this approach.

FlexSim applications are very widely, going from production, to logistics, material handling, warehouse planning, health services, customer services and includes considerable amount of objects [Sya-2021]. Additionally, many statistical distributions can be set up in some processes to reach the best similarity to the real process.

4.3 Measurements

At this point, the requirements and the specific software for the approach are known. As it has been commented before, a lot of statistical data can be extracted from the model in FlexSim. Actually, this software includes one specific tool named “Dashboard”, where data can be represented and analysed from the model. For instance, the software can calculate the total operators’ distance per day, the average throughput per hour, per day, including some parameters such as velocity of the operator, process time, waiting times, lunch breaks, among others. The main objective is to optimize the overall throughput of the system and efficiency of the operators.

In order to verify the previous hypotheses, some metrics need to be analysed from the model. However, some of them are very challenging to justify through a simulation software. For instance, RFID can provide more flexibility to the systems, track more than one product at the same time and also ensure if the packages of the pallet are correctly distributed. Although all these benefits affect to its efficiency, it cannot be easily assessed with a simple simulation model. Thereby, the first assumption is that the implementation of RFID is included with the integration of roller racks.

Including some Industry 4.0 technologies like Big Data, Cloud computing and Machine Learning can be very useful in decision-making processes on top management level. The combination of those technologies with CPS in the warehouse, like sensors, can be very decisive to predict demand behaviour, calculate future storage levels, or others. Actually, sensors like RFID that can be interconnected with the central system, can detect errors or incoming deliveries, but it is very difficult to simulate that metrics in a software without databases.

The most important Key Performance Indicators (KPI’s) or measurements that FlexSim could provide from the simulation are represented in the figure below.

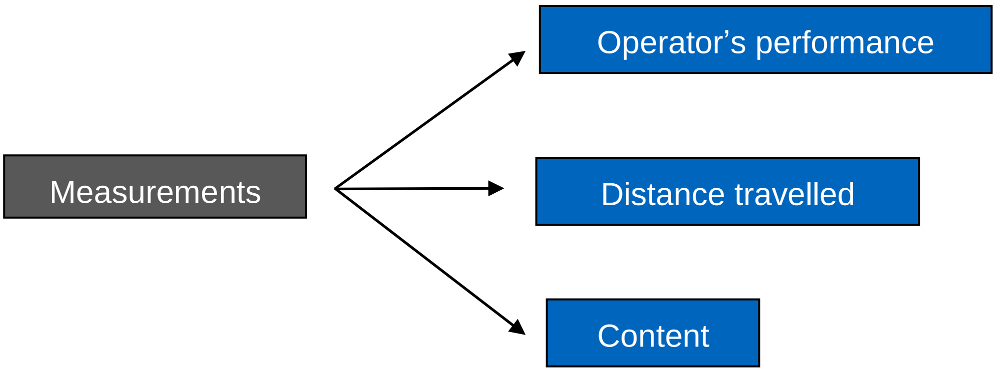

Figure 3. Measurements that FlexSim could provide from the simulation model

Overall, the efficiency of the integration of the five implementations in FlexSim are attributed to four different indicators: the operator's performance, the distance travelled and the number of packages. Five different implementations are compared with the non-implemented model and in chapter 6, the results are shown.

To start with, the operator's performance shows the state of each operator can be represented whether as a pie chart or a bar graph. The possibilities are almost infinite, but in this approach the performance is compared along one working day. For instance, it can show the time in percentage spent in each task of every process.

Secondly, the distance to travel is analysed in meters, in this case, a comparison before and after the implementation is relevant because after each implementation, the distance required to reach the same objective is quite lower than the current one. FlexSim provides a tool that calculates automatically the distance travelled per operator at any time.

Finally, the content is one of the most important parameters to consider due to it determines the workflow as well as your prediction. The last measurement to consider in this approach is the difference between the throughput per hour per rack, per operator, etc. These four different metrics are compared individually along one day, from 08.00 until 17.00, including the lunch break of 1 hour. This way, the data collected is more realistic and the simulation become more important.

4.4 Approach implementation

Basically, the approach of this model is based on a warehouse in Dresden, Germany, which is owned by a company called 'Warehouse, Ltd.', from now on called 'Warehouse. The actual name is not provided in this thesis due to confidentiality reasons. The level of automation of the warehouse should not be extremely high for this approach. Actually, the function of this thesis is not being a guide to set up automation technologies for any warehouse manager, but the disclosure of some literature and a validation in a simulation software to the reader.

The *"Warehouse"* is a standard logistics company, focused on a broad variety of products. As the wide majority of SME still not automated in most of the processes, this thesis provides some options to start with the integration of innovative technologies. Specifically, processes such as storing, picking, and packing, are the ones that implementations are based on to fulfill the principal purpose of increasing the down times of machines and the efficiency of operators, among others.

There are some principal differences when it comes to the consequences after integrating industry 4.0 technologies. Although there are some that can be partially or totally automated such as storing with an automated storage and retrieval system (AS/RS) for instance, there are others as picking or packing that human work is strictly required and cannot be implemented as easy as the others. So, in this approach, when it comes to the integration of technologies in the process of picking and packing, the integration is related to the racks, the smart sensing (RFID) and the transportation system between each process with a conveyor belt.

5 Review of relevant optimization potentials

In this chapter the importance of the four Industry 4.0 technologies that are implemented in the approach is emphasized. Although these technologies have been briefly commented previously, it is necessary to familiarize with their main benefits but also with their shortcomings in a deeper way. Moreover, three different material flow processes of the approach: inverse picking, picking, and packing are compared with the current technologies used in *Warehouse*.

Although the financial costs can be critical in the decision whether to integrate or not, the financial approach is out of the scope of this thesis, but it could be very interesting to study the different kind of investments. For instance, in the case of the stacker crane, although there is no operator on the machine while it works, its maintenance is higher and other human workforce is needed in other stages of the process such as programming, maintenance, controlling, among others.

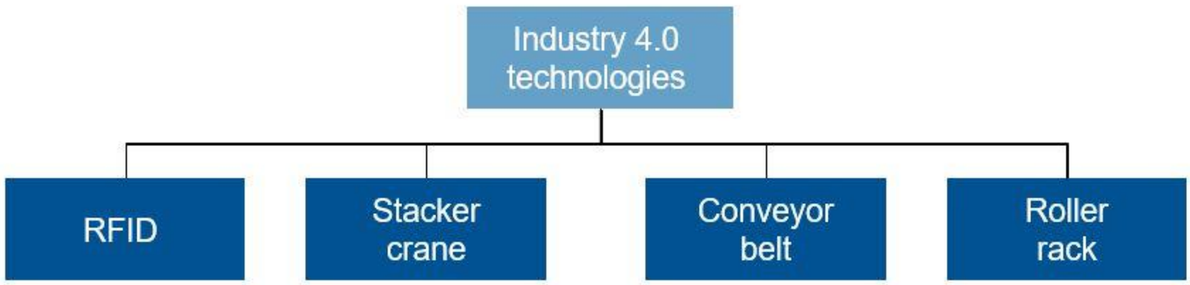

Figure 4. Innovative technologies for the approach.

5.1.1 Radio frequency identification (RFID)

Radio-frequency identification (RFID) is an innovative system that can exchange information between an RFID reader and a digital tag wirelessly using radio waves. The main objective of RFID is tracking and monitoring the location of products regardless of the environment.

This technology can automatically identify or track different objects in the shelves, racks, etc. It is very useful not only in the warehouse for tracking inventory, but also for detecting products in shops, access control, at the supermarket, libraries, or others. Specifically in Logistics, RFID is implemented to store and process data that is needed for production analytics. [Mun-2021]

A recent study proved some benefits but also disadvantages in RFID technology. When it comes to the former, it has helped many companies to solve out-of-stock items, managing the storage level in a better way, reducing the manual work and increasing the speed of data collection. Overall, it is cost saving and improves the productivity. The most important disadvantages are the security, due to the possible infiltration of hackers; overlapping of data and system assumption that leads to important problems. [Kho-2020]

One of the main problems detected in *Warehouse* is the waste of time that operators spend on picking process. The current technology used in the company in this process is barcode. One of the assumptions taken in this process is that each pack of the simulation contains one digital tag on it.

Comparing barcodes with RFID technology, one of the main differences is that RFID does not need a line of sight to scan a package, it can scan more than one product at the same time and distance needed from the scan to the package can be more than with the barcode. Regarding the benefits, the time required for the same number of packages is likely to be lower as the operator does not need to check Apart from the time spent on the process, RFID can also enhance the workload of operator due to the number of scans are undoubtedly lower than with the simple barcode system. Moreover, the storage level of warehouse can be known immediately as well as detecting if an order is packed correctly before delivering it.

5.1.2 Conveyor belt

The conveyor belt contains a power source, usually an AC motor that moves a pulley and turns a belt. Beneath the belt, there exists plenty of possibilities as rollers, wheels, chains, sheet of metal, etc. Depending on the materials to be picked, the surface of the belt can vary considerably. [Hab-2018]

The conveyor belt is considered not only as the most efficient system in warehousing, but it also is becoming the most popular in material handling processes. system is very fast, and its principal objective is to automatically transport items within an area. Additionally, the labour costs as well as the human errors declines with this technology due to the lack of human labour. [Car-2019] Conveyor belt systems are useful because:

- They can move heavy items from one position to another
- They can be inclined, therefore connected to higher levels in a rack
- The human physical workload declines
- The velocity can be configured, and possible item damages are also reduced
- Access to materials is better
- Shorter delivery time
- Minimize product life cycle

Another inefficiency detected in *Warehouse* is the throughput per hour per operator. Sometimes, the velocity from some operators is not the desired one, therefore with this technology, the number of packages that arrive to the pack stations only depends on the picking process and the parameters of the conveyor belt. In this approach, at least one conveyor belt per two different pack stations is proposed. Moreover, it also affects in a good way to the distance travelled of the operators because for them it is no longer required to move from the pack station to the shelves and vice versa. The financial analysis and the distance travelled by operator after each implementation are shown through graphics in the next chapter.

5.1.3 Stacker crane

The stacker crane system (SC) is the central machine in automated warehousing systems mainly used for transporting and storing goods in the shelves or taking them out to the delivery station. It can be considered as the most expensive equipment of this approach. [Yan-2019]

Moreover, stacker cranes are establishing in warehouse markets and many recent studies can be easily found on Internet due to the considerably reduction of storage space. Among its benefits, these are the most important:

- Provides more flexibility to the system in inverse picking and picking from the racks
- Low operational cost, no human labour is required (only maintenance)
- More storage capacity in the warehouse
- Lower investment because load and height can be customised
- More employee productivity in other tasks

In a standard warehouse, the stacker crane is placed between the racks, in the aisle, and it is able to move horizontally and vertically through the shelves [Wan-2020]. As it is connected with other physical systems due to IoT, when the central systems receive a new order, if it is available, the stacker crane processes that information and consequently move automatically to the corresponding bay. This process increases the efficiency of the retrieval of products as well as placing them into the racks.

In this case, any problem is detected on the company, however, replacing the current technology widely used around the logistics companies known as forklift by a stacker crane is proposed in this approach. This technology provides more reliability when it comes to human errors due to there is no human intervention during the process as well as a higher density of storage level. Once the stacker crane is implemented, the layout of *Warehouse* changes enabling new space for integrating new racks. However, the investment required is too high and the decision of whether to implement or not is not trivial.

5.1.4 Roller Rack

The roller or gravity rack is a flow rack that is based on gravity flow for loading and retrieving the products on the rack. The rack proposed in this approach to replace the stack rack provides more dynamic material flow in the system. Here below the main important benefits studied from the literature are shown: [Pet-2010]

- Increase flexibility of operator
- Less workload of operators loading and unloading the products
- Less distance travelled by the operators
- Improved shop-floor handling

This is the last implementation of this approach but not the least important. The combination of roller racks with RFID is proposed due to it can be decisive not only in the process of storing, but also in the picking. The current technology used in *Warehouse* is the standard rack, the most traditional one, with tags in each bay. However, the use of RFID interconnected with the central system, can provide more flexibility to the operator in the inverse picking process as well as in the picking. In fact, the distance travelled by the operator to store each product is highly declined and can be shown in the results of chapter 6.

6 Application and exemplary implementation

6.1 Specific approach

In this chapter, the four implementations with Industry 4.0 technologies are represented in graphs compared to the current situation of *Warehouse.* The aim is to provide simulations results considering the assumptions explained before to facilitate the decision whether to integrate or not these technologies.

The main objective of the approach is to increase the efficiency whether of the operators and the machines. Therefore, declining the idle time and reaching the maximum throughput possible are two important parameters for reaching the objective. Each simulation is based on a general warehouse layout, with six big racks for pallets about 12.5 meters of height and three aisles between the racks where the forklifts move. There also exists four pack stations and fifteen small racks for small products. The following two models of layouts represents the current distribution of a standard warehouse before and after the four implementations.

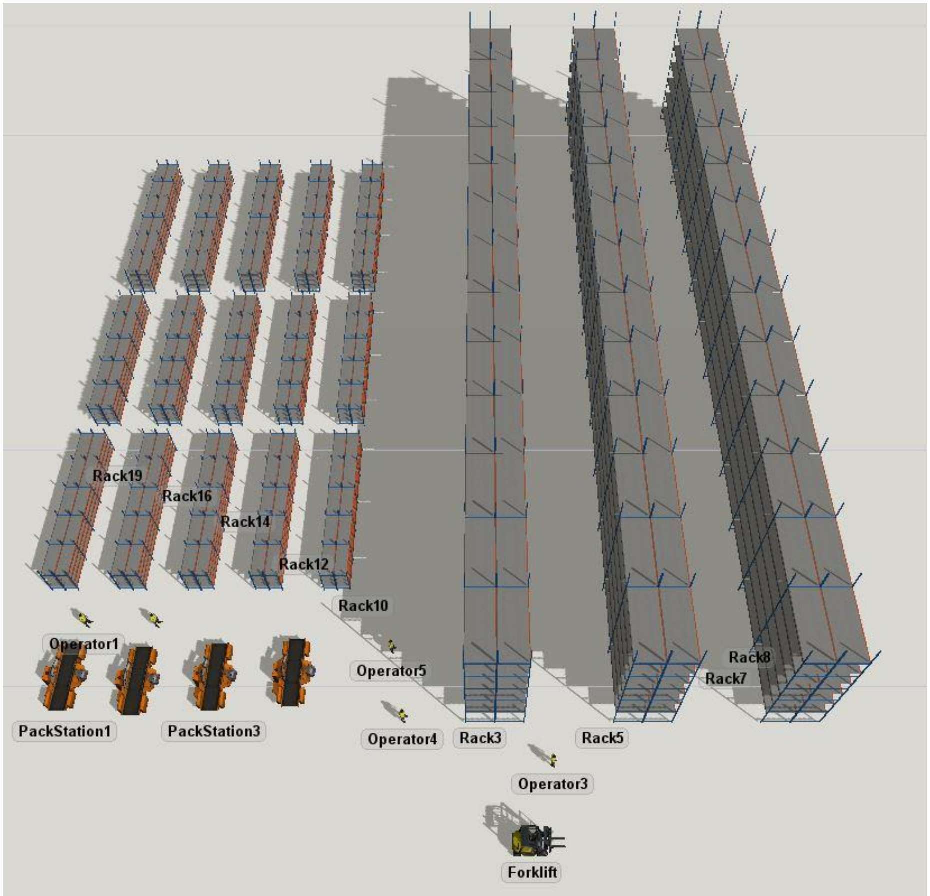

Figure 5. Current layout without Industry 4.0 technologies' implementations

6.2 Analyzing implementations results

For this approach, each implementation is simulated individually along one normal working day. The simulation starts at 08.00 am and concludes at 17.00 pm. A lunch break of an hour is set up from 13.00 to 14.00. In each simulation some assumptions are needed to reach the most similar scenario to the reality.

When it comes to the operators, it is considered that the velocity of each is the same in every process, equaling 1m/s and it is not contemplated any acceleration. Regarding the loading and unloading process of the packages, a main difference between RFID and barcode is included in the parameters of the model, accounting for both processes five seconds and ten seconds, respectively. The causes about the lower required time although it is the same task, are explained before in chapter five. Additionally, the time needed to load and unload with forklift and a stacker crane are also different and in this approach are ten and five seconds per task, respectively.

6.2.1 Integration of a stacker crane

The implementation of this technology replaces one of the most typical technology for storing and picking pallets, the forklift. In this case, the material flow process compared between the stacker crane and the forklift is inverse picking or also known as storing. Although a standard warehouse does not receive packages every minute during a day, the simulation is based on that, and the corresponding conclusions can be accepted.

Regarding the content of the eight big racks where pallets with the packages are stored, the following graphs show that with the stacker crane almost doubles the content per rack as well as the throughput per hour than with the forklift.

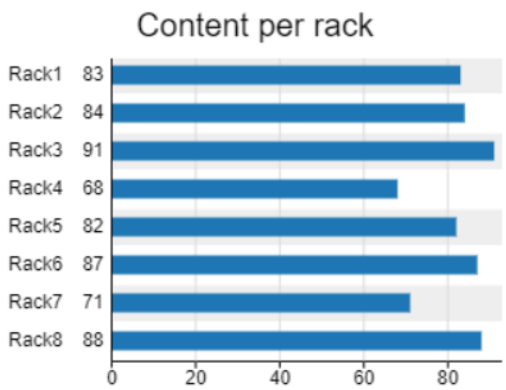

Figure 6. Content per rack with stacker crane

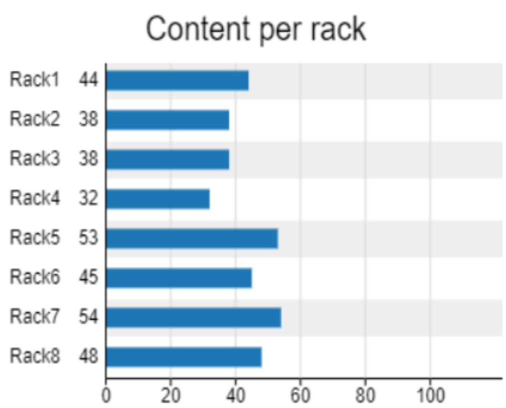

Figure 7. Content per rack with forklift

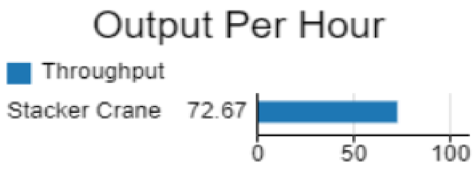

Figure 8. Output per hour with stacker crane

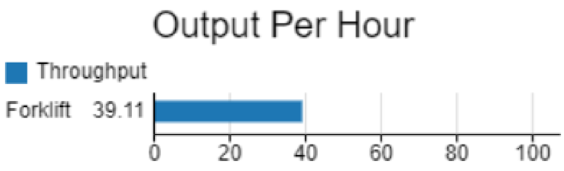

Figure 9. Output per hour with forklift

6.2.2 Roller racks in small racks

Traditionally, warehouses place each package in a fixed level of a fixed bay, and this is the process to optimize with Industry 4.0 technology. To this approach, the roller racks are proposed for small racks, with less than two meters of heigh with 6 different levels. Currently, the operators walk around the aisles and store product per product in different bays and levels of the racks. However, with the combination of roller racks and RFID, the packages are tracked automatically and the distance to travel is significantly lower due to operators only walk from the package's storage to the beginning of the roller rack. In the following bar graphs, it is shown that during a day, the number of packages per rack with the roller rack is almost sixfold compared to the current technology.

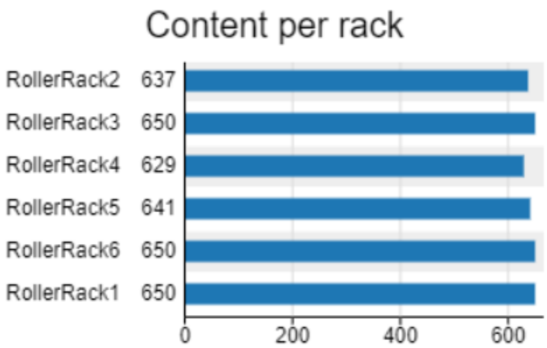

Figure 10. Content per rack with roller rack

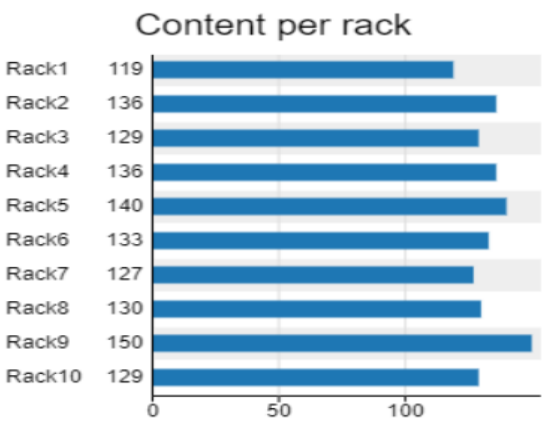

Figure 11. Content per rack with standard rack

In this approach, each simulation contains the same number of operators to compare both cases in the same conditions. Regarding the output per operator per hour, the results from the simulation show that with the roller rack almost doubles the number of packages than with the traditional method.

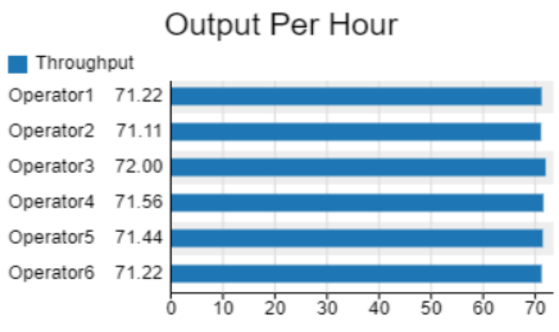

Figure 12. Output per hour with roller rack and RFID

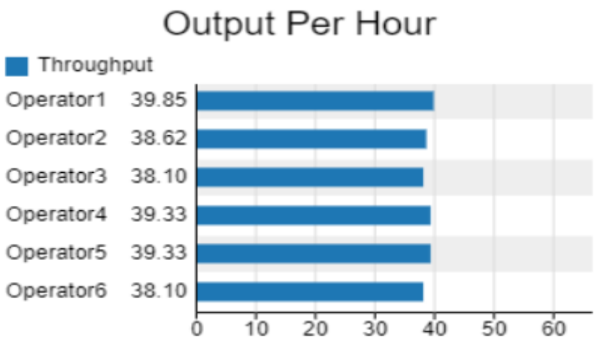

Figure 13. Output per hour with standard rack

Apart from the throughput per hour of the operators, in this approach the technologies proposed are also based on improving the efficiency of each worker. To reach this objective, declining the amount of time of operators that does not add any value to the supply chain is vital. For instance, FlexSim can calculate the percentage of the time spent of each operator in their tasks such as, loading, travel empty, unloading or even their idle time. From the next two bar graphs, some conclusions can be determined.

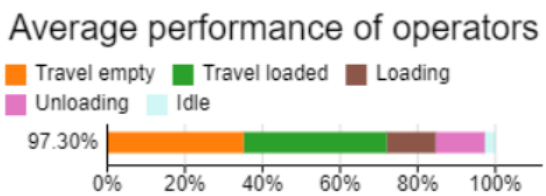

Figure 15. Average performance of operators with standard racks

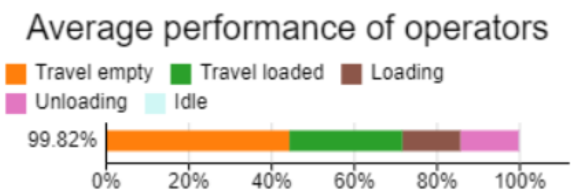

Figure 14. Average performance of operators with roller rack and RFID technology.

Firstly, although the load and unload time with the standard technology is the double compared with the integration of Industry 4.0 technologies, as it is assumed in the parameters of the simulation, it is not very relevant in their performance. Otherwise, with the roller rack implementation, the travel empty is considerably reduced, slightly less than the 10% of the total time spent by the operator, therefore increasing the travel loaded.

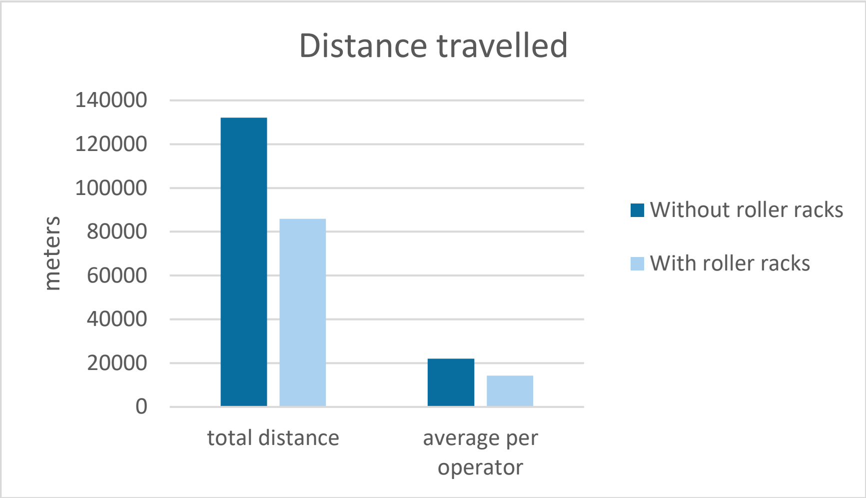

Figure 16. Distance travelled in meters after integrate roller racks and before it.

The bar graph above compares the total distance and the average distance travelled per operator with roller racks and with standard racks. It is clear, that with the industry 4.0 technologies proposed in this simulation, the three metrics are significantly better than the current one.

6.2.3 Picking process in big racks with conveyor belt

The implementation of the conveyor belt in the supply chain of a warehouse can be a very important integration and differs from current picking process in terms of distance and the throughput per hour. This integration of the conveyor belt is based on the picking process of the big racks. The current technology of the approach before the implementation includes carriages, but there is no possibility to simulate one wagon per operator moving around the aisles, so, other alternative is proposed to simulate the process.

Instead of each operator moving around the three big aisles, there are three operators picking packages from two different aisles to the same wagon. On the other hand, in the implementation model it can be shown that the technology together with the distribution changes, not only increase the output but also reduce the distance between aisles for including more big racks in that space gained.

Thus, the distribution of the picking process proposed differs significantly from the current one. In *Warehouse*, the operators travel through the big aisles for picking small packages only in the lowest level of each rack, because it is impossible to pick above the first level due to the height. Therefore, instead of travelling through the four big aisles to complete the orders, two roller or standard racks are proposed to substitute them adding a conveyor belt between them.

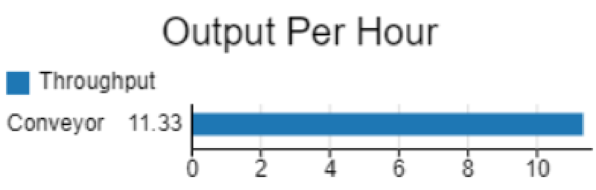

Figure 17. Output per hour with conveyor belt.

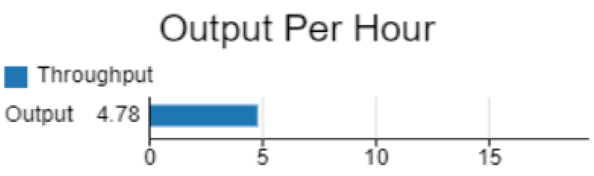

Figure 18. Output per hour without conveyor belt.

Regards to the throughput, in the current layout the output per hour with three operators is almost a slightly more than a third of the model proposed with the conveyor belt. With only one aisle of picking process, the throughput with only 3 operators is equal to the current throughput using 3 aisles with 9 operators. Thus, it is evident that including a conveyor belt declines the space required as well as the number of operators for the same task. Those operators that are no longer needed in this process can be relocated into the pack stations to decline the lead time there.

However, the average performance of the operators does not differ substantially from the current layout as the previous except the loading and unloading time that reduces roughly half of the time.

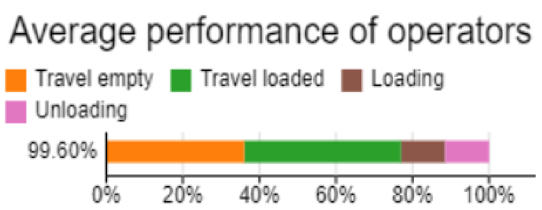

Figure 20. Average performance of operators with conveyor belt.

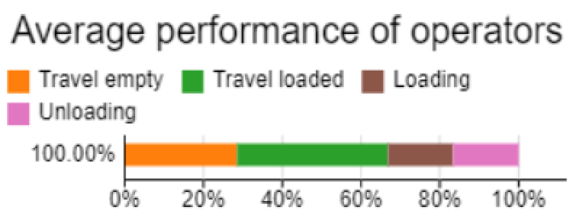

Figure 19. Average performance of operators without conveyor belt

In this case, the distance travelled in both implementations is quite similar, however, the point is that with the current technology, in order to at least equal the total throughput with the conveyor belt, the total distance travelled by all operators in the current layout threefold the distance required with the conveyor belt. But, as it is commented before, in this approach everything is compared with the same number of operators.

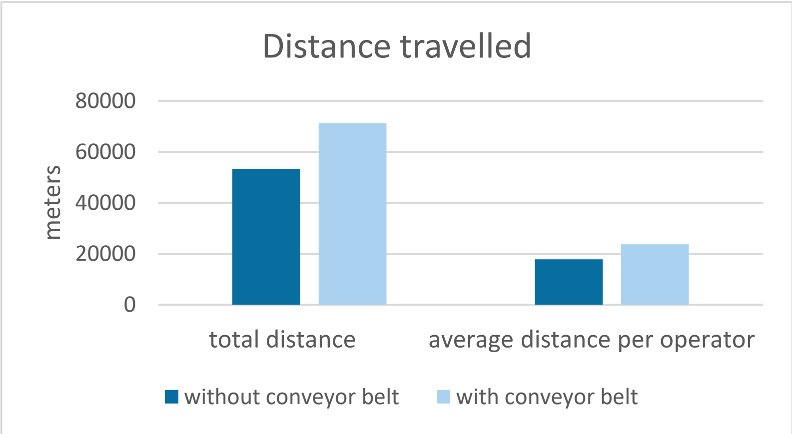

Figure 21. Distance travelled in big racks with and without conveyor belt

6.2.4 Picking and packing process in small racks with the conveyor belt and RFID

With the combination of a conveyor belt and the RFID instead of standard racks, the time spent on picking is half of the current one as it is an assumption of this approach. Moreover, the average throughput per hour of the system increases roughly 25% with the conveyor belt and RFID integrated than with the normal picking process.

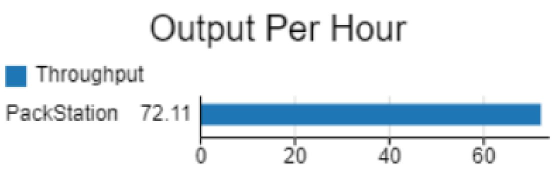

Figure 22. Output per hour in the pack station with conveyor belt integrated.

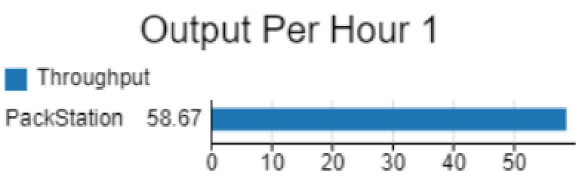

Figure 23. Output per hour in the pack station without conveyor belt integrated.

However, the simulation data shows that the implementation of a conveyor belt does not decline the distance travelled in total neither the average per operator. Nonetheless, it is also important remind that these two operators generate more throughput to the company and if it is compared in that way, the total distance travelled would be higher with the current layout.

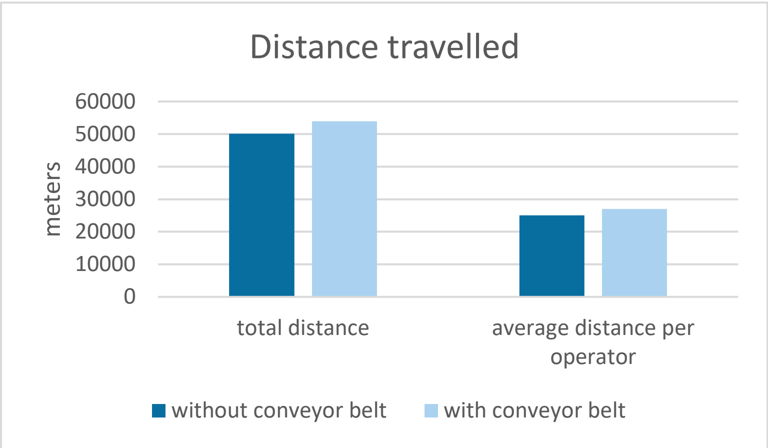

Figure 24. Distance travelled per operators in the small racks before and after the implementations of conveyor belt and RFID.

6.2.5 Add one pack stations per two roller racks

One of the main problems of *Warehouse* is the inefficiency of pack stations. Along this approach, everything is compared with the same number of operators only for this reason, to relocate the operators from the picking process to new pack stations. Thereby, as with all the implementations of Industry 4.0, less operators are needed in most of the picking processes commented before, more pack stations are proposed to be included in the new layout, specifically two pack stations per each aisle. Here below, the total throughput of the last implementations with two pack stations is compared with only one pack station. Due to some constraints of the simulation model, it is not possible to simulate it in the other implementations.

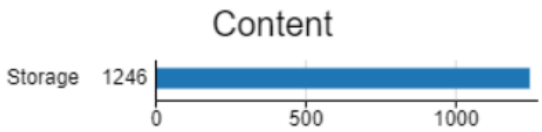

Figure 26. Packages in the storage at the end of the day with the two pack stations.

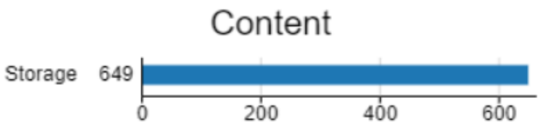

Figure 25. Packages in the storage at the end of the day with one pack station.

It is evident, that with the integration of another pack station almost doubles the total throughput accounting for 649 packages along a day and 1246 packages with only one pack station with conveyor belt and RFID and with one pack station, respectively.

6.2.6 Add two more big racks

Initially, there are three pair of big racks for storing the pallets received in the simulation model. Nevertheless, in order to reach the maximum efficiency of the model, as it is implemented in the first simulation a stacker crane in the model, less space between the aisles is required due to there is no longer forklift in the model and it needs more space than the stacker crane. Therefore, another two big racks are feasible to implement on the model.

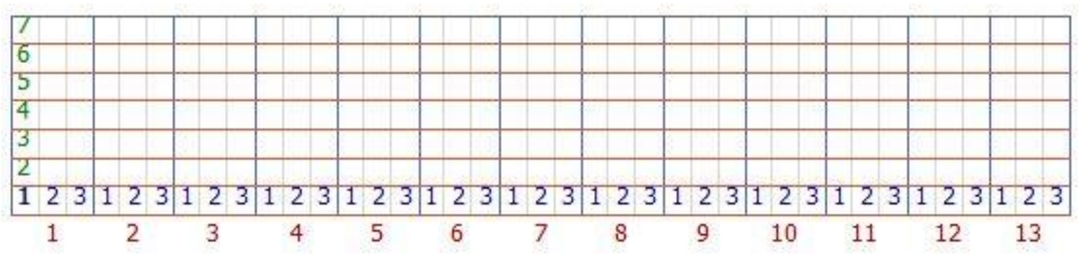

Figure 27. Simulation of a big rack in the approach.

In this model it is assumed that in every pallet there are 27 different standards boxes that inside of them can have more smaller products. In each Thus, the number of possible packages stored in the new warehouse is the number of bays (13) times the number of slots per bay (3) times the number of levels of the big rack (7), totalling 273 new packages. As it is included two identical big racks, in total makes up 546 new boxes, increasing in total 33% the storage level only in the big racks.

6.3 Final Layout

After the four technology implementations, a new distribution of the supply chain based on *Warehouse* layout is proposed to fulfill all the requirements. The main differences in comparison to the current layout are the ones that are shown in the figure below.

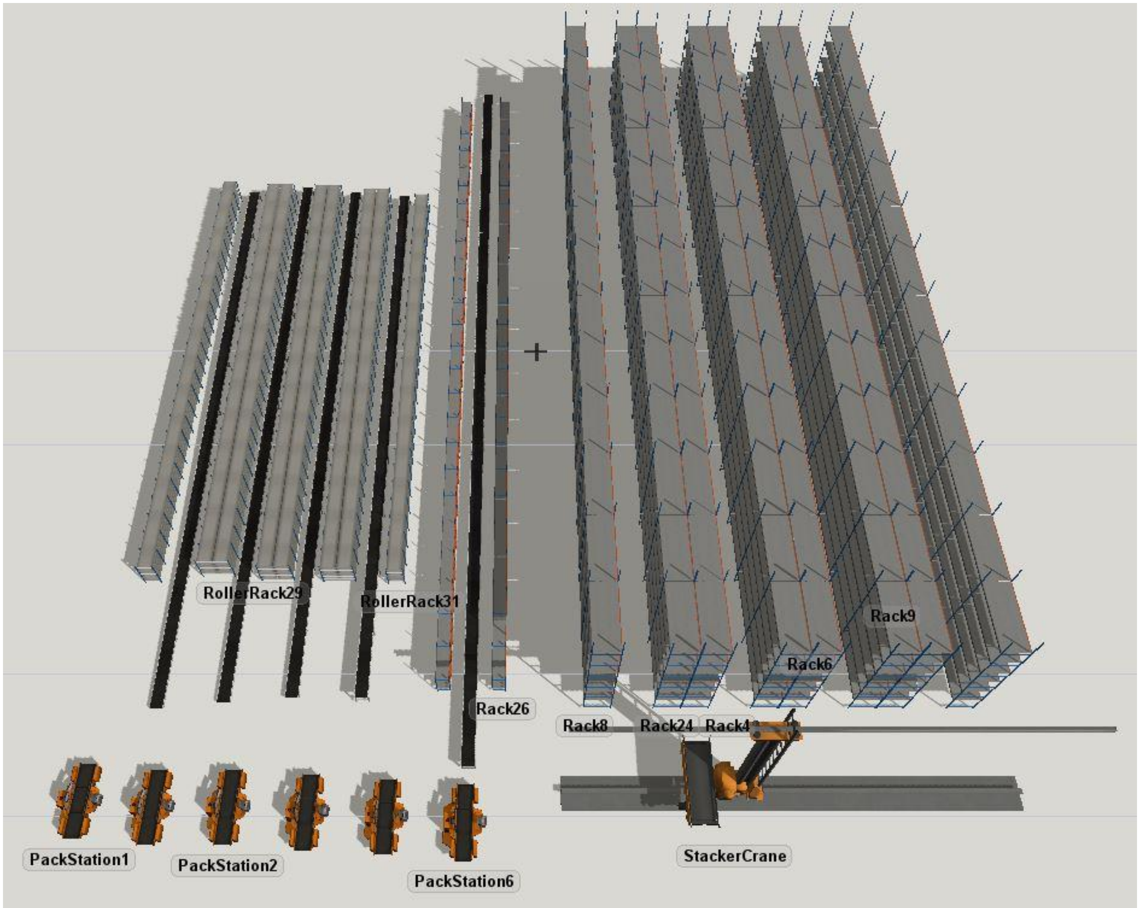

Figure 28. Final layout after Industry 4.0 implementations.

Regards to the stacker crane added in the bottom of the figure, two big racks can be added to the layout due to the space gained since the stacker crane replaces the forklift tasks. As it is commented before in this approach, the operators instead of picking packages from the big racks, they pick up from two small racks integrated on the left to the big racks, with the combination of a conveyor belt. One of the main important problems of *Warehouse* is the queue in the pack stations. As the efficiency of the previous processes is optimized and the number of pickers needed is lower, more pack stations are integrated on the model.

7 Discussion

This thesis can be split into four different objectives, all of them related to digitalize to some extent the warehouse of SME. Firstly, replacing stack storage systems for more dynamic systems including conveyor belts and roller racks. Secondly, increasing the efficiency of operators changing its role on the company. Another important goal of the implementations simulated are raising the throughput per machine as well as optimizing the space of the warehouse. All these improvements are likely to success in SME's warehouses due to the technologies explained along the thesis. However, these technologies are not usually implemented in warehouses such as *Warehouse* due to other different and more traditional technologies are implemented. This is the main reason why in this thesis every implementation is compared individually and not as a complete integration. This way every company can decide if integrate whatever technology depending on its layout, its characteristics, its requirements, or its objectives, among others.

For instance, the current technology for storing and picking process is the bar codes. However, although RFID will not replace them in the close future, it is likely that some distributors will modify its raw materials or its package processes for promoting the integration of RFID [Pat-2017]. When it comes to the decision if keep the forklift on the warehouse or move on to stacker crane technology, the financial situation of each company is one of the most relevant parameters to integrate or not. The aim behind of this paper is not to provide an economical study about the technology, but its influence on some key parameters. Regards to the integration of the conveyor belt and roller racks, a more dynamic material flow is integrated, thus critical benefits for reaching the objectives are provided to the SME.

In years to come, plenty of opportunities can appear within the logistics ecosystem due to every year a lot of new research are published and studied. These four implementations benefit the warehouses as it is demonstrated in the previous chapters, but it is also true that the investment required, and the payback period of each technology is still unclear, and the uncertainty remains in the decision about integrating.

8 Conclusion

Overall, it is demonstrated that there are many options of automating some processes including some industry 4.0 technologies in the supply chain of warehouses. Due to the lack of reliability and knowledge of these systems, it is very difficult for companies if it is worth it or not. Actually, in SME the marginal error when it comes to decisions is minimum and as the investment costs are the most important inconvenient of automating, it is required to be ensure that it is an optimal solution.

The paper gave an overview of the current state and trends of future technologies likely to be implemented in warehouses. Although each technology provides important benefits to the warehouse, the drawbacks such as, maintenance, investment, required skills, among others, are present and the decision about whether integrate or not is not very easy to take and some parameters need to be studied as well as the accounting analysis, payback period, and so on. However, a huge number of uncertainties about these technologies remains hindering its present and future applications.

It is expected that in years to come, as the current trend of warehouse technology systems is increasing on Internet and it is being more relevant in logistics ecosystem, a huge amount of research on this field is going to be examined and optimized. Moreover, new technologies will come up thanks to the large engineering efforts and they will probably overcome the current shortcomings as well as providing novel application never seen before in warehouse supply chain.

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Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been required.

Signed by ALBERTO SANCHEZ GONZALEZ -
NIF:03151196N day 31/08/2021 Garching with a secure
electronic signature ACCVCA-120

Ort, Datum, Unterschrift