TECHNICAL UNIVERSITY OF DENMARK

MASTER'S THESIS

Optimization of a worldwide distribution network and impact of Industry 4.0 in warehouses performance

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Declaration of Authorship

I, Alejandro VALLE, declare that this thesis titled, “Optimization of a worldwide distribution network and impact of Industry 4.0 in warehouses performance” and the work presented in it are my own. I confirm that:

- This work was done wholly while in candidature for a Master's degree at University of Oviedo.
- This document was fully performed at Technical University of Denmark (DTU), in cooperation with DTU Management Department.
- I have been a student of the Technical University of Denmark during the entire time I had worked with this thesis (28^{th} of January to 28^{th} of June 2019) thanks to the existing ERASMUS agreement between both universities.
- This thesis had followed all regulations and requirements from both universities.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date: 28^{th} of June 2019

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Abstract

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Optimization of a worldwide distribution network and impact of Industry 4.0 in warehouses performance

by Alejandro VALLE

This thesis is framed within the field of supply chain implementation and its potential improvements through the entire process and network.
It also aims to give a brief explanation of how distributions networks have been carried out over the years, as well as key points, drawbacks and possible performance upgrades. In order to do so, an specific theoretical research is done, discussing different distribution configurations, warehousing options and methods depending on markets, business models and company sizes.
An analysis on how do warehouses operate in industry and which are the key facts to focus on when optimizing their performances is also done.

To demonstrate the crucial consequences in terms of benefits and costs savings that network optimization can lead to, the thesis includes an experimental chapter in which a real business case is studied. Several ways of processes improvement such as transportation, production or new supply channels are studied and compared to the previous real performance of the network targeting new business scenarios and possibilities.

The third and last part of the project focuses on how Industry 4.0 and digitization are influencing the traditional logistic networks and what strategies could companies follow to adapt to this new working environment. It is also explained which challenges are companies facing and why they must readjust their planning and method so they can come up with better distribution network solutions as well as warehousing strategies.

Preface

This thesis was prepared and developed at the department of Management Engineering, in the Operations Management section, at the Technical University of Denmark (DTU).

The supervisor of this thesis at DTU was Professor Peter Jacobsen and the work was carried out during 5 natural months, from January 28^{th} of 2019 and June 28^{th} of 2019.

The thesis was done in fulfillment of the requirements for acquiring an M.Sc. in Industrial Engineering at University of Oviedo (Spain), where I, Alejandro Valle study. It was possible thanks to the exchange program agreement between my home university (University of Oviedo) and the Technical University of Denmark.

The collaboration and support from my exchange supervisor (Maria Jesus Lamela Rey) was very important and, of course, the expertise and knowledge shared by my thesis supervisor (Peter Jacobsen) had a big role in this document.

Kongens Lyngby, June 28^{th}, 2019

Alejandro Valle

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List of Abbreviations

PC	**P**roduction **C**enter
MW	**M**ain **W**arehouse
CDC	**C**entral **D**istribution **C**enter
RDC	**R**egional **D**istribution **C**enter
H&S	**H**ub **&** **S**poke
P2P	**P**oint to **P**oint
FCL	**F**ull **C**ontainer **L**oad
LCL	**L**ess than **C**ontainer **L**oad
CH	**C**onsolidation **H**ub
CW	**C**entral **W**arehouse
LP	**L**oading **P**ort
UP	**U**nloading **P**ort
IoT	**I**nternet **o**f **T**hings
CPS	**C**yber **P**hysical **S**ystem
SCADA	**S**upervisory **C**ontrol **a**nd **D**ata **A**cquisition
RFID	**R**adio-**F**recuency **ID**entification
NFC	**N**ear-**F**ield **C**ommunication
BLE	**B**luetooth **L**ow **E**nergy
JiT	**J**ust **I**n **T**ime
JiS	**J**ust **I**n **S**ecuence
WMS	**W**arehouse **M**anagement **S**ystem
TMS	**T**ransportation **M**anagement **S**ystem
OMS	**O**rder **M**anagement **S**ystem
ITS	**I**ntelligent **T**ransportation **S**ystem
M2M	**M**achine to **M**achine
LAN	**L**ocal **A**rea **N**etwork
SME	**S**mall and **M**edium-sized **E**nterprise
RTLS	**R**eal-**T**ime **L**ocating **S**ystems
CAPP	**C**omputer-**A**ided **P**rocess **P**lanning

Chapter 0

Introduction

The evolution and quick development of technologies have brought a new horizon in the way industry was working over the years. The appearance of new communication channels related mainly to the use of Internet has enabled companies to think from a new point of view: from a globalized worldwide one. Markets have expanded and competition between companies has been increasing exponentially due to the wider number of companies that are able to supply the same customer areas.

However, in these last few years, industry is evolving to a new and very promising scenario in which digitalization and smart data solutions are meant to make a very big impact. This new industry concept has been labelled as 4.0 environment and companies are spending significant amounts of money and time to take advantage and be ready for changes.

In this thesis, we aim to give an overview of how logistics networks and supply chain methodologies are important in industry, how they have been implemented over the years, parameters and characteristics of their optimization and performances and future expected scenarios that 4.0 era will bring to distribution networks and warehousing systems.

In an attempt to describe and explain the most important aspects from a theoretical point of view, a deep research has been carried out. This literature review enables us to understand the main aspects involved in the definition and analysis of distribution and logistics networks. This first section of the document is divided into two main objectives: In first place, an overview about the general details of logistics networks performances and different network configurations and possibilities. On the second part of the section, the scope is a bit more specific: globalized/world-wide logistics network.

It will be explained why there is a need of optimizing logistics networks, what are the main aspects to focus on and which will be the KPIs (Key Performance Indicators) that are more relevant and decisive to guarantee an optimized scenario in terms of cost-efficient while ensuring quality in every supply stage. Later in the chapter, an explanation of how to manage appropriately the new larger-scale networks and the many challenges and several considerations globalization has brought with it. The existence of many more routes and shipping channels, together with the larger transportation distances and greater difference in manufacturing costs over the places, makes these operations and logistics management more complex and challenging. Several business strategies and transportation configuration will be explained and similarities and distinctiveness between them and the real-case business scenario optimized by us in the second chapter of this document.

As mentioned in the paragraph above, an experimental optimization of a logistics network model based in a real-case company will be explained and described in the second part of the document. This part of the thesis targets a specific case based in an already-existing company´s network, and we have carried out several optimization proposals based on the frequent solutions and considerations discovered from the theoretical research illustrated before.

As a brief introduction to this experimental work, it must be said that this company covers a world-wide customer demand by itself. To do so, it is composed by four manufacturing channels spread throughout four continents (North and South America, Europe and Asia) and has several large-scale storage centers where the shipping process takes place aiming to guarantee the in-time supply to all its markets. Our work is divided into different optimization scenarios, each of which are focused in a specific activity, and in the last subsection we compare the results obtained from each of the approaches between them and in contrast with the already existing network performance. The final objective of this part of the document is to visualize how little changes and different working perspectives can have a very big impact in such big and complex logistics global networks.

To conclude, this document aims to introduce the new vision of logistics and warehousing solutions and their expected changes and evolution to an interconnected and digital environment.

Again, we have read several both scientific articles and company's opinions and shared information, to understand the challenges of the new industrial era and the potential that this new methods can bring. From a management of networks perspective, this section intents to show how human activity is crucial if we want to gain the most from this new scenario, as well as which aspects we all should be aware of to make the transition to these smart solutions beneficial.

0.1 Research question

The target after writing this thesis is to ensure that every reader of this document is able to respond and understand, no matter their respective background and specialties, the general questions written here below.

How is it possible to optimize a global supply chain logistics network?

* How is the new digital era changing the concept of warehouses and what do Smart Warehouses gain from new Industry 4.0 environments?

Chapter 1

Logistics networks optimization and its global approach

1.1 Logistics Network Optimization understanding and procedures

1.1.1 Definition, scope and necessity of Logistics Network Optimization

In the paper by (Jang, 2017), it is explained that the term of logistics network optimization covers the decisions that need to be made previously and during the implementation of the supply chain for a company or for one or several product areas inside the company itself. This means, as a starting point, finding the optimal combination of needed warehouses to ensure the whole supply chain from the raw material to the customer service. Therefore, the goal is to know how many warehouses will be necessary, where they will be located and how big they need be. However, this is not as simple to achieve and many different constraints need to be evaluated to find the finest strategy.

The logistics task can be divided mainly into three stages - acquisition, supply and sales. The network optimization is often only to do with the last two mentioned stages: supply and sales. Even so, in especial occasions sourcing of raw materials is also included.

Naturally, although warehouses are the main purpose of analysis in a supply chain, manufacturing factories also take part most of the times as they can potentially store part of the total stock if they have in-house warehouses.

Afterwards, the fact is that usually what influences the most when building a new factory are considerations like on terms and conditions of the site acquisition, political scene, tax benefits, market potential and size and staff sourcing. Where to locate a new factory is comparatively less crucial in the logistics network and usually the logistic circumstances are considered later on.

The optimization of the logistics network is a crucial concern because it has an important influence in the company infrastructure, investment and the supply chain itself. This task is usually carried out by a senior group of experienced decision-makers employees.

(Kawa, 2012) remarks that efficient logistics services together with reliable and fast transportation are getting more and more important with the time in the companies activities and objectives. A good developed logistics chain gives companies a competitive advantage with others but, furthermore, in the future it can be the difference whether the company can adapt itself to the market needs or not, in which case it will absolutely disappear.

Usually, when a company does not have the infrastructure and knowledge to develop adequate logistics services, they ask external companies to do it for them, which are logistics service providers who belong to the transport, forwarding and logistics industry. According to (Jeszka, 2003), this sector provides solutions for companies of different sizes, offered services and area covered. It includes large and very small companies with a very wide range of services to help them with activities such as transport (the basic one), forwarding, warehousing, palletizing, packing or directly full supply chain services. These activities can be developed in a regional scale, but also throughout a country continent or even world-wide.

The main purpose of logistics is to develop a full-performing operating system which balances working people and infrastructure. Parcels, documents and heavy freight are sent in these systems, but also and very important, information about every activity in the chain. To guarantee the appropriate communication and a quick and correct information flow between all the actors of the network, logistics service providers need to use and implement the optimal information technologies available.

Both information and telecommunication technologies are nowadays so closely connected with the operational system that one would not exist without the other. A company that is not aware of the fundamental importance of the modern information systems and the need of continuously develop them, will have no opportunities to develop in the future - without the right functioning IT systems, logistics companies cannot create a competitive advantage with others.

Increasing efficiency and automate the process as much as possible are two of the main objectives that the application of information technology aims to fulfill. Thanks to these technologies, it is possible for everyone of the chain to have numeric data presentation, fast verification and control over costs, revenues, sales and more other data. It also enables the access to archived data and information transmission to small business units, employees and contractors. The last and very important objective that the application of these services would guarantee is to provide and fulfill potential and existing customers with their needs and expectations. Customers not only care about the price of the service, but also about the shipping time and the safety of delivery, and applying these technologies would facilitate providing the clients with all the information they are interested in.

(Jang, 2017) explains that network optimization is required because of many reasons. The most representatives ones are listed below:

- Variations in the demand both by product and/or by geography
- Addition of new sales channel in a new geographical area
- Adjustments in the retail channels
- Changes in manufacturing possibilities
- New marketing strategies
- Mergers with other companies
- Changes in competitor's network strategy

As in any business, the objective is to achieve the best costumer service with the greater benefits. The refinement of the network aims to reduce the cost in the supply chain while guarantying the service, making businesses more profitable.

These last mentioned common reasons of why optimizing logistics networks is needed can be proved in many cases. Nowadays, the increased turbulence of corporate environments for production companies is characterized by shortened lifecyles of products and cumulative variants. Demand from customers in now characterized by smaller delivery lot-sizes and shorter delivery times requested, as written by (Jones, 2005). To adapt their processes to these new requirements, companies react by improving the flexibility of their manufacturing systems so they can shorten the reaction time of the lines, (ElMaraghy and Wiendahl, 2009) and (Nyhuis and Wiendahl, 2004).

These changes on the customers needs and trends oblige to reduce the buffer at the work stations and to adapt the production lot-sizes to the customer demands, which leads to a challenge that logistic systems must face. In the last years, the development of flexible productions processes has been putting all the attention in the flexibility of value-adding resources, while logistics' contribution has been underestimated, according to (Pritschow and Wiendahl, 1995).

As explained by (Schuh et al., 2008), for the production systems nowadays, there is a need of a logistics concept that is both flexible and economic. Usually, the standardization of processes and resources, makes systems and networks more efficient. It is not easy to achieve an optimal combination of both, e.g. forklifts are a tremendously flexible transport system but not very efficient and cost-friendly because of the many empty runs.

1.1.2 Logistics Network types and Project Optimization procedures

From a theoretical and basic starting point to understand logistics network activity, there must be mentioned two basic divisions: Point-to-point, where shipments are prepared in the starting unit of the network and send all the way to the final destination, and Hub-to-Spoke, where there are intermediate centers and hubs and shipping and storage tasks are divided and more integrated through the whole process.

Point-to-Point vs. Hub-and-Spoke

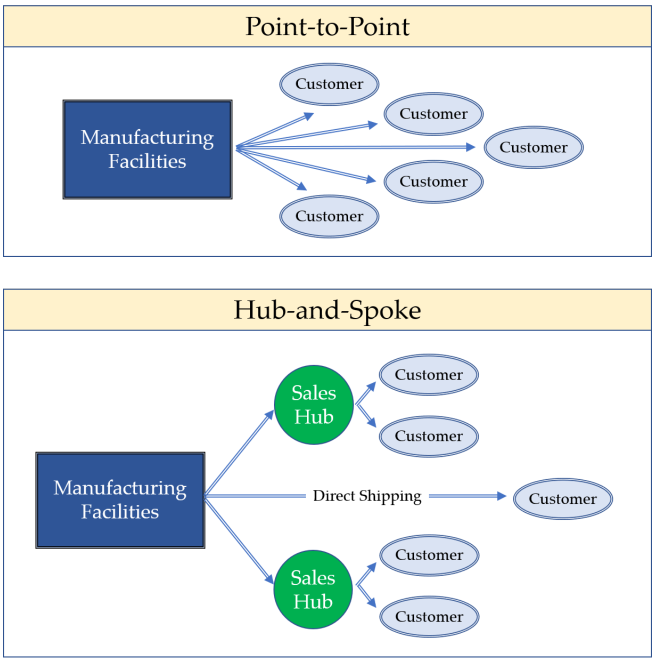


FIGURE 1.1: Point-to-Point and Hub-and-Spoke distribution configurations.

As already commented, with the Point-to-point supply system, each hub is full in charge of supplying services to customers around its area. On the other hand, in the Hub-and-spoke model, each manufacture facility provides the needs and services along different areas.

As it can be deduced, in the P2P model, difficulties and longer lead times often come up. If there is a variation in the demand rates, it becomes more difficult to plan the production and distribution to the customers. The logistics operation is centralized and an individual manufacturing factory sends services to each of its customers. As long as it is feasible for the company, it is usually a good idea to add sales hubs to the network, like it is done in the H&S model. Faster and more efficient services can be provided since each hub focuses on its own market.

Although H&S network are better solutions sometimes, P2P models are optimal in other cases. Depending on the size of the network, its distribution and the volume of each of the deliveries that needs to be done, P2P can lead to logistics and storage cost reduction while ensuring a quality service to customers.

Horizontal vs. Vertical

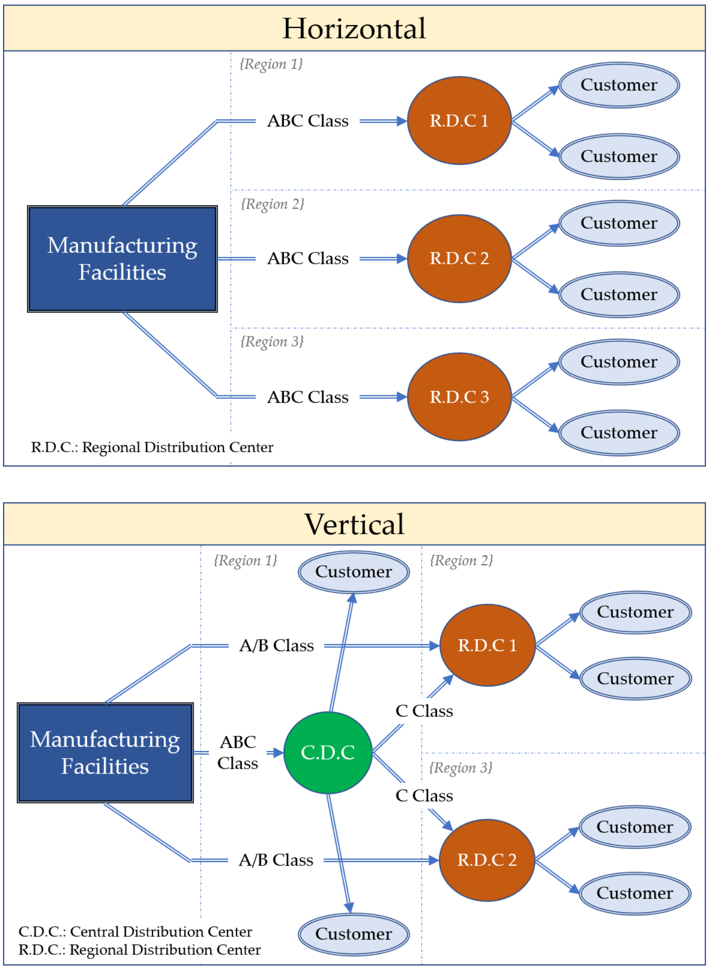


FIGURE 1.2: Horizontal and Vertical distribution configurations.

Regarding Figure 1.2 and focusing first on the H&S network, two divisions can be found. In the first one, which is known as the horizontal structure, the services are directly supplied from the Regional Distribution Centers (RCD) in just one level.

The vertical system is disposed in two different tiers, which combine both Central and Regional distribution centers. In this second option, products are categorize into three categories (A,B and C), depending on the quantity and the frequency they are shipped, with the aim of minimizing the inventory and set up an optimal strategy.

Being more precise, products classified as A and B are stored into regional distribution centers (RDCs) and the main objective in these cases is to reduce costs from transportation. On the other hand, those considered as class C are placed into central distribution centers (CDCs) which main purpose is to create inventory risk pooling effect, because by concentrating inventories into a less number of locations leads to a total inventory reduction.

TABLE 1.1: Inventory ABC-classification.

Product Class	Order Frequency	Order Quantity
A	HIGH	HIGH
B	LOW	HIGH
	HIGH	LOW
C	LOW	LOW

In addition, there are specific situations where regional distribution centers (RCDs) are not even implemented. This is the case of small-size and costly products, which can be easily store in just one center. By doing so, not only it minimizes the inventory costs but also a security transportation which is usually done by air.

Besides the very basic divisions and types of logistics networks explained above, in the last few decades new eco-friendly configurations have been developed and tested, as explained in (Turki et al., 2017).

The increasing preoccupation on environmental matters, together with the potential economic benefits and the legislation pressure, has forced supply chain and logistics management to evolve and to focus of minimizing the environmental impacts of production and transportation and in the preservation of the earth resources. That has been leading managers to orient their decisions into sustainable supply chain, and many works have dealt with industry sustainability, as presented in (Galve et al., 2016) and (Moon, Jeong, and Saha, 2016).

Some have tried to develop a conceptual manufacturing ecosystem model with the purpose of improving the environmental performance, e.g. (Despeisse et al., 2012) have analyzed the industrial practices and environmental practices and then suggested a model focused on energy balances, waste management and material flows to offer a better understanding of the connections between production processes, supporting facilities and surrounding centers. (Liu et al., 2014) propose an operational decision-making bi-objective problem which is elaborated to minimize both the shipping time and carbon dioxide emission rates. They present some results that could inspire companies to implement sustainable production plans and enrich the theories of manufacturing decisions.

In the last few years a new environmental-friendly concept has gained a lot of popularity, it known as the closed-loop supply chain. It is currently being followed by many researchers, company leaders and others and it has numerous evident benefits that have enabled it to strengthened its position in the industry, (Li et al., 2014). Apart from the restrictions from governments applying laws and regulations to promote eco-friendly solutions, customers have started to demand companies initiatives to respect the planet. With the implementation of these closed-loop logistics strategies, companies could benefit from the returns of used or broken products to the retailer or even manufacturer and they could explore the opportunity of raising profits and exploring new markets.

Project Optimization procedures and methodology

In order to proceed to the optimization of the logistics network, it is mainly done by two ways: Mathematical modeling and simulation modeling.

Mathematical modeling is the most powerful tool once an explicit expression of the pattern of behaviour is obtained, as it can be immediately analyzed the dependence on several parameters in the network. However, usually some approximations or unrealistic hypothesis related to the distribution of things must me made.

Simulation modeling provides the opportunity to take into account several constraints and factors that appear in the real performance of the network. Often, simulation is carried out in three phases.

1. *Analysis of the current status of logistics:* Understanding its operation, analyzing its processes and data and considering target results.

   A product classification by their hierarchy must be completed. Also, analyzing the characteristics of each product line and categorizing each output as detailed as possible. By doing so, a minimization of potential errors is achieved.

   An understanding of the marketing strategy is also crucial, as the network will be designed in accordance with the positioning the company aims to have in the following years. This will influence the constraints definition of the optimal network.

2. *Definition of constraints, standards and methods of evaluation:* Checking out network behaviour under what-if scenarios.

   It is essential to compare the results obtained in each scenario with the ones recorded in the past. Therefore, a baseline is developed and it is considered as an starting point to compared if the optimization attempts are really substantially improvements or not. Then it all becomes a trial and error procedure, combining qualitative and quantitative effects and analyzing the different performances of each alternative.

3. *Study of the potential implementation of the optimal alternative:* Creating an application plan.

   Once the optimization plan is chosen, it is time for the implementation phase. This step encompasses the sizing of the warehouses by year and network, work on the relocation plans, consideration of the infrastructure and investment needed and the conditions under which it should all be done.

1.2 Understanding of worldwide logistics networks

According to what is explained by (Trent and Monczka, 2003), Global Sourcing is the concept that covers the integration and coordination of procurement requirements across worldwide business units, looking at common items, processes, technologies and suppliers.

This term should not be confused with the meaning of international purchasing, which describes the acquisition of raw materials, components and sub-assemblies from different international sources to use in manufacturing, assembly or for resale, regardless whether the import source is internal or external to the company. (Kotabe and Omura, 1989) Global sourcing remarks as a key factor, the capability to schedule, coordinate and synchronize the amount of goods exchanges and physical and informational flows from source to destiny.

To achieve an effective and well development global sourcing strategy, structures and processes including logistics network must be well designed and studied, as they play a key role.

There is no doubt that the evolution towards wider global networks leads to greater transportation costs due to the longer geographical distances. However, as explained in (Krüger, 2002), another differential aspect is the increased difficulty of solving the trade-off between inventory and physical distribution costs. Although off-shore sourcing strategies are meant to save costs, they can end up not fulfilling the purpose if they are not thought in detail. To obtain the more profits and best performance possible for a world-wide network, logistics patterns such as transportation modes and networks working configurations must be adapted and evolve from the previously less extensive networks.

The exponential expansion of the globalization phenomenon over the last decades has brought new scenarios and, consequently, several challenges for an appropriate management of these "new" larger-scale networks. According to some studies carried out over these last years regarding global supply chain management, there are mainly three aspects/decisions which need to be taken into consideration for an optimal performance of the network.

- Strategic alignment of the supply chain
- Coordination between all actors operating in the global supply chain
- Design of the word-wide logistics network

There are some different supply chain configuration depending on the level of vertical integration. Large distances from the location of manufacturing centres to customer markets make the involvement of many operating parts in the supply chain a necessity. Regarding the management of global networks, it is clear that their operation and connections are more complex and larger, leading to a higher level of difficulty when optimizing their performances. To help companies to find their respective optimal solutions, different research studies have been published; some remarked the need of integrating facilities and systems and sharing the information throughout the entire chain to make the performance of the system visible for every management actor in the process (Li et al., 2006); other focused their studies in the planning of the demand coordination with suppliers; finally others proposed some mathematical models to deal with the problems derived from production and distribution activities (Goetschalckx, Vidal, and Dogan, 2002).

The last aspect that has been an area of interest of many researchers is the study of which is the optimal and more beneficial mode of transportation (which is usually container shipping through sea or airfreight for some products that require special needs), the design of infrastructures for freight consolidation and finally, the definition of the number of echelons that compose the whole logistics network.

Global logistics networks design has been analyzed from the two main actors of the system: from global carriers' point of view and from manufacturers' perspective. The first group focuses their thoughts in the use of transport infrastructures or logistics systems like Hub-and-Spoke (H&S) and shipment consolidation strategies together with internationalization and globalization policies of freight forwarding companies and logistics service providers. On the other case, manufacturer's consider transportation systems as an origin-destination process characterized by a transport unit cost but focusing a bit less on the structure of transport services and to their relative implications on the supply chain.

In the most recent studies, deeper analysis of the possible and more optimal logistics solutions have been detailed. Three transportation systems have been considered more efficient than the others: Airfreight, Full container load shipping and Less than container load shipping, and their respective influence in inventory costs for the decision making.

In general, many global product sourcing processes are meant to manufacture most of their production in Asia, where unitary costs are considerably lower than if they were manufactured in Europe or North America. Usually, although transportation costs are very high because of the large distances separating the fabrication company and the distribution centers, the cost-savings thanks to the lower salaries of workforce make these globalized networks profitable in general.

(Kawa, 2012) states the general computing problems of the logistics industry. Usually, when customers from logistics service providers want to use their services, they always have to adapt themselves to their tools. In addition, in the cases of one-off cooperation, they have to search for the carrier and browse their catalogues, websites and products every single time. In this industry, there is a lack of available solutions that integrate the services from different operators in one only place.

When applying this to the global logistics, generally client companies need to deal with many different transportation companies to guarantee their supply, which in many times, derives into the use of different transportation types used from origin to destiny. This same issue happens also for smaller scales such as national or regional transportation. For example, besides the fact that there are important distribution centers in many countries around Europe, SME use them to a small degree. These individual logistics and storage centers distinguish themselves from their competitors thanks to their value-added services, but they all ensure similar infrastructure conditions.

These mentioned systems that add value to logistics center can be, for example, shared information on schedules for arrivals and departures of regular charter services, tracking and tracing across organizational borders, real-time business monitoring, etc.

Over the last year SME logistics companies have been focusing their investments on business competence instead of fully developing their IT systems, so they have a limited IT-competence and are not yet ready to install digitalized processes in their operations.

(Kawa, 2012) finally remarks that the biggest problem of the logistics industry is the lack of standardized semantics which can allow an automated data integration in the processes. Some universal solutions are still missing so they could allow smaller companies to work together in a co-operational environment in the changing industry conditions.

1.2.1 Logistics network configurations in global supply chains

According to (Creazza, Dallari, and Melacini, 2010), ocean container shipping is normally the main transportation mode for carrying products across the Globe. This transportation system is characterized by its low freight rates and by its main drawback which is its long transit time.

Focusing our research now into sea container shipping possibilities, it has been concluded that there are two main ways to perform these transportation activities: shipment with Full Container Load (FCL) and shipment with groupage container, or what it is the same, with Less than Container Load (LCL). These networks based on sea transportation have usually several similarities and common aspects, like doing the shipment activity from a consolidation hub and receiving it in cross-docking centers. A consolidation center is where shipments from different manufacturers and suppliers are collected and prepared for their shipments across the sea, whereas cross-docking facilities are hubs which receive the products from the ships and organize them for supplying to the RDCs or customers.

The configuration of the logistics network that use ocean shipping has been divided into three main groups: direct shipping networks, one echelon networks (which can be subdivided depending on the location of the consolidation hub) and two echelon logistics networks. In the one-echelon networks, if the consolidation hub is located close to the suppliers it will be named as upstream hub and if it is located near the marked it is called downstream hub.

Based on the possibilities and divisions in which logistics networks can be grouped, and of course accepting that there are always modifications and specialties between every network, logistics ocean-shipped networks can be separated in 5 different configurations:

1. **Direct Shipment + Full Container Load (FCL):** Single producers ship full container load to RDCs in the customers market. Every network connecting manufacturing center and customer does not interact with the others.

2. **Direct Shipment + groupage containers (LCL):** Non-containerized goods are shipped by road to a facility near the Loading Port (LP), where containers are consolidated. Containers are transported by the sea and deconsolidated in an Unloading Port (UP), where they are hauled to their correspondent RDCs.

3. **One echelon network + Consolidation Hub Upstream (near suppliers):** Non-containerized goods are shipped by road to a Consolidation Hub (CH) where products are temporary stored. Then, the shipments are consolidated and again shipped by FCL containers to its LP, where ships will carry the products to the UP and from there to the RDCs.
   * *Consolidation Hub is the same center that is referred in the experimental case as Main Warehouse.*

4. **One echelon network + Central Warehouse Downstream (near customers):** Each supplier ships its products individually across the sea. Shipments are received in the UP closer to the Central Warehouse, where they are stored, deconsolidated and shipped non-containerized to the RDCs.

5. **Two echelons network + Consolidation Hub Upstream and Central Warehouse Downstream:** Non-containerized goods shipped by road to the CH in suppliers' side. Goods are consolidated, and containers are shipped to the LP, with FCL treatment. Sea transportation across the ocean finishes in the UP, where goods are sent to the closest CW. In this hub, products are deconsolidated and then transported to the RDCs.

Figure 1.3 shows schematically what are the different connection within each of the 5 global logistics network configurations.

LCL usage together with the one or two echelon logistics network is not included as one of the main configurations of most important and usual global sea transportation logistics networks. This is because the use of these type of configurations leads to a redundancy of the logistics activities, producing inefficiencies for both costs and delivery lead times, making these possibilities not very optimal.

Regarding transportation of all 5 configurations described above, there are differences between the configuration that includes LCL shipping (Configuration 2) and all the others. LCL configuration includes road transportation, sea container shipping and handling costs at forwarders' facilities. FCL configurations include the ocean shipping which is the same for all configurations, and the road transportation which depends on the distance to be covered (pick up and delivery).

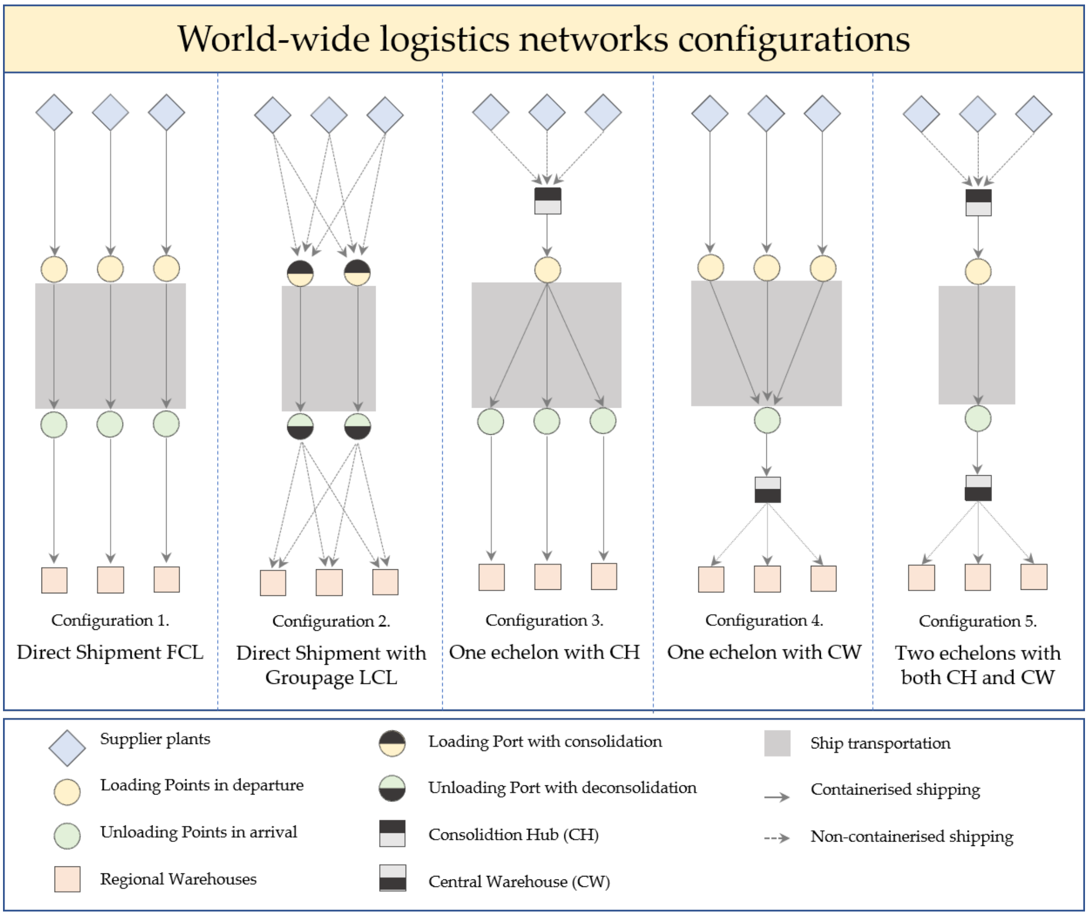


FIGURE 1.3: Possible world-wide logistics networks configurations

In respect to handling and storage costs, configurations face also different scenarios between them. Configuration 1 and 2 (Direct shipments) require only one handling activity, which is carried out in the last stage of the chain, in the RDCs. In the other three configurations handling and inventory operations are also needed in other stages like in the CH and the CW, where it also exists a certain cycle stock. There is a need of deciding where safety stock is allocated and, therefore, there will be some hub which will store the safety stock and others that will only be transition points, where no safety stock will be stored. Normally, most of network real configurations held their safety stocks in the RDCs (Michelle L.F. Cheong and Graves, 2007), since it is the closest point to customers and therefore it is easier to adapt the demand and be ready for unexpected changes.

The different rates of safety stocks in the RCDs which, of course, depend on demand and lead time distributions, are a function of the mean value and variability of the lead time inherent to each configuration. With other words, order processing costs for each RDC is only a function of the reorder frequency and it is never influenced by which of the five configurations the logistics network is about.

Lastly, analyzing every configuration behaviour regarding supply lead lime, it is known that Configuration 1 proves to have the lowest mean lead times. The main explanation is the lower number of existing nodes in the network. It is clear that, when there are more actors involved as it is the case of Configurations 3 and 4, this mean supply lead time increases. Configurations 2 and 5 are the ones with the longest lead times. This same pattern appears when describing the potential risk of delays in the supply; the more complex and longest the logistics chain is, the higher possibilities of having delays (lowest chances in Configuration 1 and highest in Configuration 5).

To sum up the contents of this section, it must be remarked that there are several recurrent configurations in global logistics networks strategies. Each company should analyze and study the optimal and more suitable configuration for their own business activity, ensuring the service level. Usually, many companies adopt configuration 1 network design, mainly because of its simplicity and lower interconnection, which reduces the possibility of supply issues and extra shipping times.

Coming back to Global sourcing processes analysis and basics explanations, (Zeng, 2003) focuses on the effectiveness of a particular global sourcing case. In his book, (Anupindi, 2006) gives a set of attributes that can be used to measure the ability of processes to manufacture and ship products and services. Three main measures are suggested to be adopted to evaluate the effectiveness of the global distribution networks: Process cycle time, logistics cost and cost-to-value ratio.

1. *Process cycle time:*
   This factor is divided in two - the manufacturing time at the production center and the total transportation lead-time. Transportation lead-time is harder to estimate precisely in these big global networks, and yet a fundamental indicator of the operational effectiveness of the global sourcing strategy.

   There are mainly five transportation systems when it comes to global networks shipping processes:

   - All air
   - Water-rail Full container load
   - Water-rail Less than container load
   - Water-truck Full container load
   - Water-truck Less than container load

   Air shipping activities represent the lowest uncertainty out of all five, and it also requires the shortest amount of shipping time. In contrast, two limitations reduce the availability of using this transportation mode: the shipping quantities of each lot and the freight cost.

2. *Logistics cost:*
Global networks tend to classify cost elements into 6 categories that take into account the manufacturing, logistics and selling activities: transportation, inventory holding, administration, customs charges, risk and material handling and packaging.

3. *Cost-to-value ratio:*
In many cases, logistics managers are concerned with the percentage of the value of the outsourced parts that is spent on the logistics activities.

To sum up, there must be said that there are two main systems of implementing a global sourcing network when the manufacturer and the seller are two different companies. Many companies decide to outsource the production to countries where the manufacturing costs are much lower and therefore they can get bigger profits that producing them themselves.

First, the **Vendor-Required-Material (VRM) structure**, in which the selling company purchases the raw materials from the suppliers and then ships them to the manufacturer. This structure's material flow is shown in Figure 1.4.

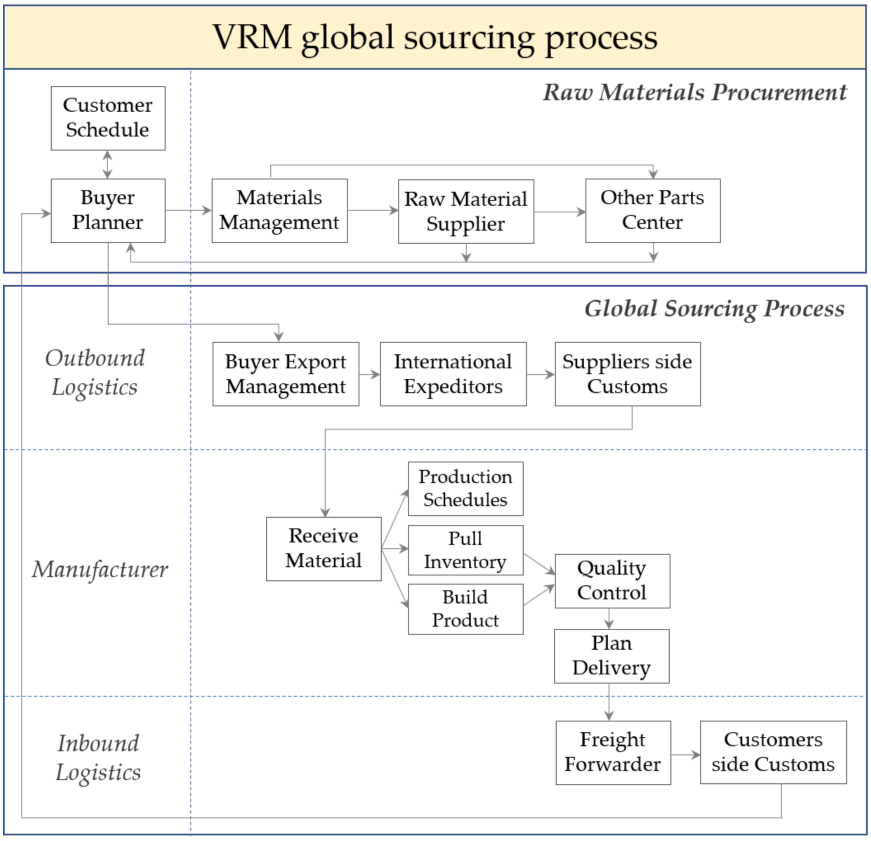


FIGURE 1.4: VRM Global sourcing process

On the other hand, in the **Vendor-Supplied-Material (VSM) structure** the manufacturing company has direct contact with the raw material providers and, therefore, they have the responsibility for decisions on procurement, materials management, production planning and delivery tasks. In this case, the selling company will have a lower involvement in forecasting demand and developing internal schedule requirements. The process is much more simple for this structure, as it can be seen in Figure 1.5, where its process is represented.

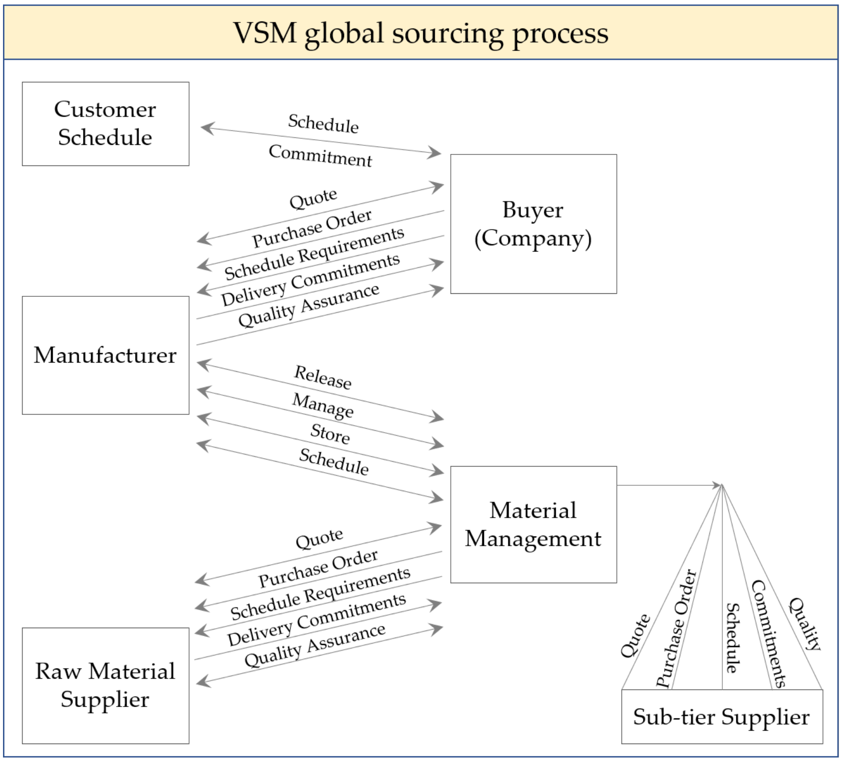


FIGURE 1.5: VSM Global sourcing process

Finally, Table 1.2 shows the comparison between both global sourcing structures.

TABLE 1.2: VRM vs VSM comparison.

		VRM Structure	**VSM Structure**
Advantages	Company	•Has full control •Easy to make changes •Highest degree of independence	•Focus on coordination •Focus on strategic planning •Less involvement in production & distribution
	JV	•Less financial responsibility •Focus on production planning & scheduling	•Smoother production & resource planning •More flexibility & communication with suppliers
Challenges	Company	•Responsible for all critical decisions •Substantial financial burden	•Increased responsibility for coordinating the entire supply chain •More investment in administrative functions •More currency risk
	JV	•Slow response from company due to no communication with suppliers •Difficult production planning & scheduling	•IT technology must catch up to improve the speed of communication •Cooperate with both the parent company & suppliers

Chapter 2

Experimental optimization of the worldwide distribution network

2.1 Introduction to the experimental approach and set-up considerations

In this Chapter, an analysis and interpretation of a distribution network is carried out. The model is based on a real case but its data has only experimental purposes and therefore, it is not expected to be used in any further studies.

The Chapter is composed by three main different sections. The introduction (Section 2.1) aims to give an overview of how it looks and performs the network, its geographical distribution and connections between channels. Then, in the Section 2.2, it is explained how business carried out regarding the current performance of the network. Transportation channels, expected demand distribution and costs definition will be also included in the section. After that, different optimization scenarios will be investigated and the purpose will be to find some improvements that could lead to a cost reduction and better performance of the actual network.

As a summary of how this experimental chapter is distributed:

- Introduction to the experimental approach **Section** 2.1
- Model set-up and existing performance analysis **Section** 2.2
- Improved models and optimization
  1. Analysis of potential demand increases and network limitations **Section** 2.3
  2. Transportation channels optimization **Section** 2.4
  3. Production channels differentiation by product **Section** 2.5
  4. Production channels optimization **Section** 2.6
  5. Production and transportation combined optimization **Section** 2.7
  6. Cost comparison and feasibility study **Section** 2.8

*This section is not an optimization, just a study of hypothetical network performance.
**This section compares the improvements derived from each scenario in terms of cost reduction.

The network is defined by its production, storage and distribution centers, which all aim to supply in a wide scale. Products are meant to be delivered to every continent.

However, productivity is limited, as there are only four production centers, which are located in four very different locations as it is shown in Figure 2.1.

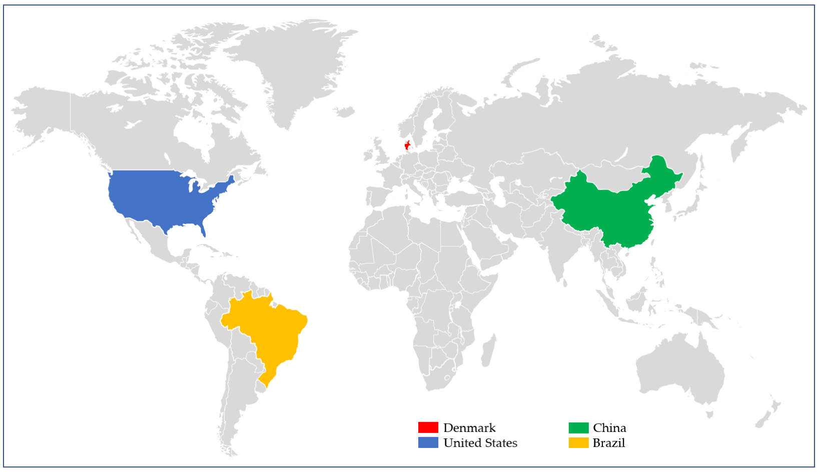


FIGURE 2.1: Locations analyzed

The existing network's performance emulates an Horizontal Distribution Network model, similar to the one represented in Chapter 2, more precisely in Figure 1.2. The three different products (or parts) are produced by each PC and supplied through distribution centers to the final customers. There is no direct supply from the manufacturing facilities (PCs) to customers and, therefore, it represents an horizontal channel. The main distinction from the previously mentioned figure is that, in this model, not only RDCs are needed but also CDCs and one MW near each production facility. The network is so large and covers so much extension that intermediate centers are needed to storage and manage the shipping to the final customers.

Yet, the final stage between RDCs and customers is not covered in this thesis. At the end, the overall process which is analyzed through this document is the one shown below in Figure 2.2.

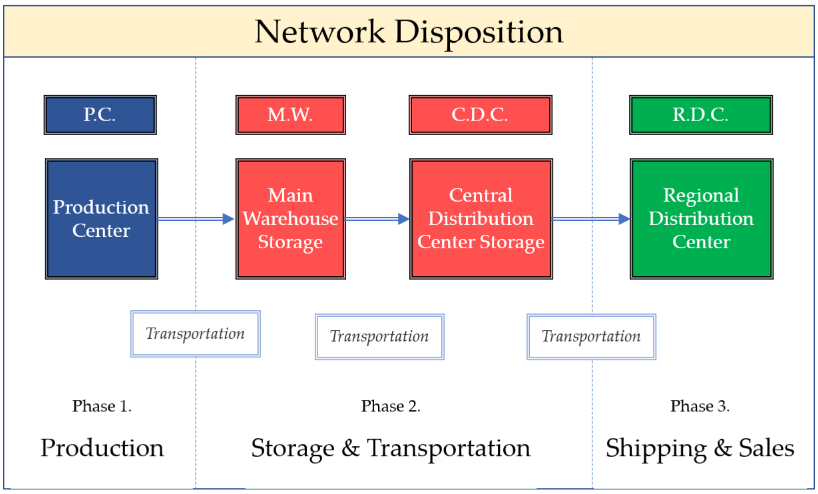


FIGURE 2.2: Schematic of the logistics network operation

The production process is carried out in United States, Denmark, Brazil and China but the supply chain covers a worldwide extension.

These four locations are treated in reality as if they were four different channels. This means that each production facility has an assigned number of customers that must supply and productivity, transportation and storage are designed individually in all the four tracks.

To explain which are all the agents that make up the network, Figure 2.3 has been added. Numerically, these are the actors of the logistics network:

- **United States channel:** 1 PC, 1 MW, 8 CDCs and 38 RDCs (4, 4, 2, 3, 4, 10, 5 and 6 respectively)
- **Denmark channel:** 1 PC, 1 MW, 8 CDCs and 89 RDCs (8, 11, 16, 8, 9, 11, 20 and 6 respectively)
- **Brazil channel:** 1 PC, 1 MW, 2 CDCs and 22 RDCs (9 and 13 respectively)
- **China channel:** 1 PC, 1 MW, 3 CDCs and 25 RDCs (3, 14 and 8 respectively)

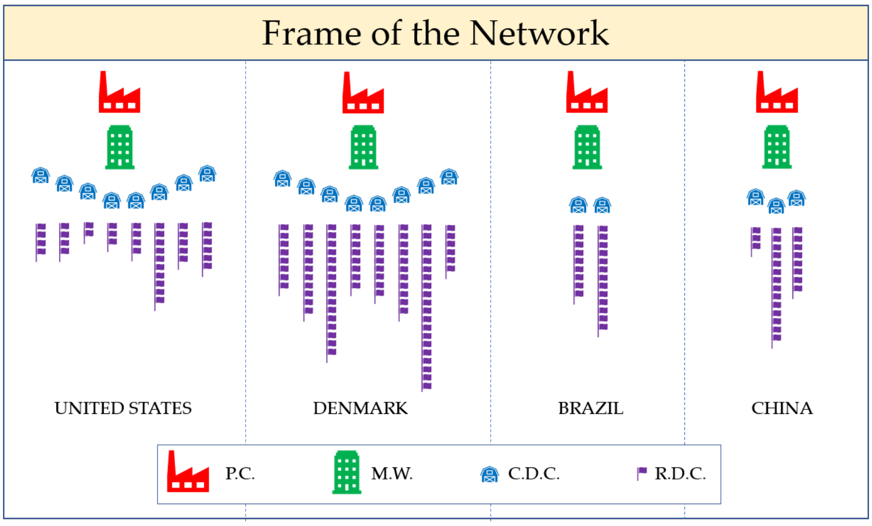
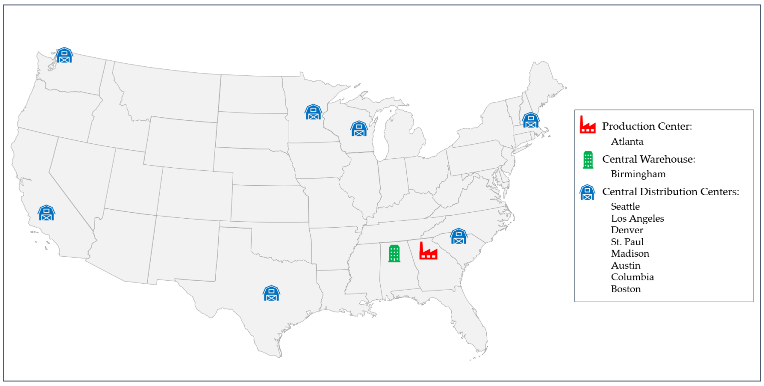


FIGURE 2.3: Network setup schematic explanation

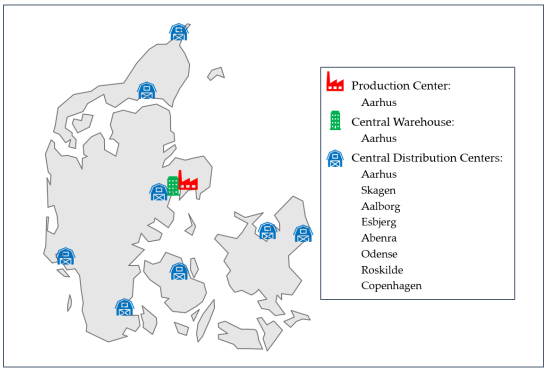
It is important to remark that the analyzed network has previously been designed in a way in which productivity and shipping are determined by distances. This means that the crucial factor to decide whether one or another PC supplies to a customer is only proximity between both. The shortest distance from the starting to ending point of the transportation is the one chosen, even if there was an hypothetical case in which longer distance would not mean higher transportation costs.

Once a short schematic representation of the network is done, the exactly locations of every component of the network should be displayed.

Firstly, it is relevant to mention that both MWs and CDCs are in the same country where the PCs are. Thus, in Figure 2.4, both production and storage centers are precisely market in their individual maps.

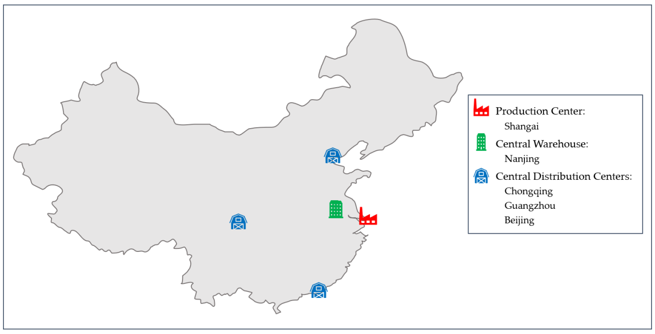


(A) *PC, MW & CDCs location in United States.*



(B) *PC, MW & CDCs location in Denmark.*

(C) *PC, MW & CDCs location in Brazil.*



(D) *PC, MW & CDCs location in China.*

FIGURE 2.4: Location of Production Centers, Main Warehouses and Central Distribution Centers in the four countries that integrate the network

On the other hand, locations of all the RDCs around the globe are also known. In Figure 2.5 they are pointed individually by continent so is visible and understandable.

Sum it all up, the connections between Central Distribution Centers and Regional Distribution Center, which can be done both by sea or by road, look like Figure 2.7

There is an important particularity that is to be explained regarding the shipping from CDC to RDC. It was mentioned that the decision of which center was supplying certain customers was only a matter of distance. Nevertheless, the supplying channels work a bit different when it comes to Denmark.

It is basically because of geographic reasons. While in other cases (e.g. China) CDCs are separated by a notable distance of several hundreds of kilometers, in Denmark distances are almost insignificant taking into account that it is a worldwide network in which distance are really long in general.

In contrast with the other three production locations, in Denmark not every CDC stores all three types of products. Some of them were previously designed to host just one or two types of products, as it is shown in Table 2.1

TABLE 2.1: Products detailed storing in Central Distribution Centers in Denmark .

Location	**Product type**		
	Part A	Part B	Part C
Aarhus	✗	✗	✓
Skagen	✓	✓	✗
Aalborg	✓	✓	✓
Esbjerg	✓	✗	✗
Abenra	✓	✓	✓
Odense	✗	✓	✓
Roskilde	✓	✓	✓
Copenhagen	✓	✓	✓

Not every customer (RDC in our case) demands all three types of products. To some of them it is only supplied one or two types of products, and that is not an exception in the ones delivered from Denmark.

The distinctness in Denmark is that, no matter where the RDC is located, the decision of which CDC is providing commodity depends only on how good the provision and demand fit. As an example, if an RDC demands only Part C products, it is going to be supplied by Aarhus, as that CDC stores only specifically that type of products.

However, there are four CDCs that store all three kinds of products. In these cases, they supply based on geographic areas, as transportation channels are set up and already designed. Aalborg CDC is in charge of supplying the Baltic area and UK, Abenra supplies to southern Europe, Roskilde to central Europe, Turkey and Middle East and, finally, Copenhagen ships to Poland, Slovenia and Croatia.

There are in total 174 RDCs spread all around the globe. All of them are listed below, divided by geographical areas. Figure 2.5 help us to understand their positioning in each continent.

North America: Portland, Vancouver, Edmonton, Calgary, San Diego, San Francisco, Las Vegas, Hermosillo, Salt Lake City, Kansas City, Winnipeg, Fargo, Grand Forks, Milwaukee, Chicago, Indianapolis, Cincinnati, El Paso, San Antonio, Houston, Dallas, Oklahoma City, New Orleans, Monterrey, Mexico DF, Merida, Guadalajara, Miami, Charleston, Charlotte, Pittsburgh, Orlando, Quebec, Philadelphia, Toronto, Ottawa, Washington DC, Montreal.

Europe: Valencia, San Sebastian, Nice, Dortmund, Leipzig, Istanbul, Esmirna, Brno, Coimbra, Barcelona, Lyon, Munich, Genova, Graz, Athens, Cardiff, Lulea, Klaipeda, Edimburgh, Goteburg, Malmo, Glasgow, Galway, Dublin, Stockholm, Bergen, Turku, Tallin, Riga, Liverpool, Manchester, Southampton, London, Oporto, Gijon, Gant, Bratislava, Linkoping, Paris, Sevilla, Lisbon, A Coruña, Madrid, Zaragoza, Burdeaux, Montpelier, Nantes, Bilbao, Palma de Mallorca, Wroclaw, Milan, Turin, Salzburg, Oslo, Helsinki, Lille, Toulouse, Liege, Rotterdam, Hamburg, Frankfurt, Stuttgart, Hannover, Roma, Bari, Ankara, Antalya, Bursa, Gdansk, Warsaw, Poznan, Katowice, Maribor, Zagreb.

Africa: Casablanca, Marrakesh, Rabat, Cape Town, Port Elizabeth, Johannesburg, Medina, Riad, Tel Aviv, Doha, Dubai.

North Asia: Moscow, St.Petersburg, Krasnodar, Nizhny Novgorod, Astana, Baku.

Oceania: Kuala Lumpur, Singapore, Jakarta, Manila, Melbourne, Sidney, Brisbane, Adelaide, Perth, Auckland, Wellington.

South Asia: Mumbai, Nueva Delhi, Bangalore, Bangkok, Taipei, Hanoi, Sapporo, Tokyo, Osaka, Hiroshima, Fukuoka, Seoul, Tianjin, Changchun.

South America: Belo Horizonte, Recife, Fortaleza, Belen, Bogota, Quito, Panama, San Jose, Managua, Santiago, Concepcion, Buenos Aires, Bahia Blanca, Cordoba, Rosario, Montevideo, Curitiba, Lima, Asuncion.

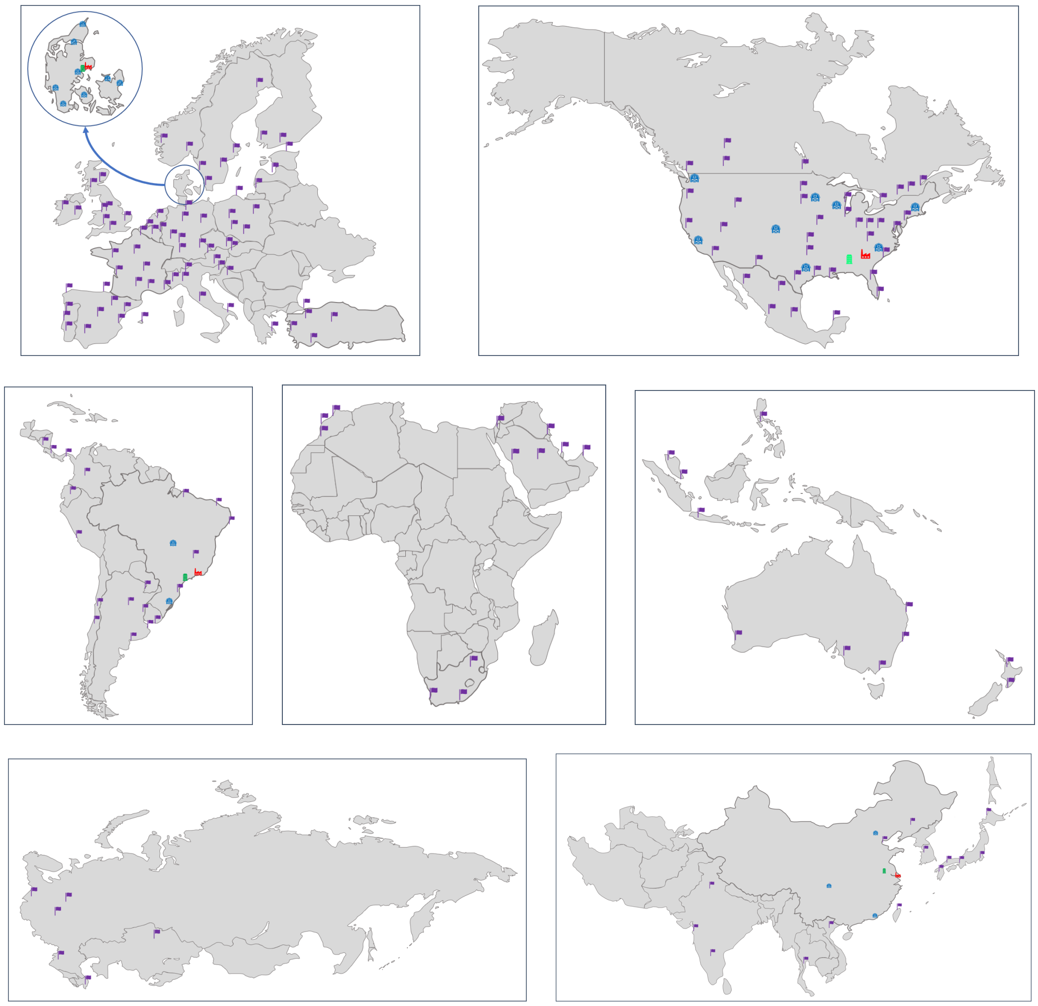


FIGURE 2.5: Location of all Regional Distribution Centers that integrate the network

Once treated individually by continent, it is interesting to give an overview of the entire distribution of every center in the network. This is shown in Figure 2.6, where it can be seen how, mainly Europe, but also North and South America the areas where there is a higher density and number of centers by area covered are.

It was previously explained in this section that supply programming is mainly a matter of distances, and that customers are part of one production channel or another based mostly in their closeness to one or another. Figure 2.7 show the existing connections between CDCs and RDCs. With this it is possible to get an idea on the area covered by each channel, the number of customers that are in charge of and the type of transportation that might be performed in each connection based on geography and distance.

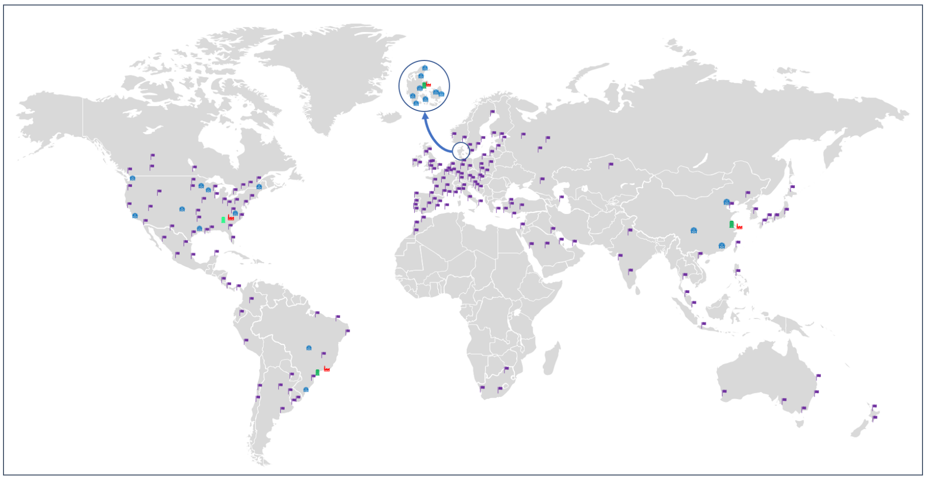


FIGURE 2.6: Network's centers location worldwide

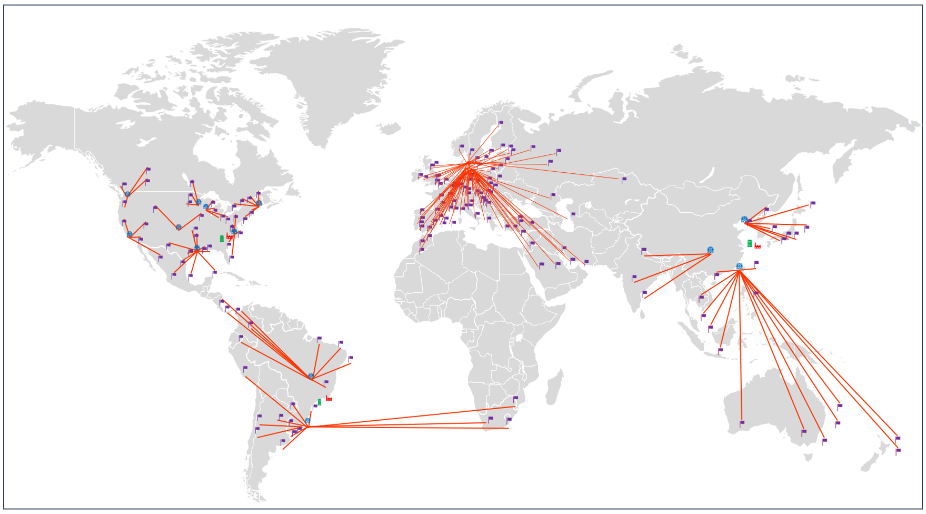


FIGURE 2.7: Network distribution 1st approach

To sum up this section and, although it will be described and more detailed in the next one, Table 2.2 introduces the predicted demand rates in each of the channels by product part and in total. This is added here to clarify that the total number of customers that a channel supplies to is not directly linked to the total expected demand for it, e.g. in China less customers than in other channels represent a much higher demand.

TABLE 2.2: Total demand by country and by product type annually.

Location	**Product type**			**Total**
	Part A	Part B	Part C	
United States	10.0 M	10.5 M	11.5 M	**32.0M**
Denmark	17.2 M	12.55 M	12.55 M	**42.3M**
Brazil	9.8 M	6.7 M	7.5 M	**24.0M**
China	88.9 M	94.4 M	89.8 M	**273.1M**

2.2 Model setup and analysis of the existing network performance

Once the structure of the logistics network is introduced and geographically positioned, it is time to detail the internal process and evolution throughout the entire operation.

The tracking of the production, transportation, storage and shipping is done daily. This means that the analysis will be done focusing on one natural year and comparing multiple parameters and criterion based on the evolution of each of them during the entire year.

Another remarkable aspect to understand the behaviour of the processes is that the demand from each of the RDCs that compose the network is variable. Everyday, a different amount of products is required from each of them and it was already checked that they do not follow any pattern at all. The demand assumption was based on data collected from previous years and no forecasting study was done as yet. The demand is meant to have the same sequence as in previous years.

2.2.1 Current status of the network and performance understanding

The current display of the production channel shows that the manufacturing systems are set up in a way in which they produce a constant amount of products every day over a year.

Furthermore, as it was assumed that demand would not vary from previous years and that data was collected, the amount of units of each product manufactured daily in each PC is the total yearly demand divided by the number of days in a year, which in this case is 366 as 2020 is a leap-year.

In relation to what was previously mentioned of the daily data collection, it can be graphically explained how do production, transportation and storage rates vary daily.

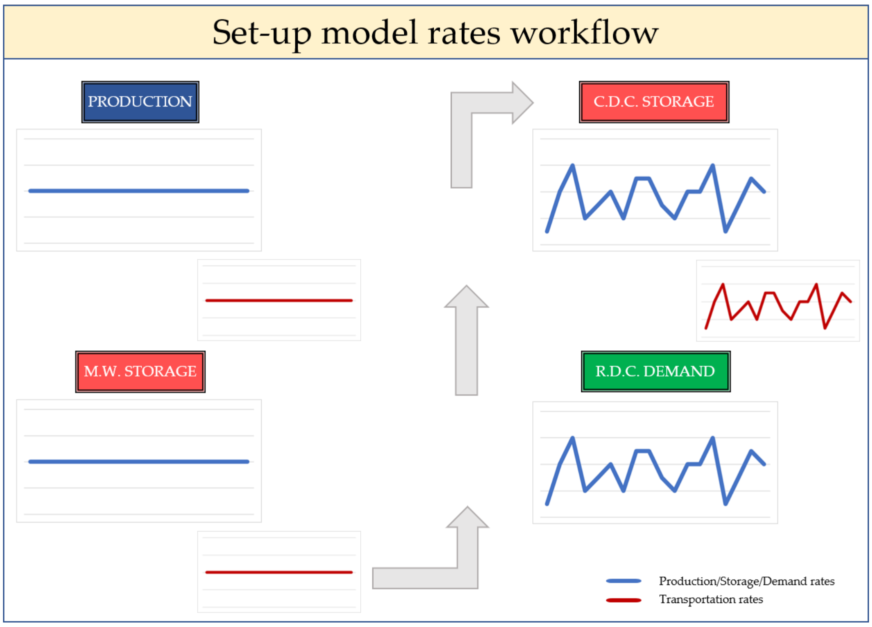


FIGURE 2.8: Work-flow rates performance in the distribution process

With the Figure 2.8 we intend to give an idea of how the logistics network vary during the days. Comparing this work-flow with optimized scenarios will help us to understand better what is changed in the process and how it is improved.

The model has been working in a way in which manufacturing volumes are the same everyday in the year. Based on the demand from previous years, it is decided to divide that amount by the number of days in a year to make production constant.

NOTE: Production Centers and Regional Distribution Centers are considered as if they would not have any storage capacity. This last ones have some capacity in reality but very little and designed to be used just in case emergency or special occasions, so it is neglected for our study.

Production centers do not have any storage capacity and, therefore, all products must be shipped daily. Since the production is constant, transportation from Production Center to Main Warehouse is also constant every day over the year.

The same lot that arrives to the MW is shipped to the different CDCs everyday. That leads to a non-changing occupancy rate in main warehouses. Nevertheless, since these centers are only around 50% of occupancy, other shipping and storage possibilities can be found for further analysis in case it would be more beneficial.

Last stage from CDCs to RDCs changes from previous ones. As it was explained in the statement, demand is inconstant for every RDCs and it does not follow any specific pattern.

Regarding the previous Note, it is known that it can not be shipped more quantity than what it is demanded from RDCs, as they have no possibility to store it. The process sends, as it works right now, exactly the amount needed everyday, so transportation changes also day by day.

As CDCs receive uniform receipts and ship different quantity everyday, their occupancy is variable over the year. However it never reaches rates close to full occupancy or zero level.

Demand and occupancy levels

Regarding the expected values of demand in each for channels of the logistics network, a graphic representation is done to help the understanding of the important market points and its distribution.

First of all, in Table 2.3 the total amount of expected demand is shown by country and by hub/CDC regardless its type. This means that these quantities appearing in the table are the sum of Part A, B and C products.

TABLE 2.3: Product demand for each of the locations.

Hub	Denmark	United States	Brazil	China
Hub 1	2.6 M	4.0 M	20.0 M	138.0 M
Hub 2	8.2 M	4.0 M	4.0 M	12.6 M
Hub 3	6.7 M	4.0 M		122.5 M
Hub 4	8.5 M	4.0 M		
Hub 5	3.7 M	4.0 M		
Hub 6	6.0 M	4.0 M		
Hub 7	5.6 M	4.0 M		
Hub 8	1.0 M	4.0 M		

There are several notes to remark from the previous table. For example, that the expected total demand for all eight CDCs in United States is the same one. However, this does not mean that their dimensions and capacities are also equal and, as it can be seen in Table 2.10 they have different storage limits.

It is also commendable, the fact that there are two CDCs with a much bigger market and demand than the rest and they are both located in China, supplying to all Asia and Oceania. To a lesser extent, there is also another CDC with big market in Brazil.

Finally, it is significantly particular the fact that, in United States and Denmark, there are up to 8 CDCs to cover the business and all of them ship similar amounts and small compare to Brazil and China, where only 2 and 3 centers supply a very wide and demanding area.

(A) *United States products demand.*

(B) *Denmark products demand.*

(C) *Brazil products demand.*

(D) *China products demand.*

FIGURE 2.9: Annually product expected demand for each of the CDCs reprensented by ptroduct type.

In Figure 2.9, demand in each CDCs is split by product type. In the statement was already mentioned, but with the graphic it can be seen how, apart from Denmark, all CDCs supply and store all three kinds of products. On the other hand, there are some CDCs in Denmark that are in charge to deal with the demand of only one or two products e.g. Esbjerg providing only Part A products.

It is also quite particular how there are two very demanding and big centers in China (Chongqing and Beijing with total demands of 138 and 122.5 million units per year respectively) and another CDC which is very small in comparison. This is mainly because this last center is particularly designed to cover the demand from the important market of India and its capacity is adapted to the expected demand from that special market.

Although production is currently adjusted and designed to manufacture based on the expected demand, the infrastructure is prepared to changes in the market. All four Production Center are capable to increase productivity in case it was necessary, but some have more room for manoeuvre than others.

NOTE: Not only can Production Center increase the productivity of a product type to the top capacity, but also if it was needed, a manufacturing line can be modified so it starts producing another product type than before using the same machining tools.

Regarding the MWs activity, the maximum storage capacity of each four centers is detailed in the right column of Table 2.4, where we see how in Shangai it can be store three times more products than in the rest of centers. These limits may play a role for the optimization scenarios, but the current performance of the process, using rates of all warehouses do not vary from 50% of usage in each of them.

TABLE 2.4: Production and warehouse capacity for each of the locations.

Location	**Production Capacity**			**Warehouse Capacity**
	Part A	Part B	Part C	
Atlanta	12.5 M	11.8 M	13.1 M	20 M
Aarhus	20.0 M	15.0 M	15.0 M	20 M
Rio de Janeiro	14.0 M	10.4 M	9.4 M	20 M
Shangai	90.2 M	98.0 M	93.4 M	60 M

Although it will be further analyzed and explained in detail in Section 2.3, in the following Table 2.5 and Figure 2.10 it can be noticed which is the usage rate of the production centers and the potential possibility to increase these percentages.

In this first table two parameters can be compared; the first one is the total number of units of each product type manufactured in each PC, and the second one is the percentage that the rate represents over the total production capacity.

TABLE 2.5: Production rates of each of the four Production Centers expressed by total units and percentage used

Location	**Production Rate** [*units*]			**Capacity used** [%]		
	Part A	Part B	Part C	Part A	Part B	Part C
Atlanta	10.0 M	10.5 M	11.5 M	80.00%	88.98%	87.79%
Aarhus	17.2 M	12.55 M	12.55 M	86.00%	83.67%	83.67%
Rio de Janeiro	9.8 M	6.7 M	7.5 M	70.00%	64.42%	79.79%
Shangai	88.9 M	94.4 M	89.8 M	98.56%	96.33%	96.15%

Both table and graphic show how Production Center of Shangai (China channel) is very near full capacity in all three product lines, while in the other three countries is closer to 75-80%. However the margin to increase productivity is similar or even larger that in other centers. The difference is that, since production in this center is much larger, the perceptual increasing available is not much representative.

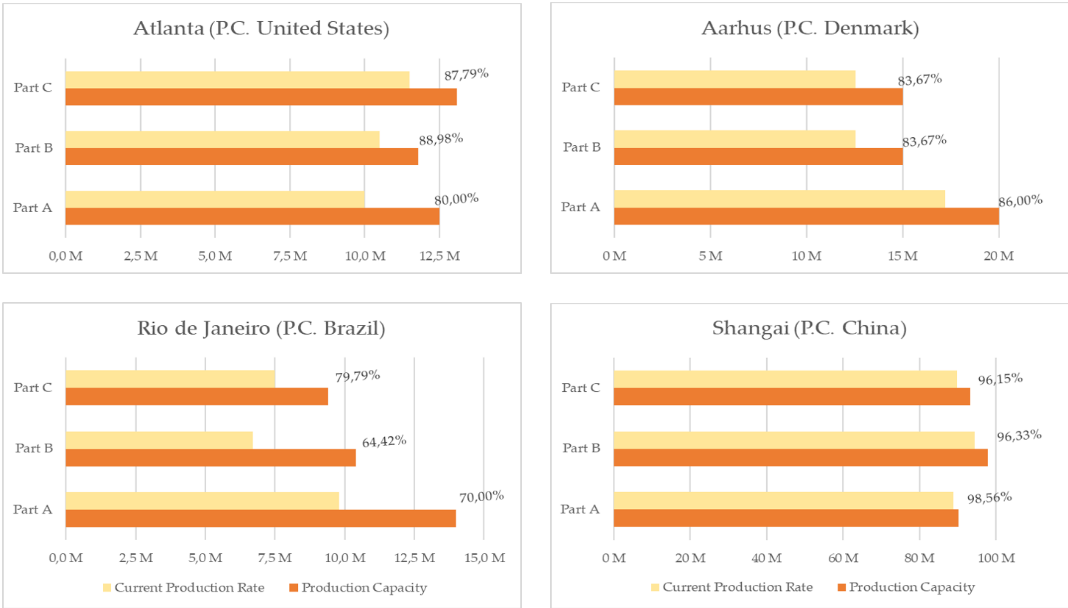


FIGURE 2.10: Production rates over capacities in each PC.

Further analysis and optimization scenarios based on production will take these quantities into consideration together with the unitary costs derivatives of manufacturing, which are explained in Subsubsection 2.2.3.

Once the main aspects of how the logistics network performs and which sequences and connections take part in the entire chain, it is time to use the information researched in Chapter 1.

When we explained the typical global logistics network configurations which are based in sea shipping transportation, it was shown how there are five different main patterns followed by logistics managers. The shipping procedure of this network has clearly several similarities with some of those configurations, but also some specific differences.

In all the explained configurations, only one consolidation hub is considered both upstream and downstream the sea shipping. However, in this case, there are two consolidation centers upstream (near suppliers) which are the Main Warehouses and the Central Distribution Centers. On the other hand, there are no consolidation hubs after the sea shipments are done (downstream).

Figure 2.11 represents schematically the configuration of one channel in the network. Characterized for having only one very big manufacturing center for each channel in the network, produced parts are shipped to another big and central storage center such as the Main Warehouse.

Another remarkable fact is that, after the lots go through the CDCs, they do not all have an assigned specific loading port. They are generally sent to the port that facilitates the shipment to its destination. This was meant to shorten the travel sea shipping distances the maximum possible. However, it also forces the involvement of much more logistics operations and personal in many ports. The more the operations are spread in different places, the hardest it is to manage and guarantee the control of quality and time of every lot.

Then, after the sea transportation is done, each lot is unloaded in the closest port to its destiny. In general, distances between customers and RDCs are very large so it is not possible to have a common unloading port downstream.

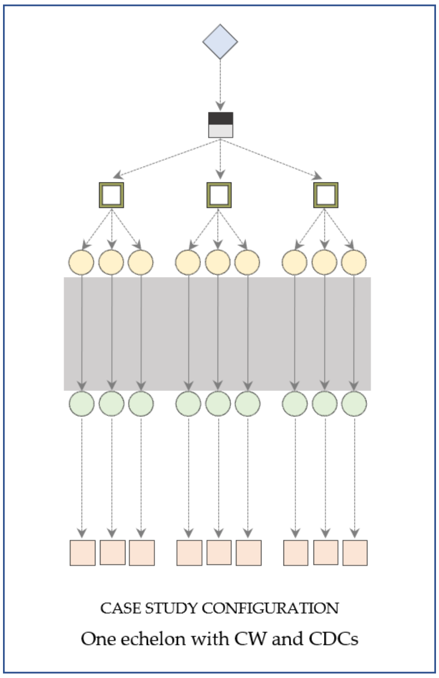


FIGURE 2.11: Logistics networks description of the analyzed global case

Usage rates of the storage capacity of Main Warehouses does not vary among the time as the network performs nowadays. This is because the units the center receives daily match with the ones that are sent - the demand of a year is divided by the number of days equally and constantly manufactured and shipped to these centers.

However, regarding the occupancy levels in the Central Distribution Centers, some flow-rates have been obtained from the analysis, and they help us to get an overview of how there are used during all year long. It is also useful to see which is the margin available to store more or less quantity depending on the needs of the system.

Figures 2.12, 2.14, 2.15 and 2.13 show respectively the evolution of CDCs occupancy rates during the year. In general, variations are not very relevant or determinant since none of the storage centers reach points close to the full capacity limits at all.

Because of this, in hypothetical future studies of the structure of the network components, it could be interesting to see if the company is paying extra costs by having more CDCs than what are really needed. This, of course, would be compared assuming that the demand do not change.

Having always in mind that geographical conditions will determine its viability, in a few cases it might be interesting to close one CDC and storage in those that are next to it the products which were previously kept in that CDC. The advantage that this could bring is to save the maintenance cost of operating in the CDC warehouse during the year, the fixed cost. Since there will be probably space enough to put these products in the surrounding CDCs, it will be a matter of checking if the rent cost it is being saved is greater that the extra cost derived from longer transportation distances.

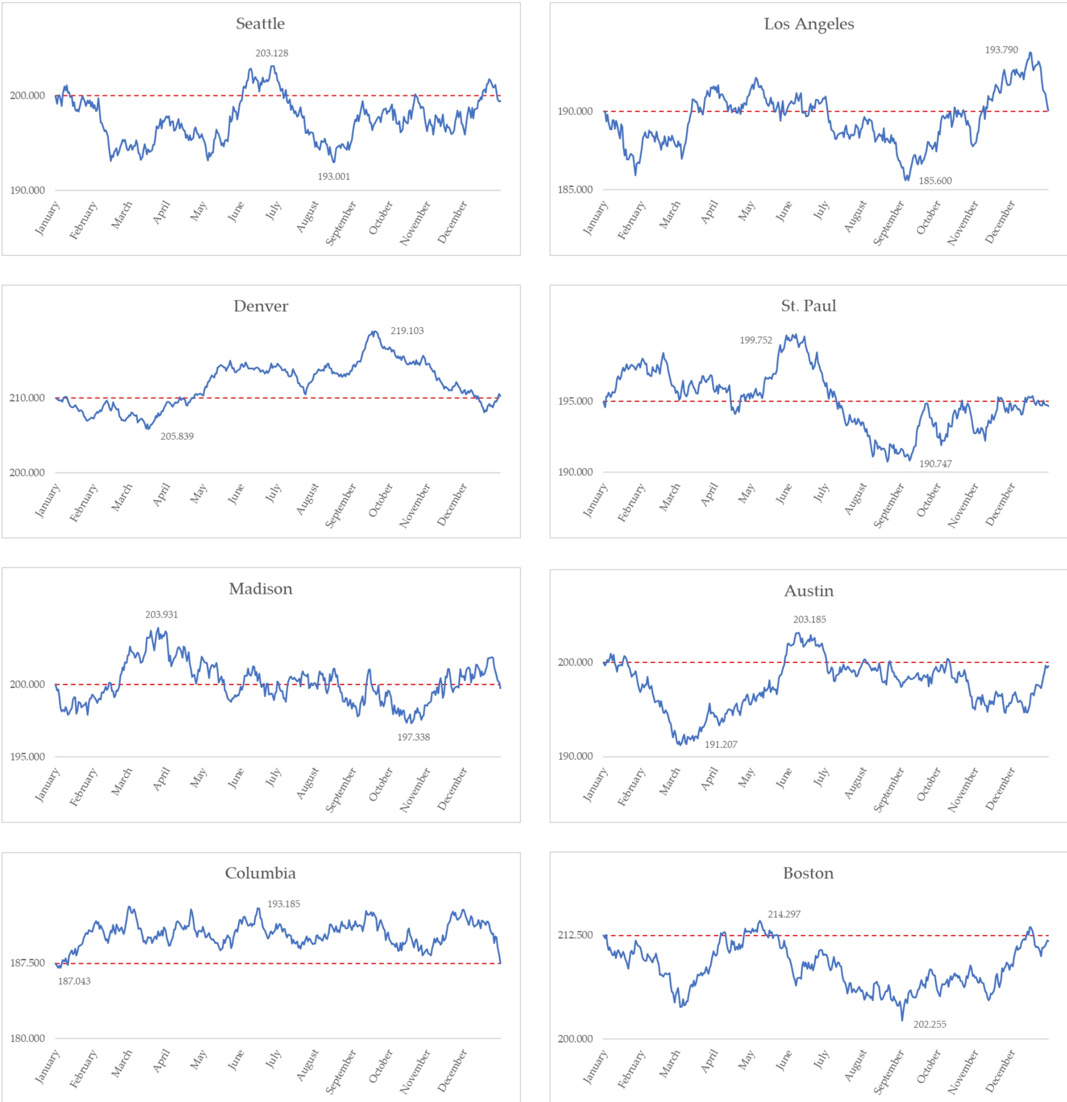


FIGURE 2.12: Levels of occupancy among all 8 CDCs in United States during a year.

FIGURE 2.13: Levels of occupancy among all 3 CDCs in China during a year.

FIGURE 2.14: Levels of occupancy among all 8 CDCs in Denmark during a year.

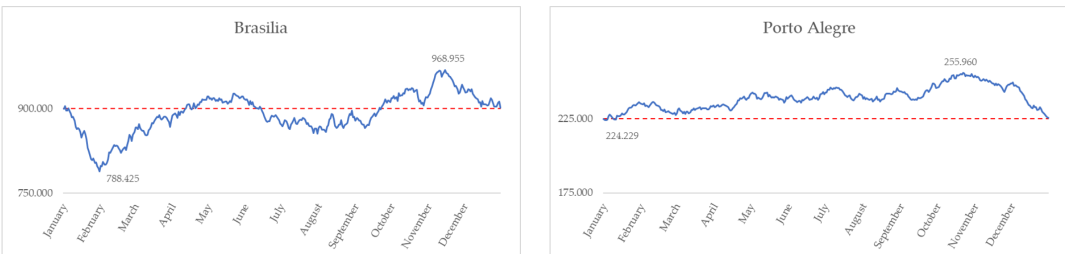


FIGURE 2.15: Levels of occupancy in both CDCs in Brazil during a year.

As a complement to the graphics shown above, Table 2.6 help us to compare numerically what are the different status of each intermediate warehouses and what is the capacity that it is not being used with the model as it is right now.

TABLE 2.6: Central Distribution Centers usage levels

CDC	**Initial Usage**	**Extreme points**		**Capacity**	**Margin available**	
	[*units*]	[*max*]	[*min*]	[*units*]	[*units*]	[%]
Seattle	200.000	203.128	193.001	400.000	196.872	50.78
Los Angeles	190.000	193.790	185.600	380.000	186.210	51.00
Denver	210.000	219.103	205.839	420.000	200.897	52.17
St. Paul	195.000	199.752	190.747	390.000	190.248	51.22
Madison	200.000	203.931	197.338	400.000	196.069	50.98
Austin	200.000	203.185	191.207	400.000	196.815	50.80
Columbia	187.500	193.185	187.043	375.000	181.815	51.52
Boston	212.500	214.297	202.255	425.000	210.703	50.42
Aarhus	150.000	155.960	146.743	300.000	144.040	51.99
Skagen	400.000	415.018	397.913	800.000	384.982	51.88
Aalborg	325.000	340.612	313.378	650.000	309.388	52.40
Esbjerg	450.000	457.775	361.566	900.000	442.225	50.86
Abenra	250.000	289.033	249.584	500.000	210.967	57.81
Odense	300.000	304.517	273.159	600.000	295.483	50.75
Roskilde	275.000	278.532	251.139	550.000	271.468	50.64
Copenhagen	75.000	81.190	73.009	150.000	68.810	54.13
Brasilia	900.000	968.955	788.425	1.800.000	831.045	53.83
Porto Alegre	225.000	255.960	224.229	450.000	194.040	56.88
Chongqing	5.825.000	5.841.336	5.192.561	11.650.000	5.808.664	50.14
Guangzhou	600.000	613.759	558.686	1.200.000	586.241	51.15
Beijing	5.200.000	5.412.280	4.578.856	10.400.000	4.987.720	52.04

2.2.2 Transportation channels analysis

Dealing with a worldwide logistics network leads to a crucial effect of transportation channels. An efficient, consistent and optimized supply channels can lead to considerable benefits and cost reductions. This subsection aims to detail deeply how do transportation work in the current network and to find possible ideas of how it could be improved.

NOTE: As mentioned in other parts of the experimental optimization, all three product types have same size and weight, so they do not have an influence in transportation or storage. Not only that but every package have cube shapes.

Other considerations:

- Trucks storage capacity: 36 m^3
- Unitary package volume: 0.072 m^3
- Package length, width and height: 42 cm
- Ship container length: 6.058 m
- Ship container width: 2.438 m
- Ship container height: 2.591 m

Packages per truck: 500 units

Packages per ship container: 420 units

Once it is known how many packages fit into the transportation services and regarding the considerations of the work-flows explained in the Subsection 2.2.1, it is possible to predict the amount of trucks/ships needed for each supply channel among the year.

The first step when analyzing the transportation routes was comparing for each channel connection the relation between distances and supply amounts. To do so, it was represented both the total sum of trucks/ships needed during one year and the kilometers that each truck/ship had to drive along for each time.

The aim of doing this is to find which are the most important routes in both demand and distance. Some might be very demanding but distance between supplier and intermediate center or customer very short; others can be very far from each other but barely non used. When there is a peak of both parameters compared it will mean that those routes are supplying to important customers and are the main objectives to reduce total transportation cost.

Also, although it is not the purpose of this thesis, finding the biggest customers and market influences would help the company when deciding potential geographic re-distributions of the centers that compose the network.

In this first graphics below (Figure 2.16 and Figure 2.17), they are shown the connections between each PC with the MW and all four MWs with their connected CDCs respectively.

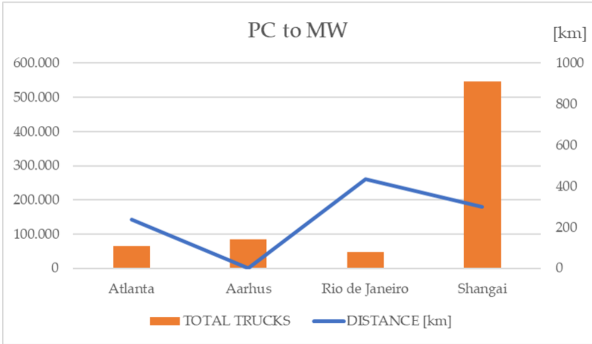


FIGURE 2.16: Trucks needed in a year and route distance between PC and MW connections.

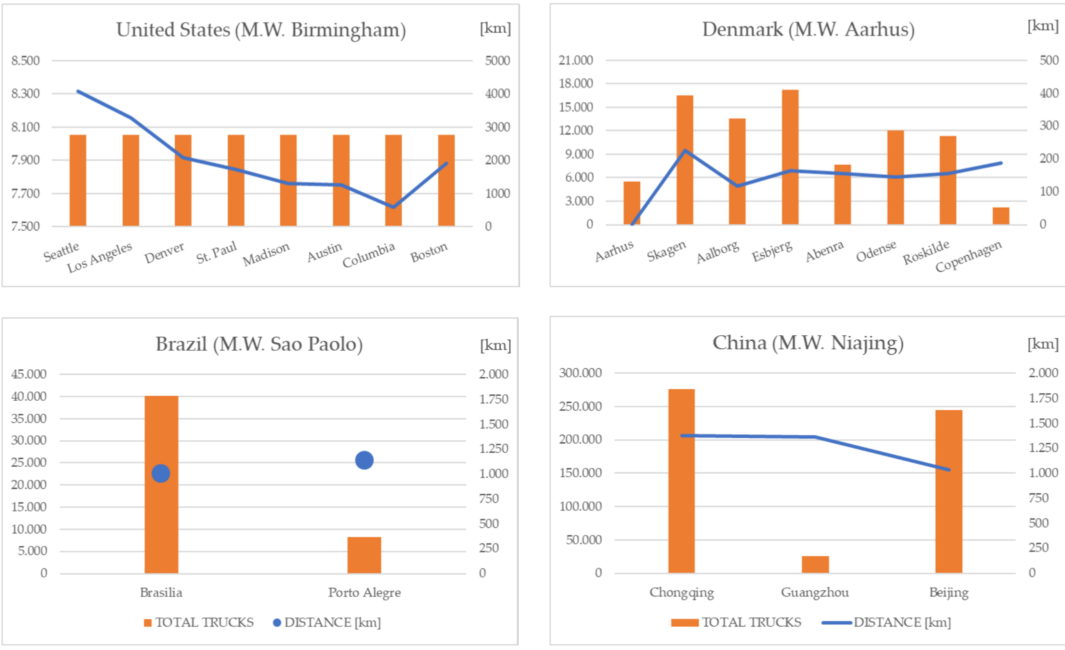
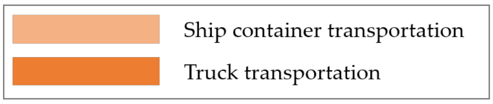


FIGURE 2.17: Trucks needed in a year and route distance between MW and CDC connections.

In the distance scale in kilometers comparison between all four countries, it is seen that the two longest routes are by far from Birmingham (US) to Seattle and Los Angeles respectively. Distances within Denmark are very short and these routes quite cheap compare to others. On the other hand, although distances from Nanjing (China) to Chongqing and Beijing are not extremely long, the fact that so many packages are shipped makes this routes very important and its performance especially interesting for the optimization.

Then, the connection between CDCs and RDCs for each four network channels is explained in Figures 2.18, 2.19, 2.20 and 2.21.

To help with the proper understanding of the following graphics, a simple caption is added below. The strong orange columns will correspond with the routes that are shipped by road, so in truck. Those columns which are coloured with a lighter orange represent transports done by sea.



Differentiate between the two types of transportation in the graphic is very relevant. Sea transportation requires generally larger distances and more time because of geographical reasons and its very nature. Besides that, very high peaks with sea transportation are relatively not as important. The reason is because, as it is shown later in Table 2.11 and Figure 2.29 sea transportation lead to much cheaper expenses.

FIGURE 2.18: Total number of trucks needed in a year and route distance between all 8 CDCs in United States and their respective RDCs.

Focusing first in Figure 2.18, it is seen that the longest distances appear mainly in the connections from Austin (to Mexico DF, Merida and Guadalajara distance is above 1500 kilometers). However, as it will be seen in the following figures, compared to the connections of the other 3 channels, distance are quite shorter and, therefore, more irrelevant for our optimization.

Regarding the number of packages sent to each RDC, we can see that there are not extremely high peaks. The higher amount of trucks needed in a year reach up to almost 4000 in the connections to Calgary, San Francisco, Salt Lake City, Kansas City and Fargo.

Production from United States is only supplied to North America and the north part of Mexico. Although it is a wide area covered, it is not as big as the other three channels. That, together with the fact that there are up to 8 CDCs spread around the United States territory, make distances shorter in this last transportation stage.

FIGURE 2.19: Total number of trucks needed in a year and route distance between all 8 CDCs in Denmark and their respective RDCs.

When analyzing Figure 2.19, some combined peaks of demand and distance are found. Considering only distance, the longest distances from their related CDCs are to Astana, Marrakech, Rabat and the RDCs located in the Middle East. Besides that, the only route among all of these that is quite demanding is the connection between Roskilde and Tel Aviv, with nearly 1500 trucks needed per year.

In terms of market demand, there are mainly three destinations which are much more relevant than the others: Brussels, Barcelona and Paris is this order. There is the circumstance that these three RDCs are located in very important cities, and that their connections with their respective suppliers are quite short and through main roads all the way. Maybe it should be paid a bit more attention the one to Barcelona because it is further than the others, but it should not be much margin to optimized in these three routes.

In Brazil, (Figure 2.20) there is a different scenario than the previously mentioned in United States and Denmark. The fact that there are only two distribution centers means that they cover very little area and that increases transportation costs quite a lot. Not only that but also some poor infrastructures and land obstacles make that although some straight distances are not so long compared to other continents, in reality trucks take much more time and distance to provide materials to customers.

Moreover, demand in some RDCs is much higher than before, making this routes specially interesting for optimization. Particularly, from Brasilia there are three connections that buy quite a lot of products and are very far at the same time. These are Bogota, Quito and Panama, located on the top of South America and Central America, where the access from the Easter part of Brazil is poor because of having the Amazon in between.

Lastly, it may be interesting to analyze the cost of shipping to South Africa, specially to Johannesburg. Since the distance is so long and demand quite high, although it is a sea channel shipping, it could lead to considerable expenses.

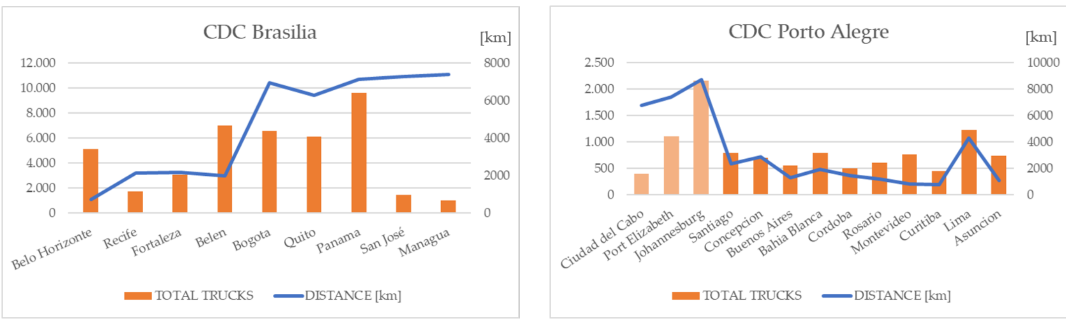


FIGURE 2.20: Total number of trucks needed in a year and distance traveled in every journey between the 2 CDCs in Brazil and their respective RDCs.

Talking now about the channel from China, there is clearly a need of optimizing as much as possible its connection, since here it is where most of the company´s total world-wide production is manufactured.

Looking at Figure 2.21, it is specially remarkable the amount of trucks needed from the CDCs of Chongqing and Beijing. However, the main objective it is clearly connections from the first one.

CDC Chongqing is intentionally designed to supply just the demand from India, which is very significant. Packages are sent only to three different RDCs and that is why each route gains an ever more significant role, because they are very frequented.

In the shipping to India, it appears also a critical geographical problem that is having a mountain chain so huge in between origin and destiny. Again, this fact leads to very long transportation distances and costs. To avoid paying so much extra money, the company has previously decided to send every order by sea. Of course, this derives into a larger shipping time but the cost benefits are so big that it is much better this way.

In the rest of connections the order are mostly also sent by ships. However, in this cases, this is only because of geographical reasons.

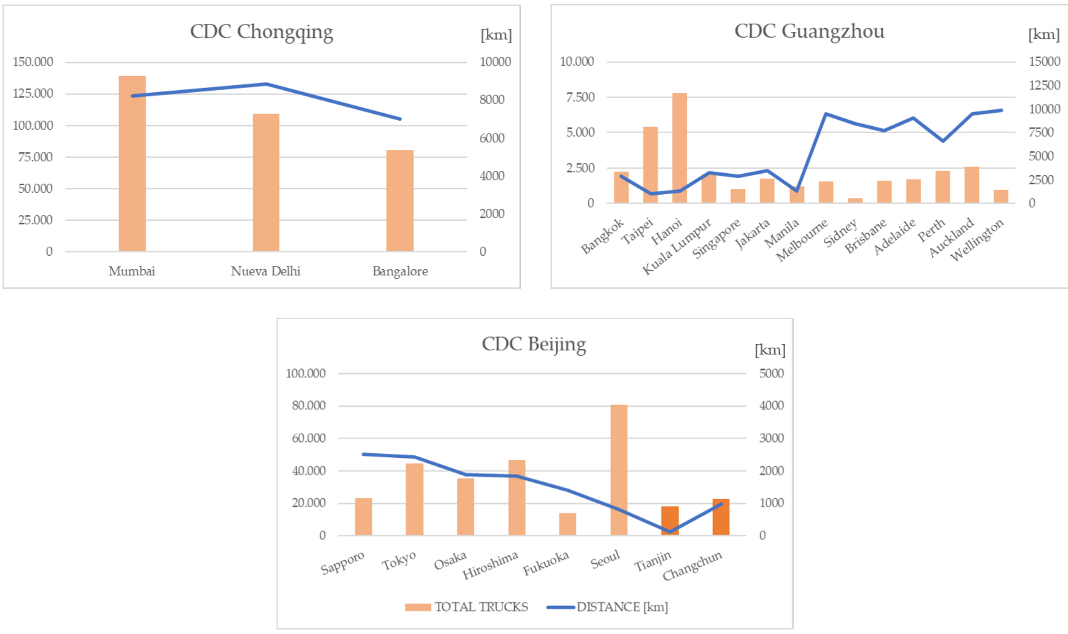


FIGURE 2.21: Total number of trucks needed in a year and distance traveled in every journey between the 3 CDCs in China and their respective RDCs.

2.2.3 Cost set-up

In this subsection, what it is to be detailed is the explanation of the existing costs in which the company incurs annually and their effect in the total cost distribution and investment.

Previous to anything, it should be mentioned that setup costs are mainly divided into three areas which are Production, Storage and Transportation.

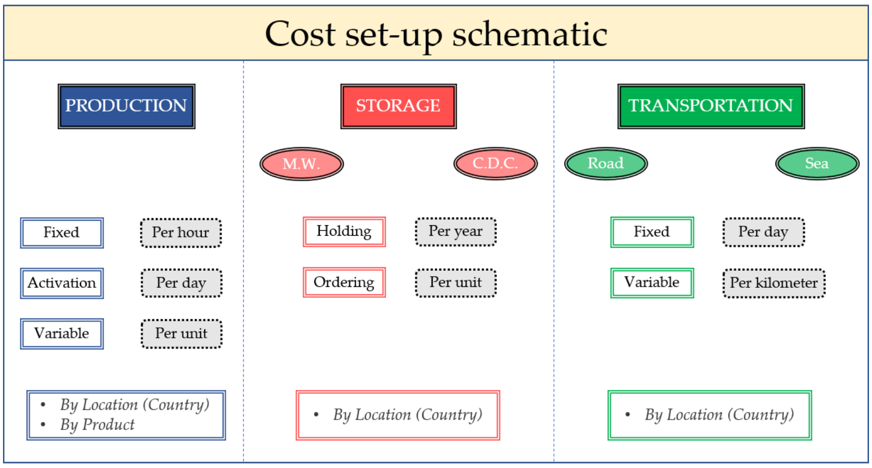


FIGURE 2.22: Cost set-up schematic explanation

In Figure 2.22 the three main groups mentioned are represented together with the cost division each of them include.

Costs vary depending mainly on the location where business is taking part. However, as it can be seen in the lower part of the schematic, in the production phase costs also change depending on the product type it is being produced. This is predictable as each product has its own requirements, equipment needed and its manufacturing process is different, which leads to various fabrication costs.

The reason why the product type does not determine the following stages (storage and transportation) is because, as it was commented in the initial statement, the volume of the already-packaged final product is exactly the same for all three parts. That, together with the fact that the weight variation is so little that it can be neglected, outcomes with the fact that product type do not influence storage and shipping costs.

Production costs

Table 2.7 brings up the three costs that appear in the production level. They are not referred to the same time basis and even one depends on the amount of units produced and not at all in the time elapsed.

Firstly, Fixed cost it is the amount to pay for having the system turned on per hour. It is accordingly related to the volume of production and it may be considered to fabricate the maximum in those centers where is cheaper.

Activation cost refers to what it is to pay daily if the system is used at anytime. Energy, employees, security and many other costs are included here and in order to limit the cost the most, it is desirable to produce full capacity during the minimum amount of days if we only focus in this parameter.

The third cost (Variable) is basically the unitary cost. It takes into account how much it cost to do one unit, considering raw material, manufacturing, packaging and so on.

TABLE 2.7: Production set-up costs based on location of the PC and product type.

Location	Product	Fixed [€/h]	Activation [€/day]	Variable [€/unit]
Atlanta	Part A	1450	34350	4.97
	Part B	2124	48050	9.65
	Part C	1555	28940	4.19
Aarhus	Part A	2130	45980	6.36
	Part B	3695	59870	10.56
	Part C	2015	39990	4.86
Rio de Janeiro	Part A	1080	26095	3.91
	Part B	1870	28050	8.02
	Part C	1180	16800	3.60
Shangai	Part A	1445	39900	2.94
	Part B	2575	49575	9.52
	Part C	2975	29050	5.09

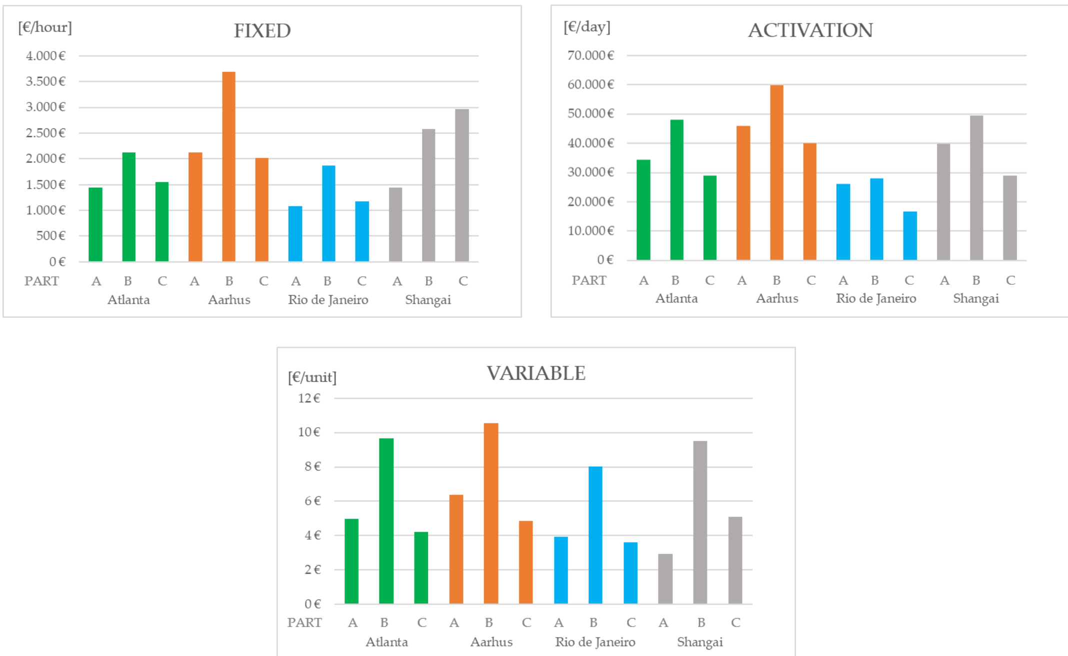


FIGURE 2.23: Production costs (fixed, activation & variable) detailed by country and product type.

In Figure 2.23 the comparison between the three production costs in all four production channels is shown.

The general tendency in the graphics shows that the most expensive product to manufacture is Part B, followed by Part A and Part C respectively. The unitary cost (Variable) is quite similar between all centers but it can be seen that United States and Denmark are a little higher prized than Brazil and China.

Yet, these costs are represented unitary by hour, by day and by unit respectively. Activation cost is expected to play a big role in the final production cost and the reason of this is the fact that it does not depend on production rates. Since this cost component only considers if the fabrication process is activated through one day, the biggest production rate will redeem this daily payment more than other that is barely producing any products.

Consequently to this, and because China has a much higher production capacity and need, it is expected that the cost of producing one unit will be lower than any other country of all four.

Storage costs

In this second group of the logistics chain, costs are considered for both MW and CDC storage phases.

Warehousing total cost is subdivided by two different payments. The first one, which we call Holding cost, looks at the expenses derived from maintaining the warehouses operating during all year long. On the other hand, Ordering cost takes into account the charge of receiving, classifying and putting in place each of the orders taken and shipped.

TABLE 2.8: Central Distribution Centers set-up storage costs based on location of the C.D.C.

Country	**Location**	**Holding** [€/*year*]	**Ordering** [€/*unit*]
United States	Seattle	354230	0.0415
	Los Angeles	666790	0.0420
	Denver	660550	0.0414
	St. Paul	872445	0.0419
	Madison	555290	0.0425
	Austin	657890	0.0422
	Columbia	558220	0.0405
	Boston	443300	0.0409
Denmark	Aarhus	605000	0.0560
	Skagen	694850	0.0550
	Aalborg	679800	0.0560
	Esbjerg	700220	0.0565
	Abenra	690900	0.0580
	Odense	720430	0.0560
	Roskilde	676500	0.0520
	Copenhagen	662200	0.0570
Brazil	Brasilia	1013350	0.0300
	Porto Alegre	456800	0.0298
China	Chongqing	4399000	0.0190
	Guangzhou	882000	0.0205
	Beijing	3442500	0.0210

TABLE 2.9: Main warehouse set-up storage costs based on location of the M.W.

Location	**Holding** [€/*year*]	**Ordering** [€/*unit*]
Birmingham	1025450	0.043
Aarhus	1240050	0.056
Sao Paolo	775460	0.029
Nanjing	2455500	0.018

Both graphics representing the ordering costs in MW and CDCs show a similar tendency than the ones describing the manufacturing process. Storage is more expensive in Denmark and is the cheapest in China.

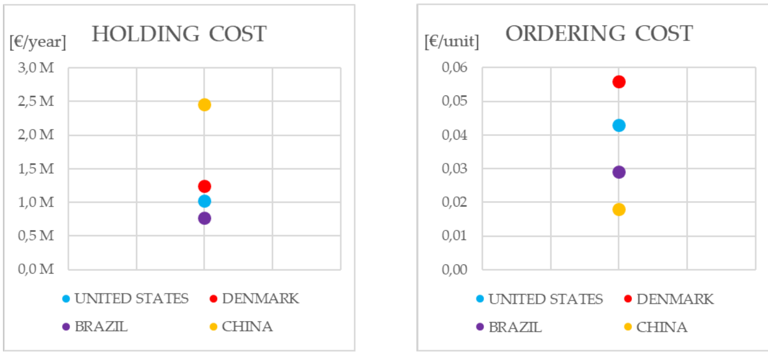


FIGURE 2.24: MWs storage costs (holding and ordering) represented by country.

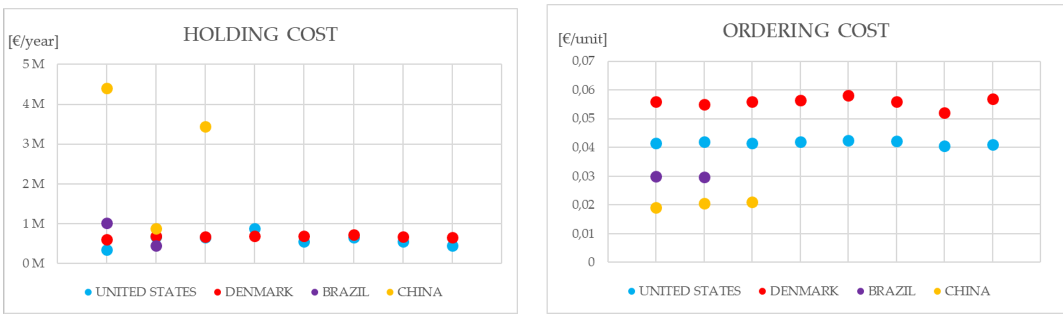


FIGURE 2.25: CDCs storage costs (holding and ordering) represented by country.

However, the two graphics from Figure 2.24 can be a bit confusing if they are not well explained. Apparently, it looks as if the amount to pay in China is the highest of all MWs/CDCs stations respectively.

However, it is convenient to remember that the holding cost is the sum of money that the company pays annually as a rent or as a credit in case they own it. Therefore, although it is expected to have a similar tendency as other cost components (China is in general the cheapest and Denmark the highest prized), holding costs may vary a lot for each storage center.

The main factor that influences directly the annually holding cost is the MW/CDC storage capacity. The more capacity the biggest the center needs to be, and consequently, the maintenance of it will require more employees and money invested.

To show more clearly the influence of capacity in the Holding costs some complementary information from Figures 2.26, 2.27, 2.28 and Table 2.10 has been added.

In the first two figures, the intention is to show that there is a direct link between storage capacity and holding costs.

Figure 2.26, for example, proves that those main warehouses with the same capacity (United States, Denmark and Brazil) have similar holding cost. Of course there are differences because expenses are now equal in all three countries and, once again, Denmark is more costly than United States and Brazil. The capacity in China is three times bigger and the holding cost nearly three times bigger.

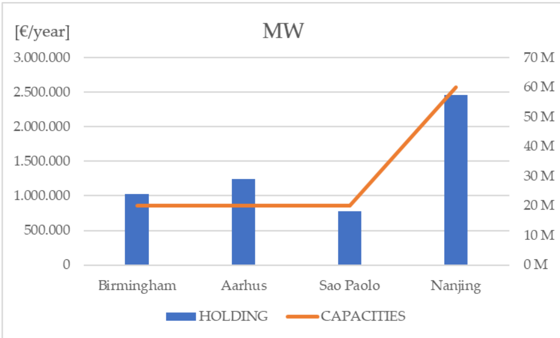


FIGURE 2.26: MWs holding costs and capacity comparison

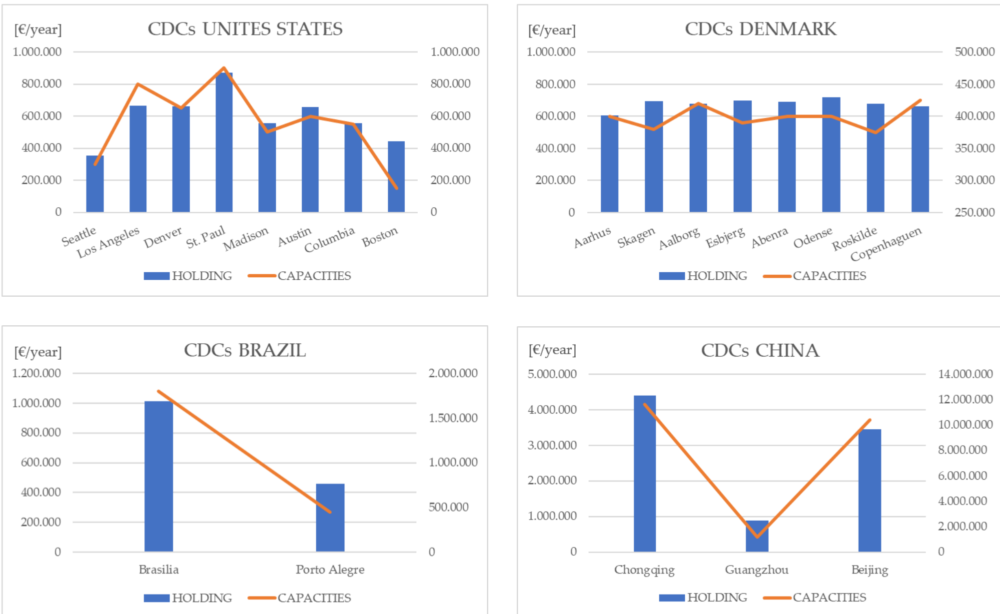


FIGURE 2.27: CDCs holding costs and capacity comparison by country

If we divide the holding cost between the total capacity, we can weight and compare a bit more realistically the expenses of all four countries. Starting with the main warehouses, we obtain the following ratios:

- Denmark: 0.062
- United States: 0.051
- China: 0.041
- Brazil: 0.039

With so, we can confirm what it was supposed before; expenses in China are lower than in other places considering the same amount of storage used.

Doing the same process with all the CDCs we obtain the following Figure 2.28. This graphic put together the information obtained in Figure 2.27. In this case, we can see that some warehouses maintenance are slightly more expensive in United States than in Denmark. However, there are some exceptions like CDC Copenhagen, where the capacity is quite small but the holding cost is not and, therefore, the ratio is the highest among all other CDCS.

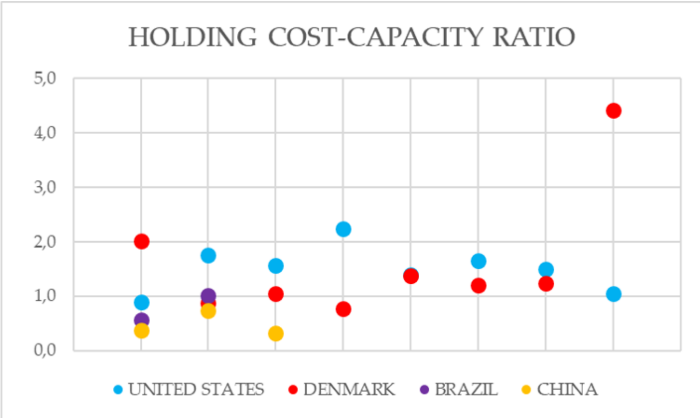


FIGURE 2.28: CDCs holding costs and capacities ratio

TABLE 2.10: Holding cost and CDC total capacity cost relation

Country	Location	Holding [€/*year*]	Capacity [€/*unit*]	Ratio
United States	Seattle	354230	400000	0.89
	Los Angeles	666790	380000	1.75
	Denver	660550	420000	1.57
	St. Paul	872445	390000	2.24
	Madison	555290	400000	1.39
	Austin	657890	400000	1.64
	Columbia	558220	375000	1.49
	Boston	443300	425000	1.04
Denmark	Aarhus	605000	300000	2.02
	Skagen	694850	800000	0.87
	Aalborg	679800	650000	1.05
	Esbjerg	700220	900000	0.78
	Abenra	690900	500000	1.38
	Odense	720430	600000	1.20
	Roskilde	676500	550000	1.23
	Copenhagen	662200	150000	4.41
Brazil	Brasilia	1013350	1800000	0.56
	Porto Alegre	456800	450000	1.02
China	Chongqing	4399000	11650000	0.38
	Guangzhou	882000	1200000	0.74
	Beijing	3442500	10400000	0.33

Transportation costs

Last classification of costs is related to transportation. To explain it, it is important to remark that the existing logistics network only considers road and sea transportation.

In following analysis, other transportation scenarios may be taken into action but, for now, trucks and ships are doing all the work. Generally, reasoning who ships in a channel is a matter of geographical conditions. Another remarkable information is the fact that carriage is outsourced to an external company and, therefore, payment conditions are imposed by them.

Transportation includes two kinds of payments. The first one, which is fixed in a daily scale, concerns about the operation time that one single transportation needs. It is the amount to pay for renting the serving during one day. In this case, those channels that need a time near 24 hours but a bit lower are more optimal than those which only take a few hours or need little extra than 24 hours for example, as the cost is fixed as long as it is used at any time during a day.

> NOTE: It is assumed that they are all round trips. Instead of multiplying the time needed for each transportation, daily cost has been multiplied by two for the calculation.

The second cost refers to transportation distances. This one is directly related to the gas costs and, therefore, it can vary a long among the year. However, for this study, it is assumed that is unchanging during over the year.

TABLE 2.11: Road and Sea transportation set-up detailed for each of the four countries involved

Location	**Road Transportation**		**Sea Transportation**	
	Fixed [€/*day*]	Variable [€/*km*]	Fixed [€/*day*]	Variable [€/*km*]
United States	190	0.21595	135	0.0505
Denmark	305	0.54040	200	0.0610
Brazil	145	0.35465	125	0.0458
China	95	0.33215	110	0.0404

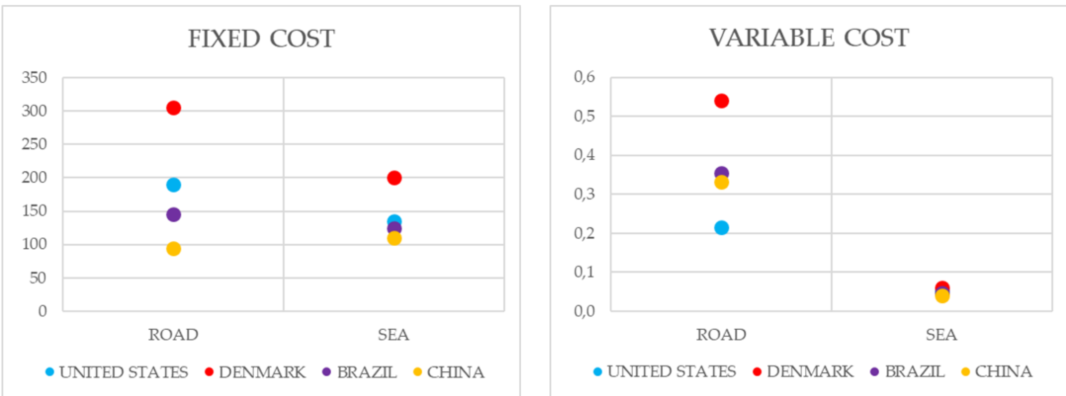


FIGURE 2.29: Transportation costs (fixed & variable components) by country.

Figure 2.29 shows the distribution of costs among all four countries involved. The main two facts we see are that sea transportation is considerably cheaper than road (more time consuming) and secondly, that sending from China and United States is still cheaper than the other two countries considering transportation.

NOTE: Most of the transportation routes are internationally. Yet, the company in charged of the shipping in local for each of the four countries. In case it was needed to refuel in another country during the transportation, the assumption is that it would cost the same amount of money as the initial deposit filling

2.2.4 Cost analysis and potential improvements of the network

Once the existing performance of the network is explained including geographical distribution, shipping channels and cost analysis, a numerical analysis of the distribution of payments is carried out.

TABLE 2.12: Cost summary for the set-up model

Location	**Production**	**Storage**		**Transportation**		
		MW	CDCs	PC → MW	MW → CDCs	CDCs → RDCs
US	273.41 M	3.77 M	7.42 M	15.43 M	43.48 M	23.78 M
Denmark	405.24 M	5.97 M	10.12 M	0	31.72 M	141.42 M
Brazil	163.08 M	2.16 M	2.90 M	14.45 M	24.56 M	60.36 M
China	1717.98 M	12.27 M	19.61 M	106.54 M	273.83 M	474.50 M
Total	2559.72 M	24.18 M	40.07 M	136.43 M	373.61 M	700.09 M

After all, the total expenses of one year activity goes up to **3.834.120.520 €** with the current performance of it.

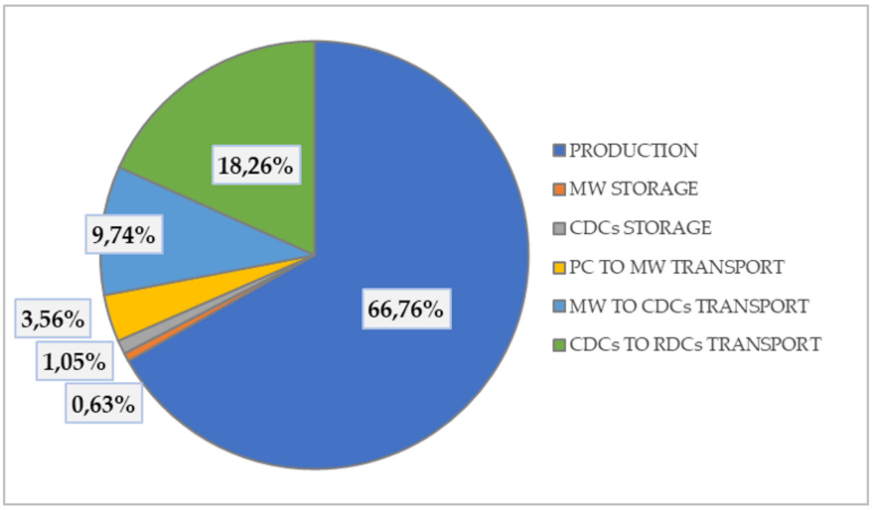


FIGURE 2.30: Cost summary according to the set-up model

The distribution by percentage of the different costs by type is shown in Figure 2.30. It can be seen how production drifts two thirds of the total amount and how storage has barely no influence comparing the total payments. This is the reason why the main goal of the following optimization scenarios is going to be obtaining a cost reduction in either transportation and production, where little changes can have a bigger impact.

In Figure 2.31, the division of the total cost is done by country instead of activity. The result is that now, more or less two thirds of the total is paid because of China production.

The explanation to that fact is very intuitive and directly connected to the volume of sales in each four markets.

Total demand in China goes up to 273.100.000 units, which represents around 73.5% of all the sales worldwide combining all four channels.

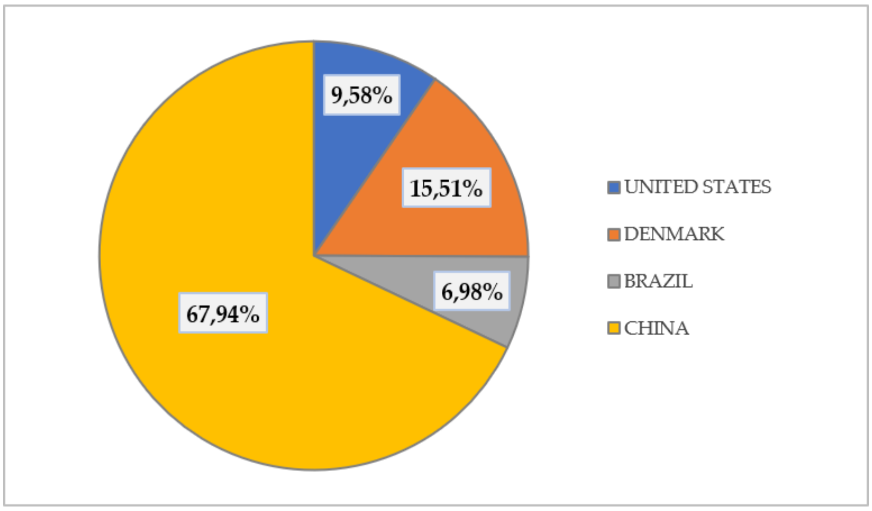


FIGURE 2.31: Cost distribution by country according to the set-up model

Figure 2.32 help us to understand the numerical relation between the total volume of activity and the total expenses.

In the subsection 2.2.3 where we detailed how costs are set up, it was proved how, in general, there was a tendency in which all unitary costs or costs by unit of time where following similar patterns: China was the cheapest, followed by Brazil and United States and Denmark was the most expensive one in general. What it is seen in the graphic is that, by far, China is in effect the most economical solution among all four. The percentage in the demand scale is 5.6% greater than the one of costs, while in the other locations are all lower.

To conclude, from a general perspective analysis by country, it can be said that the closer productivity could get to full capacity the more profitable the solution would be, as long as the expenses in transportation do not raise too much to compensate it.

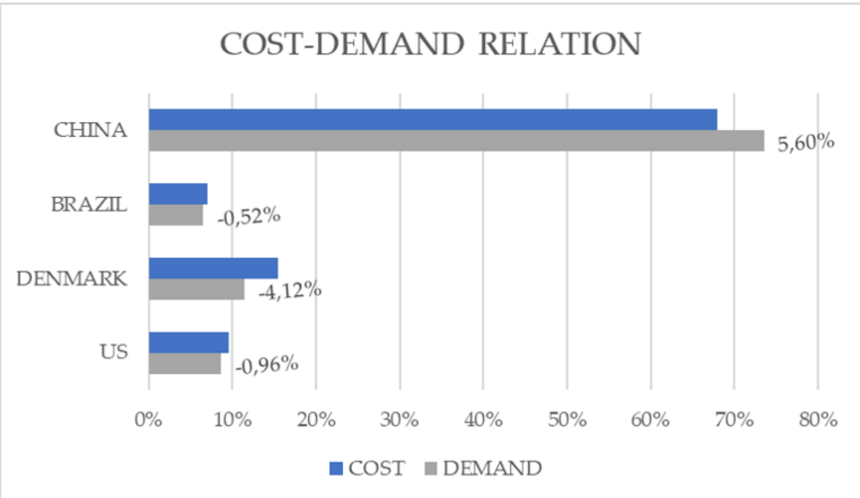


FIGURE 2.32: Cost and demand relation by each country

2.3 Analysis of potential demand increases and network limitations

Although through the document this subsection is cited as "Scenario 1", what it is analyzed in the following lines it is not an optimization case.
The purpose is to add extra information to that one given in Tables 2.4 and 2.5 and in Figure 2.10 in relation to the production potential that exists in the totality of the network.
To analyze and discuss the hypothetical changes that the business can expect or suffer in the future. The company asks us to explain if the network is ready for a certain demand increase in each of the four existing channels. More specifically, the increase they consider is described in Table 2.13.
It is important to remark that no modifications have been assumed in the system, so all customers are supplied by the same centers and all centers are connected in the same way between them.
The last but not least important fact that needs to be explain is that the manufacturing lines work in a way in which the one producing a product can be modified and converted to fabricate another product if necessary. Of course, this fact would carry extra costs but it can be used in case it is beneficial and if it would help to guarantee the production volume requirements of all product parts.

The numbers related to demand increasing that need to be checked in order to guarantee feasibility or not in the production system are showed in Table 2.13.

Logically, because of the amount of productivity existing in China, the hypothetical demand increasing would not be as high as in others. Although a 4% in China is equivalent to a 15% increase in the rest, the adaptation to a higher volume of customers will drift through a lower percentage.

TABLE 2.13: Demand increase scenarios in each of the four production channels

Location	**Demand Increase** [*units*]		
	Part A	Part B	Part C
Atlanta	15%	15%	15%
Aarhus	15%	15%	15%
Rio de Janeiro	15%	15%	15%
Shangai	4%	4%	4%

After the statement is set and requirements are known, it is time to deepen into the real possibilities the network offer.

First of all, based on the current production volumes in a year scale among all four locations, as well as their respective maximum manufacturing capacities, the margin to raise production can be obtained.

This is shown in the right columns of Table 2.14, which are shown in colours depending on the percentage they can be increased.

Starting from the manufacturing center with less production (Brazil), it can be seen that it is also where the highest rise can be performed. It can increase even higher that 50% for Part B machines and close to 45% for Part A line, which is a very significant expansion. Also, in Part C it is perfectly possible to fulfill the company's wishes, as it can be raised up to 1/4 more of what it is at present.

If we focus now on United States production, we see that an increasing of 15% in demand could not be guaranteed for Part B and Part C products, assuming that the system it is not modified. However, Part A volumes could be raised up to 25%, more than what it was even pretended. This margin gives the company the possibility of using the Part A line to manufacture the units that can not be produced in their original Part B and C machines. The feasibility of this will be described in next paragraphs.

Denmark manufacturing centers shows that, as it happened with the PC in Rio de Janeiro, an increase of 15% in the demand of all three parts can be guarantied without the need of modifying any parameter or performing conditions in the system. Nevertheless, the difference is that while in Brazil there was a very large margin of increase, here the system would be very close to full capacity after this expansion is carried out.

Lastly, in China we were asked to decide if a 4% increase in all three products was possible. Having a look again at Table 2.14, there the proof than only Part C extra demand can be guaranteed and that the residual margin is so small that in this case there is no possibility of achieving this number even with a modification in the process.

TABLE 2.14: Production rates in total units and % used of the four PCs

Location	**Production Rate** [*units*]			**Capacity margin** [%]		
	Part A	Part B	Part C	Part A	Part B	Part C
Atlanta	10.0 M	10.5 M	11.5 M	25.00%	12.38%	13.91%
Aarhus	17.2 M	12.55 M	12.55 M	16.28%	19.52%	19.52%
Rio de Janeiro	9.8 M	6.7 M	7.5 M	42.86%	55.22%	25.33%
Shangai	88.9 M	94.4 M	89.8 M	1.46%	3.81%	4.01%

GREEN [25-100] % **YELLOW** [15-25) % **RED** [0-15) %

What was previously explained about Table 2.14, can be seen graphically in Figure 2.33. The graphics shows the situation for each three products in the four Production Centers. The two thin dark-grey and black lines are both the current production rate and the maximum production volume. Related to them, the yellow-orange are filled up between the lines represents the feasibility field. Then, the thick dark-red line reefers to the company's desired increase of production. To understand the graphic, when the line of 115%-104% demand respectively is within the filled area, the biggest supply amount can be certified. When it is over its limits, either there is no possibility to do it or, at least, the production system would need to be changed in some ways.

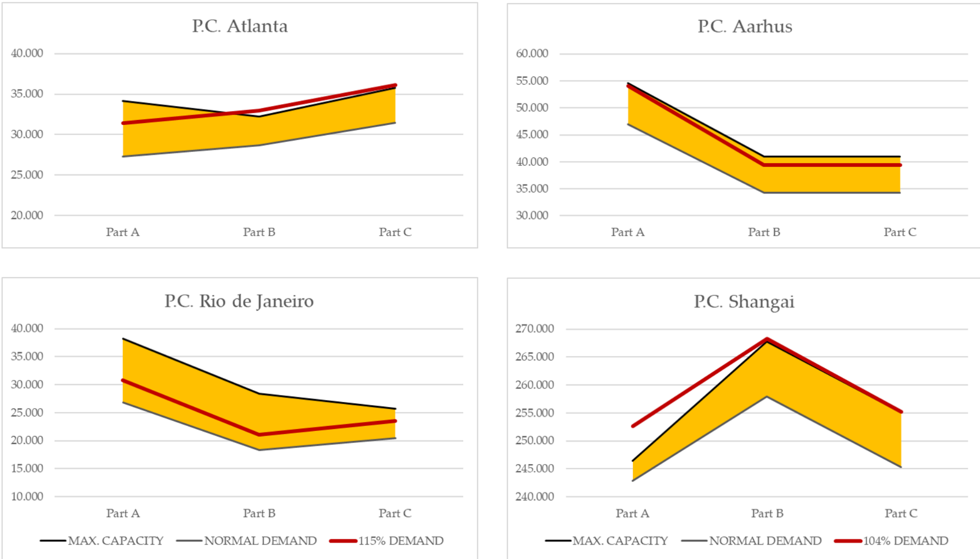


FIGURE 2.33: Comparison between the desired increased production and the capacity margins of all 4 Production Centers.

To complement the last figure, another one is created showing the comparison in a daily basis between the current production, the maximum production capacity and the new hypothetical demand requirements for each manufacturing line and center. This in shown in Figure 2.34, where it is also remarked the difference in number of units between the desired rates for this scenario and the maximum rates each line is able to produce. In red, the lines which would not be able to guarantee the supply for themselves - in blue, the ones that can do it by restructuring some parameters.

FIGURE 2.34: Current production, desired new production and lines capacity for each PC.

After the study of the different situations regarding the theoretical demand growth, it can be concluded that Denmark and Brazil PCs are already prepared for that specific production increase of 15%. In China, the 4% percentage of more demand can only be ensure for part C, while the other two products can not be shipped unless there is a reconstruction of the manufacturing process.

At the end, the only production channel in which there are doubts of its capability to produce the amount needed is the one in United States.

Just looking at Figure 2.33, it was checked that although just one of the three lines has capacity to manufacture its products, by changing some parameters in that mentioned line the need of producing some extra parts of the other two could be compensated.

In a daily basis Table 2.15 and in a yearly basis Figure 2.35 show numerically and graphically how would it look like the situation in the production center if no changes in any lines are taken into consideration.

Two manufacturing lines do not fulfill the need, but the margin in the other one left seems to be enough to produce the parts left.

TABLE 2.15: Production capacity vs demand increase in the United States channel in a daily basis.

Product	115% Demand	Max. capacity	Margin	115% Exceed
Part A	31.420	34.153	2.733	-
Part B	32.992	32.240	-	752
Part C	36.134	35.792	-	342

In the figure, the filled red amounts are the extra demand that is out of the production limits for both manufacturing lines B and C. The Part A line can cover all the demand and that is why the light blue section is added, so it shows the margin between the demand required and the maximum capacity of it.

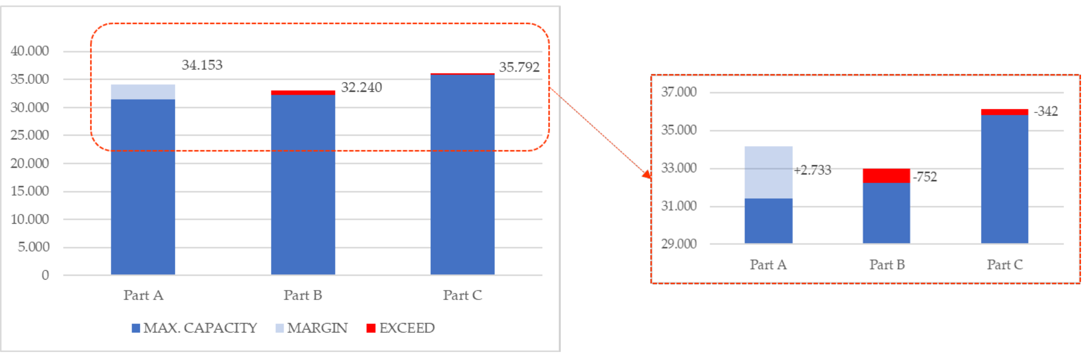


FIGURE 2.35: United States production response to an increase of 15% in demand.

Of course, although it was mentioned before that this adaption of the production lines can be done thanks to their respective flexibility, it also leads to extra costs and time.

Therefore, the optimal case is to produce the less quantity possible in the adapted line. In this case, that line is Line A. That explains why line B and C would be working full capacity in the fabrication of their respective products and only the lots that can not be done there will be transferred to the Line A.

To conclude, we can say that by a little reorganization of the system, the Atlanta production center can also guarantee an increase of 15% in their assigned customers.

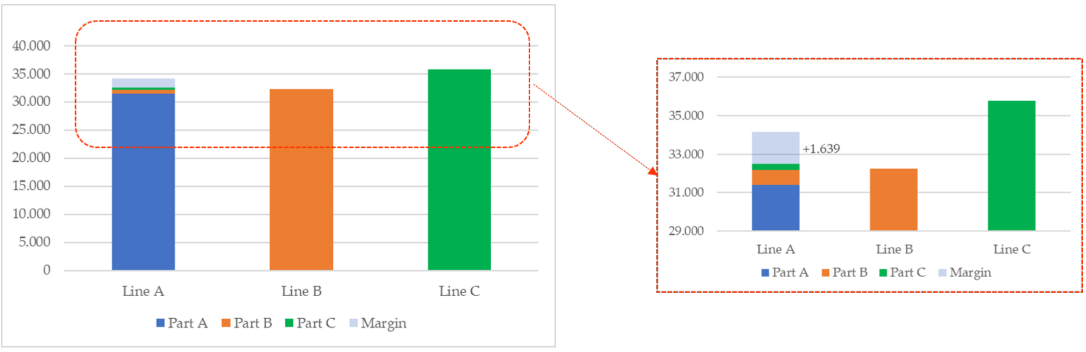


FIGURE 2.36: United States production modification to ensure supply for a demand increase of 15%.

The three production lines capacity utilization is detailed in Figure 2.36.

As previously explained, we see how manufacturing lines B and C work at full capacity and that they are only focused on the fabrication of their designed products B and C respectively.

However, line A takes charge of its own product manufacturing and also of the extra demand of the other two products that their lines are not capable to supply.

These amounts manufactured in line A are very small compared to the total capacity. That is why there is still some margin for manufacturing in line A.

Although it is proved that the system is able to guarantee the supply for a demand of 115%, the extra costs generated by having to convert line A twice due to the manufacture of part B and C might not be worth it. The quantity is too low and the extra costs that changing the parameters of the line would bring will not be amortized.

Therefore, the optimal solution for the demand increasing in United States would be to guarantee the supply of product A only in its totality for a 15% demand increasing. For the other two, it will only be guaranteed up to 97.72% and 99.05% of the demand increasing wished. This means that for part B and C it will be fulfilled an increase of demand of 12.38% and 13.91% respectively.

The final decision is of course a matter of economical reasons and guarantee of supply to customers. The company would need to negotiate new agreements and unitary costs if the demand has to reach up to 15% more.

NETWORK RESPONSE TO DEMAND INCREASES IN EVERY CHANNEL:

- 15% demand increasing in United States → Feasible ✓
  - Restructuring of the production system needed.
- 15% demand increasing in Denmark → Feasible ✓
- 15% demand increasing in Brazil → Feasible ✓
- 4% demand increasing in China → Not feasible ✗

2.4 Transportation channels optimization

This section aims to give a new perspective about the way transportation between every center in the network is done.
There will not be any changes about the transportation types, company's agreements or about the routes. These areas could of course be studied in further analysis as it is definitely interesting and potentially very important, hypothetically leading to cost reductions and improvements in quality. To be able to take part in the decision-making of these points, more confidential and detailed data from our company's operation would have been needed.
What it is really to be analyzed in this section is how to minimize the amount of transportation services while producing and shipping the same quantities to the final customers. The interest in doing this experimental calculation is well supported by the information shown in Tables 2.18, 2.19 and 2.20, where it is shown how full do trucks travel in a yearly base.

To understand following explanations in this section, it is essential to explain how is the calculation of trucks/ships needed for transportation everyday done.

Day to day production is entirely shipped to the correspondent Main Warehouses. Then, also in a daily scale, the average expected demand of the sum of the demand for each Central Distribution Center is transported from the MW to the CDCs. The last stage, from these last ones to the Regional Distribution Centers, since the demand is different everyday, the amount of trucks involved varies with the aim of guarantying the individual demand.

It is known the capacity of trucks is up to 500 units and that each ship container has room for 420 packages. The way it is decided how many do they need is basically filling up to full capacity each unit and send the last truck/container with the amount of units that is left.

When we analyzed the utilization of these last trucks/containers, it was seen that some of them were sent with very little number of packages. That means that the transportation costs of these last packages was very high, since the transportation cost is more or less the same no matter how much the truck is filled. Of course, depending on the weight of the truck, it will consume more or less litres of gas, but this can be almost neglected as it would not have a substantial impact on the results.

It was already mentioned in the Section 2.2, the important fact that both Production Center and Regional Distribution Centers storage capacity is very limited. Therefore, is was previously not taken into account. Nonetheless, that small capacity can be very useful for our improvement, as it can give us the possibility to make the process more flexible leading by so to cost reductions.

Having a look at Table 2.16 and 2.17, it can be proved how the usage rates of the last truck filled daily is very low in some routes. These two tables show information about PC to MW and MW to CDCs transportation. In the routes that connect CDCs to RDCs the shipping amount is variable, that is why a direct percentage can not be obtained as it was in these tables.

TABLE 2.16: Last truck capacity used from PC to these respective MWs.

United States		**Denmark**		**Brazil**		**China**	
Birmingham	86.4%	Aarhus	15.0%	Sao Paolo	14.8%	Nanjing	34.8%

TABLE 2.17: Last truck capacity used from MW to these respective CDCs.

United States		Denmark		Brazil		China	
Seattle	85.8%	Aarhus	20.8%	Brasilia	29.0%	Chongqing	9.8%
LA	85.8%	Skagen	80.8%	P.Alegre	85.8%	Guangzhou	85.2%
Denver	85.8%	Aalborg	61.2%			Beijing	39.8%
St. Paul	85.8%	Esbjerg	44.8%				
Madison	85.8%	Abenra	21.8%				
Austin	85.8%	Odense	78.6%				
Columbia	85.8%	Roskilde	60.2%				
Boston	85.8%	CPH	46.4%				

As it can be guessed, the total amount of trucks needed in each of the three stages is similar. However, the first stage has the fewer number of units, followed by the second (MW to CDCs) and ending with the connection between CDCs and RDCs. This is because while in the first stage there are only four routes, in the other two the number of connections increase exponentially. Most of the trucks are filled up fully in the transportation from PC to MW, while in the last stage many less trucks are totally filled perceptually.

TABLE 2.18: Percentage of trucks that are completely full from PCs to MWs.

United States		Denmark		Brazil		China	
Birmingham	99.43%	Aarhus	99.57%	Sao Paolo	99.24%	Nanjing	99.93%

TABLE 2.19: Percentage of trucks that are completely full from MWs to CDCs.

United States		Denmark		Brazil		China	
Seattle	95.45%	Aarhus	93.33%	Brasilia	99.09%	Chongqing	99.87%
LA	95.45%	Skagen	97.78%	P.Alegre	95.45%	Guangzhou	98.55%
Denver	95.45%	Aalborg	97.30%			Beijing	99.85%
St. Paul	95.45%	Esbjerg	97.87%				
Madison	95.45%	Abenra	95.24%				
Austin	95.45%	Odense	96.97%				
Columbia	95.45%	Roskilde	96.77%				
Boston	95.45%	CPH	83.33%				

TABLE 2.20: Percentage of trucks in average that are completely full from CDCs to RDCs.

	United States	Denmark	Brazil	China
Average	80.54%	67.64%	86.02%	98.60%

To prove what it was explained in the paragraphs above, some number are obtained. Firstly, transportation from PCs to MWs is analyzed. Table 2.18 show the number of trucks filled up to full capacity over the total number of trucks in percentage. It is seen that numbers are so close to 100%, which means that the margin to optimize the transportation in this stage is not very wide. The fact that there are only four channels in this phase, makes transportation very uniform and predictable.

Further in the transportation process, MWs to CDCs routes are studied in detail. In Table 2.19, percentages of full packed trucks are shown for each of the existing routes. Numbers are lowered down in comparison with the previous stage. However, percentages are still quite high, specially in those connections that carry the most units among the year.

Finally, the last stage (from CDCs to RDCs) numerically evaluation is summarized in Table 2.20. In this case, it is not detailed for each of the routes since there are so many. That is why it was decided to evaluate the average for each of the four channels. In this table, percentages are much lower than in previous stages. The fact that the process is distributed now into many more connections and with lower amount of packages leads to this result. In China, for example, where the market demand is much bigger that in the other locations and where there are less RDCs so less routes, the percentage does not go down much. On the hand, in Denmark, where there are so many connections to RDCs and the quantities required daily are in general not so high, average percentage has descend to 67%, a big reduction from previous stages.

Once it is numerically described the number of trucks/ships that are not being optimally used among all the transportation stages, a research it is carried out to find better ways of shipping the packages while saving money in transportation.

To explain the new proposition for transportation, Figure 2.37 brings up the workflow of the entire process, regarding storage and transportation needs.

NOTE: The small storage capacity that both the Production Centers and the Regional Distribution Centers have it is going to be used in the way the process works in this scenario. The storage volume in both centers will never raise higher than 500 or 420 (depending if it is road or sea transportation) units, which are the respective capacities of trucks and containers.

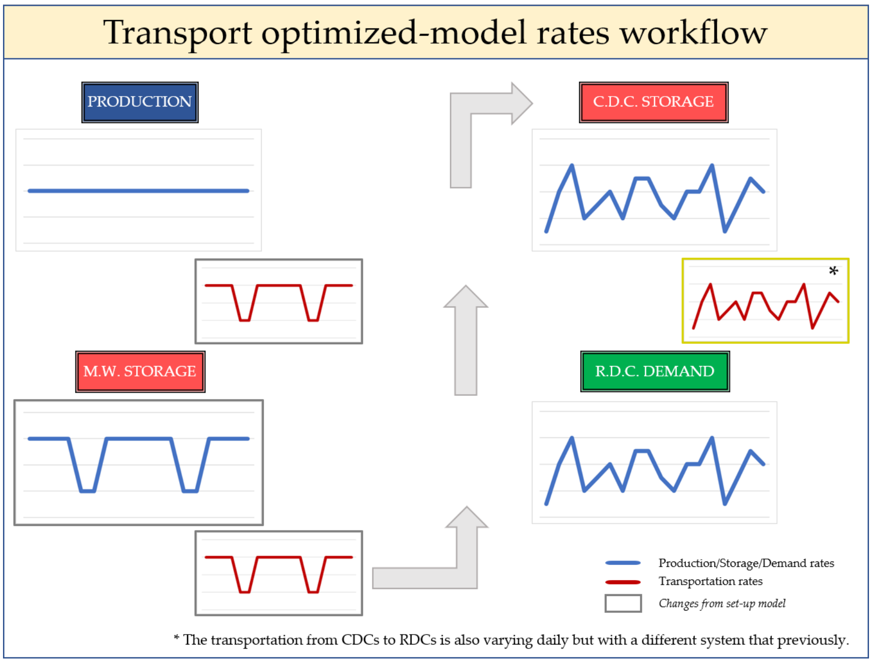


FIGURE 2.37: Work-flow rates performance in the distribution process once the transportation is optimized

In first place, production inside the manufacturing center does not change from the current performance of the process. However, transportation from PC to MW will no longer be fixed in a daily basis.

Transportation is now periodic and not all units manufactured are shipped everyday. Instead, it is sent the amount derived from the trucks that are 100% filled. The amount of fabricated units that are not shipped are stored in the center. This process will be repeated until the amount of units stored are enough to fill up an entire truck, in which case one more truck is used that day.

Next transportation stage will operate in the same way. Storage capacity in MW is much bigger, so there would not be a problem even if the extra number of units store raise higher than 500 or 420 packages. Again, for this connections, the amount of trucks is adjusted to fill them all. In some cases more quantity than required is shipped but after certain days some few trucks are used to fit the demand. In other routes, less packages than needed are sent to ensure full loading of trucks and then, after certain days, some more trucks are used to readjust the demand from CDCs.

Derived from the fact that both PC to MW and MW to CDC transportation have a periodic chart, the usage rates of the respective Main Warehouses varies also periodically.

Focusing from now on how this new methodology of managing the transportation units and shipping lots through the entire supply chain works, we will divide the explanation in two groups because of the difference in calculating the system needs in each of them:

1. PC to MW and MW to CDC transportation
2. CDC to RDC transportation

1^{st} Group (PC $\rightarrow$ MW $\rightarrow$ CDC) methodology

The first group is characterized by the constant shipping rates existing in the current status between the hubs.

Production of every manufacturing line does not vary over the days and all units are shipped daily to the next center, the Main Warehouse. From that point to the CDCs, the daily shipped amounts are also constant since the expected demand over of the year is divided equally for every day.

The proposal in this new model is to fit those daily shipping rates to the capacity of trucks, maximizing the filling of the transportation units as much as possible.

This is done by rounding the previous values to multiples of 500 (maximum number of units that fit in a truck) and, after certain days, equalize the total shipped units to the demand requirements by using more or less number of trucks during one day. This procedure will be repeated periodically during the year, so the management of these operations seems to be very simple and easy to program it with partners and employees.

To facilitate the understanding of this new strategy, Figure 2.38 represents an example of how the indication parameters such as units shipped and trucks needed perform for a random MW to CDC connection (from Aarhus to Copenhagen).

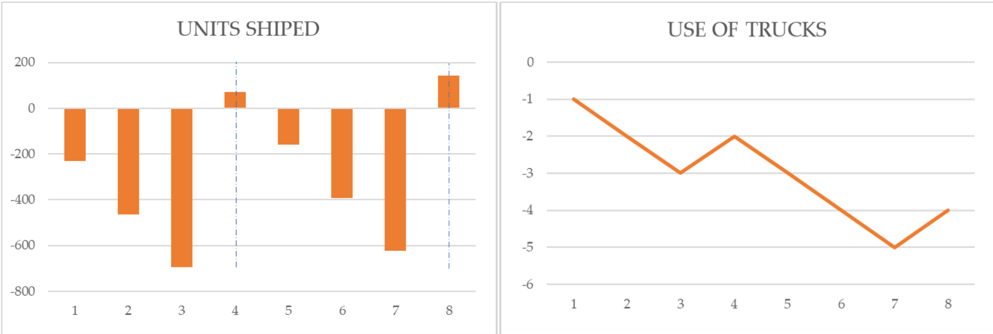


FIGURE 2.38: Transportation example group 1: Comparison between shipments evolution and trucks used

On the left, the total units shipped daily are compared (taken as a reference the current status as the horizontal line at 0). In this case, it is designed as a 4-day period, in which the first three days a slightly lower quantity is shipped and the fourth one it is compensated by increasing the units shipped.

On the right, we see how the orange line shows the variation of the needed trucks in comparison with the actual performance. The trend matches in a sense with the other graphic as it can be obviously guessed (when more fully loaded trucks are shipped, more units are sent to the next center). It can be seen how during the first three days of the cycle the units were rounded to a lower number and therefore, one less truck is needed during those days. On the other hand, the fourth day, aiming to fit the demand requirements two more trucks are shipped (one more than in the current status).

In general, as a conclusion, with this method we can very precisely fit the demand while reducing a bit the number of transportation units involved.

TABLE 2.21: Complementary numerical explanation example of transportation programming for Group 1.

	Current network		Transportation restructuring	
Demand [*units*]	Trucks used [*trucks*]	Capacity not used [*units*]	Trucks used [*trucks*]	Variation [*units*]
2732	6	268	5	-232
2732	6	268	5	-464
2732	6	268	5	-696
2732	6	268	7	$+72(\approx 0)$

To complete the explanation of this procedure, Table 2.21 is added above. Thanks to it we can prove numerically why this new scheduling system is enhancing the existing solution.

As a punctuation, the existing system rounds up the number of trucks needed and ships units matching exactly the demand every day. However, it is an over-use of resources, since there is capacity to send more products (in this example 268 a day) that is being wasted. Also, the variation from the daily real needs with the new shipping rates does not reach significant number in general - even if the differences would be big there is a large margin because of the units that are stored in both MW and CDC, that could be used to guarantee the supply over the year.

For this example, there is a reduction in the total number of trucks used for every cycle of 2. Prolonging it throughout the year, there would be a need of 182 trucks less than the number we get right now.

2^{nd} **Group (CDC → RDC) methodology**

Transportation management from Central to Regional distribution centers is meant to be done in a completely different way.

The demand from the regional hubs varies randomly all year long, making the previous cyclic procedure impossible to implement now. In this case, trucks needed and shipping amount would be forecasted in advanced based on the expected demand using a protocol of simple formulas.

The basic strategy now would be to round the demand of the starting day to a digit that guarantees the total filling of trucks and to compensate the difference between the demand and shipped units in the following days.

This variation is designed in a way that will never be greater than 490 units which is the capacity of trucks (a small margin of 10 units is left for each transport to prevent unexpected and little fluctuations). Whenever the systems detects that the variation will decrease from -490 or raise higher than 490, one truck more/less would be sent and variation would be back to a value close to zero.

To facilitate the understanding of this new system, some variables are presented below and will be used in following explanations:

- X_{i-1}: Accumulated variation between supplied parts and real demand
- X_i: Reminder variation between supplied part and real demand after daily operations
- D_i: Daily demand required to shipping center
- S_i: Daily amount of shipped parts from the center
- C_t: Transportation capacity of trucks
- C_s: Transportation capacity of sea containers

In general, the decision-making will be based on the following expressions:

- IF D_i <= $X_{i-1} \rightarrow S_i = 0$
  & $X_i = X_{i-1} - D_i$
- IF $D_i > X_{i-1} \rightarrow S_i$ = ROUNDED $[D_i - X_{i-1}]$*
  & X_i = ROUNDED $[D_i - X_{i-1}]$* - $[D_i - X_{i-1}]$

*Rounded to multiples of C_t/C_s or to zero in case it is a low value. **

Explaining the procedure in words. When the demand is lower than the accumulated variation, no shipments will be sent. For this situation to happen there must occur two circumstances: the variation must be positive (more products shipped than demand requested in previous days) and the demand of that exactly day must be lower than 490 units or 1 trucks, since it is the maximum value that the variation can reach.

On the other hand, when the demand is greater than the accumulated variation, shipped amount would be equal to the difference between exact demand and accumulated variation, rounded to multiples of the trucks/ships loading capacities. This case takes places most of the times, as the other is very unlikely specially in those routes where the demand is quite high (demand never below accumulated variation).

To complete the explanation of these routes planning, some examples will be added in the following lines.

Firstly, Figure 2.39 shows graphically how the process evolves from knowing the exact required demand to calculate the reminder variation for the day after.

Before explaining it, we should detail some values: Demand D_i = 910 and Accumulated variation X_{i-1} = -190.

Firstly, the demand is known. Then, since the accumulated variation has a negative sign, it means than supplied demand is currently below the required demand from the RDCs - this variation is therefore summed to the demand. Then, once the optimal and exact hypothetical shipment in terms of fitting the demand is known, it will be rounded to multiples of the transportation resources capacities. In this case, since the sum of D_i and X_{i-1} is closer to 2-trucks capacity (980 units) than to 3 trucks (1470), the shipped amount it is adjusted to 980 units. The difference between the previous step total amount and the shipped units will be the remainder variation for next day.

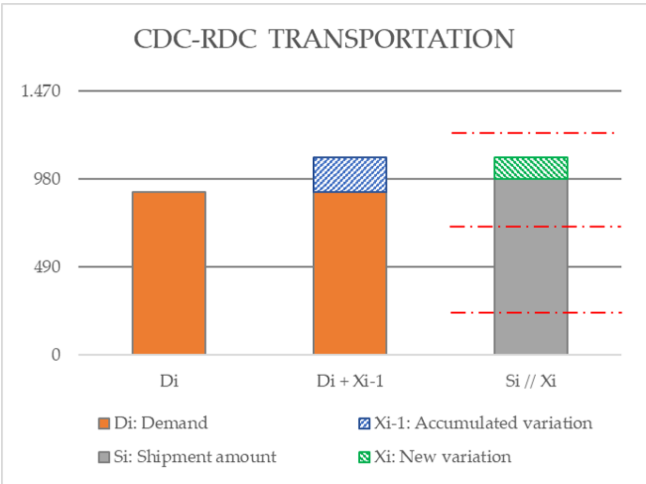


FIGURE 2.39: Graphical explanation of how shipments are managed between CDC and RDC centers.

To complete the explanation and show the evolution between the respective daily operations, two more examples will be extracted from the calculations.

The first example is shown numerically in Table 2.22 and graphically in Figure 2.40. In the table, the first line corresponds with the first day of year, in which an accumulated variation equal to zero is assumed. On the left, the current network status parameters are shown, such as the need of trucks and truck's capacity which is not used. On the right, regarding the optimized model, also the used trucks are detailed together with the accumulated variation among the days.

TABLE 2.22: CDC-RDC Transportation example 1 (Zagreb): Characteristic parameters from current network status and optimized model.

	Current network		**Transportation restructuring**	
Demand [*units*]	Trucks used [*trucks*]	Capacity not used [*units*]	Trucks used [*trucks*]	Variation [*units*]
380	1	120	1	+110 [1]
645	2	355	1	−45 [2]
295	1	205	1	+150 [3]
540	2	460	1	+100 [4]
570	2	430	1	+20 [5]
550	2	450	1	−40 [6]
635	2	365	1	−185 [7]

As it will proved in the following expressions, in every day from the example the demand was greater than the variation, so the expression related to the second "if" was used in all cases. Therefore, demand required minus the accumulated variation is rounded based on trucks capacity to decide the shipped lots. The difference between the rounded and not rounded values it is the next variation.

1. $S_i = D_i - X_{i-1} = 380 - 0 = 380 \rightarrow [\text{Round}] \rightarrow 490$
   $X_i = S_i - D_i = 490 - 380 = +110$
2. $S_i = 645 - 110 = 535 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 535 = -45$
3. $S_i = 295 - (-45) = 340 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 340 = +150$
4. $S_i = 540 - 150 = 390 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 390 = +100$
5. $S_i = 570 - 100 = 470 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 470 = +20$
6. $S_i = 550 - 20 = 530 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 530 = -40$
7. $S_i = 635 - (-40) = 675 \rightarrow [\text{Round}] \rightarrow 490$ // $X_i = 490 - 675 = -185$

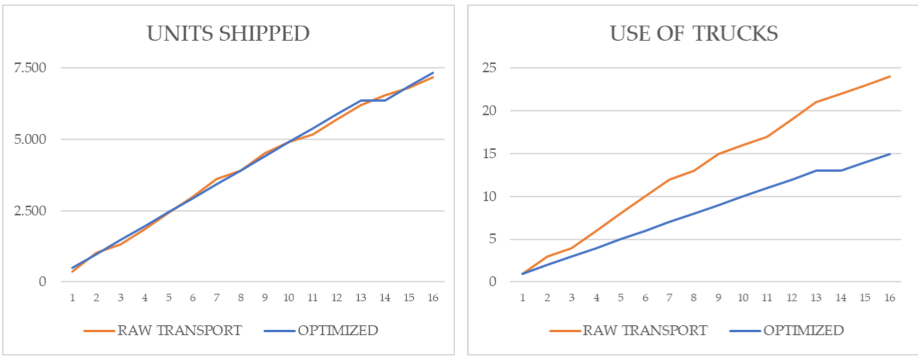


FIGURE 2.40: Transportation example 1 (Zagreb): Comparison between shipments evolution and trucks used

Figure 2.40 help us to understand which is the impact of this new planning method. We focus on demand fitting rates and need of trucks.

On the left, the difference between the required daily units and, therefore, the ones that are sent as the network performs right now (in orange) and the new shipping rates with this new scenario.

It is proved that the variation can almost be neglected (no higher than an absolute value of 185 for this example) since the maximum peak would be 490 units and that number in comparison with the total shipped units is not very representative.

To contrast the beneficial trends seen in the first example, another one is detailed in Table 2.23 and Figure 2.41.

In the table we can see that demand rates are slightly lower than in the other case. Only one truck is used daily in this extracted data in the current network status (left column). Optimizing its performance, we managed to avoid using any trucks during some days (column in the right)

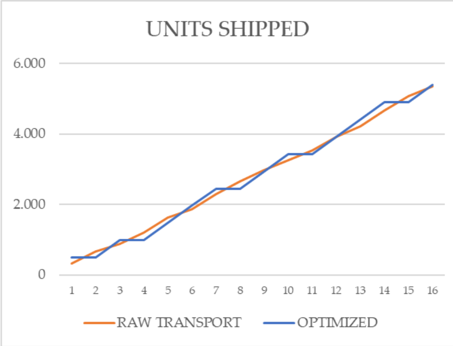
TABLE 2.23: CDC-RDC Transportation example 2 (Maribor): Characteristic parameters from current network status and optimized model.

	Current network		**Transportation restructuring**	
Demand [*units*]	Trucks used [*trucks*]	Capacity not used [*units*]	Trucks used [*trucks*]	Variation [*units*]
315	1	185	1	+175 [1]
340	1	160	0	−165 [2]
235	1	265	1	+90 [3]
300	1	200	0	−210 [4]
445	1	55	1	−165 [5]
220	1	280	1	+105 [6]
430	1	70	1	+165 [7]

Again, accumulated variations are not greater than demand at any of these studied days so calculations are based on the second formula. However, since the demand is quite low, the combined values of demand and variation do not raise up to trucks capacity certain days. Because of the fact that no truck will be sent without its total filling, some days there are no shipments to this RDC and its demand will be all sent the next day.

1. $S_i = D_i - X_{i-1} = 315 - 0 = 315 \rightarrow \text{[Round]} \rightarrow 490$
   $X_i = S_i - D_i = 490 - 315 = +175$
2. $S_i = 340 - 175 = 165 \rightarrow \text{[Round]} \rightarrow 0$ // $X_i = 0 - 165 = -165$
3. $S_i = 235 - (-165) = 400 \rightarrow \text{[Round]} \rightarrow 490$ // $X_i = 490 - 400 = +90$
4. $S_i = 300 - 90 = 210 \rightarrow \text{[Round]} \rightarrow 0$ // $X_i = 0 - 210 = -210$
5. $S_i = 445 - (-210) = 655 \rightarrow \text{[Round]} \rightarrow 490$ // $X_i = 490 - 655 = -165$
6. $S_i = 220 - (-165) = 385 \rightarrow \text{[Round]} \rightarrow 490$ // $X_i = 490 - 385 = +105$
7. $S_i = 430 - 105 = 325 \rightarrow \text{[Round]} \rightarrow 490$ // $X_i = 490 - 325 = -15$

Again, the figure below shows how the demand rates are quite closely fitted in this other example and also how a substantial reduction of the number of trucks involved is also achieved.



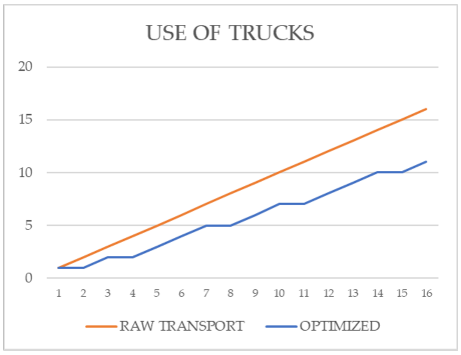


FIGURE 2.41: Transportation example 2 (Maribor): Comparison between shipments evolution and trucks used

From both examples and the overview of the total calculations carried out in the model, we can conclude that the main objectives of this transportation scheduling system are achieved:

- Fitting closely demand rates ✓
- Reducing considerably the need of trucks ✓

Once the method of controlling the operations is explain, we move forward to analyze which is the impact in terms of system's resources optimization and cost savings in comparison with the current status of the network.

It was explained before that some connections were using several trucks to carry very little quantity. In the graphics showed in Figure 2.42 and 2.43 the last truck shipped daily occupancy is compared.

In the first figure, the biggest savings will come from the routes of Denmark and Brazil, since their use of the last truck is very low. On the other hand, in the United States these routes is quite well designed since even the last truck is close to the full occupancy.

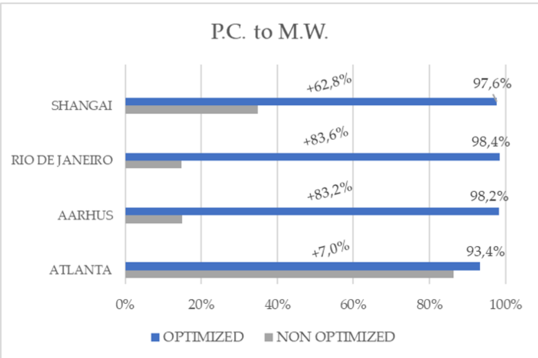


FIGURE 2.42: Last truck occupancy comparison between initial model and transportation optimized model in PC to MW route.

This combined figure, about the MW to CDC transportation, shows how some routes had a big margin of optimization e.g. Abenra and Aarhus in Denmark and Chongqing in China and others do not improved that drastically e.g. the ones in United States, Porto Alegre and Guangzhou.

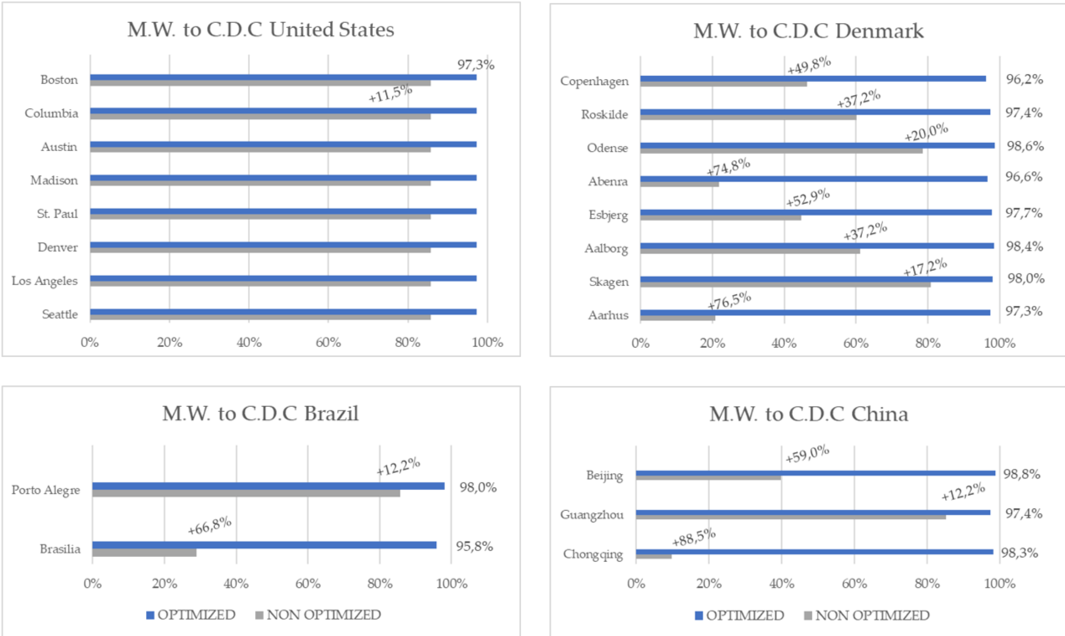


FIGURE 2.43: Last truck occupancy comparison in MW to CDCs routes

It can be seen how the optimized trucks do not reach full capacity levels. This is because we have decided to leave a little margin in all trucks in this new model scenario. It was though that it is convenient to leave a small edge in each connection to be aware of some unexpected changes or process failures that can occur. This will lead to a little extra cost but help the system to be in the safe side and more prepared for changes.

To understand the optimization in the routes connecting CDCs with RDCs (Figure 2.44), it is shown the total number of trucks reduced, since the occupancy rates in the starting model were varying daily so it was not possible to do the same comparison.

It can be seen how, although the number of trucks needed in a year for the channel of China is up to 6 times greater than the other three channels, the reduction of trucks used is not very significant. On the other hand, in Denmark, the reduction of total trucks needed is around 3 times bigger than in the other three tracks.

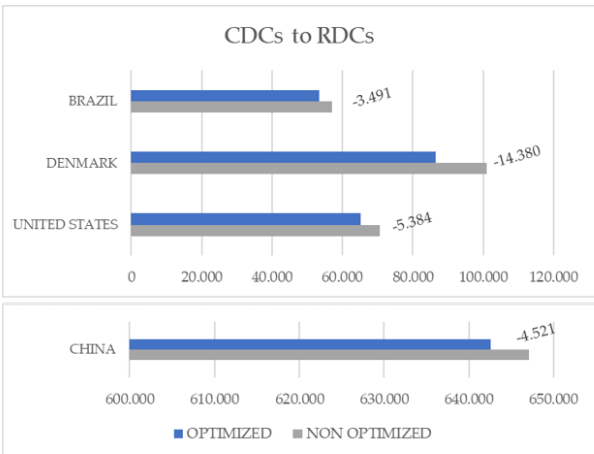


FIGURE 2.44: Total need of trucks and reduction between CDCs and RDCs routes.

In order to find an explanation for this, we have checked the number of different routes existing in each of the channels. The number of RDCs assigned for each network channel are: 38 in United States, 89 in Denmark, 22 in Brazil and 25 in China. It can be proved that the biggest number of connection, the greater reduction was achieved.

However, this does not necessarily needs to be a direct relation. There is another fact that is a bit harder to quantify which is the demand needs daily and the percentages last trucks are filled. i.d. it is not the same if the demand is 950 units (in which case there would have been one truck filled 100% and the other 90%), than if the demand is 1050 units (where two trucks would be totally loaded while the third one only 10%), although the total number of units shipped only differs in 100 products.

In order to help with the explanation, Figure 2.45 shows the percentage of trucks that are fully loaded in each of the CDC to RDC connections.

It is seen how some routes have a quite high overall percentage while others do not even have any trucks totally loaded during the year. This simply graphic really help us to understand why the truck needs in Denmark decreases very significantly and in China it is not possible to do it as much. A lot of the routes in the Danish channel have lower demand, sometimes even lower that the capacity of just one truck. That only happens in one route in the Chinese channel, while there are some others where the demand is so high that just one truck not totally loaded represents a very low percentage (those that are virtually 100% full loaded trucks).

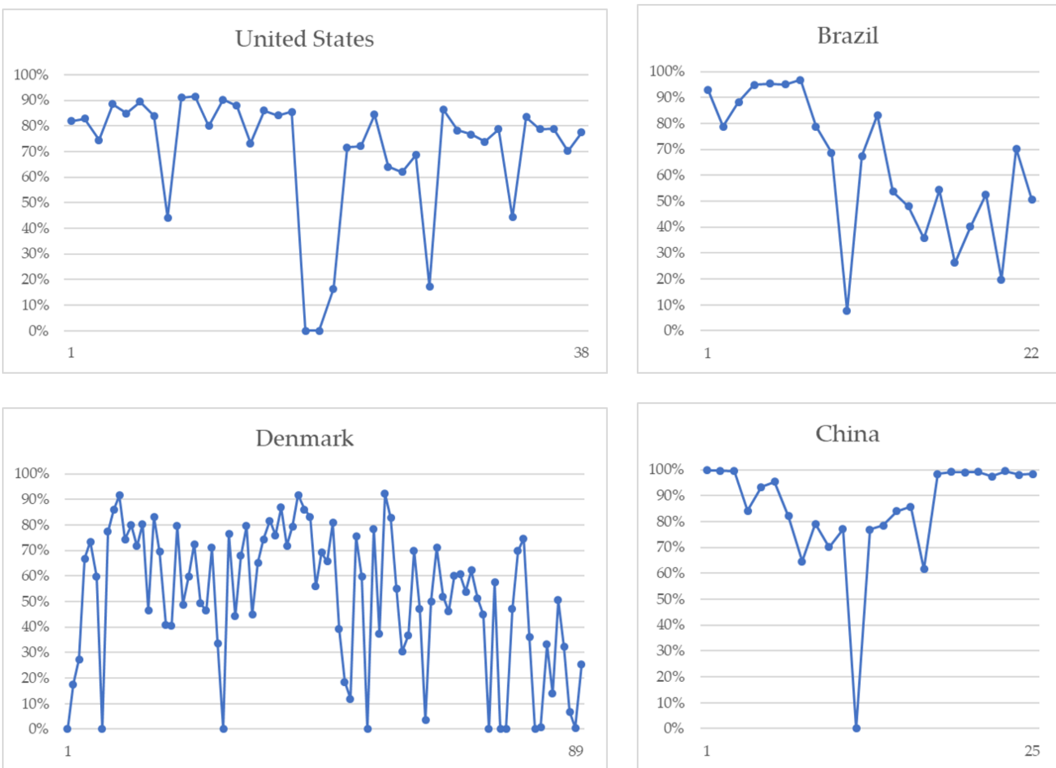


FIGURE 2.45: Percentage of trucks that are completely loaded in comparison with the total amount of trucks needed for each route connecting CDCs and RDCs.

Combining the information of every CDC to RDC route by each of the four channels, it is obtained the average of those trucks totally loaded. These averages are compared here below, showing the values for each of the four channels:

US: 80.54% | Denmark: 67.64% | Brazil: 86.02% | China: 98.60%

Indeed, while in China most of the trucks are fully loaded, in Denmark they represent only two thirds of the total amount. This is one of the reasons why the margin of improvement is much better in Denmark than in any of the other routes.

Another important reason that could take part in the transportation process performance is, not only how many trucks are not fully loaded, but also what are the loads of these incompletely loaded trucks.

To be able to add some numbers to compare all the channels, Figure 2.46 is used.

The graphics show the yearly average of the last trucks usage. In general, it can be seen how all routes are around 50% of load capacity. There are certain peaks which reach values up to approximately 70% and low limits which are around 35% or even 25% of capacity in the daily last truck usage.

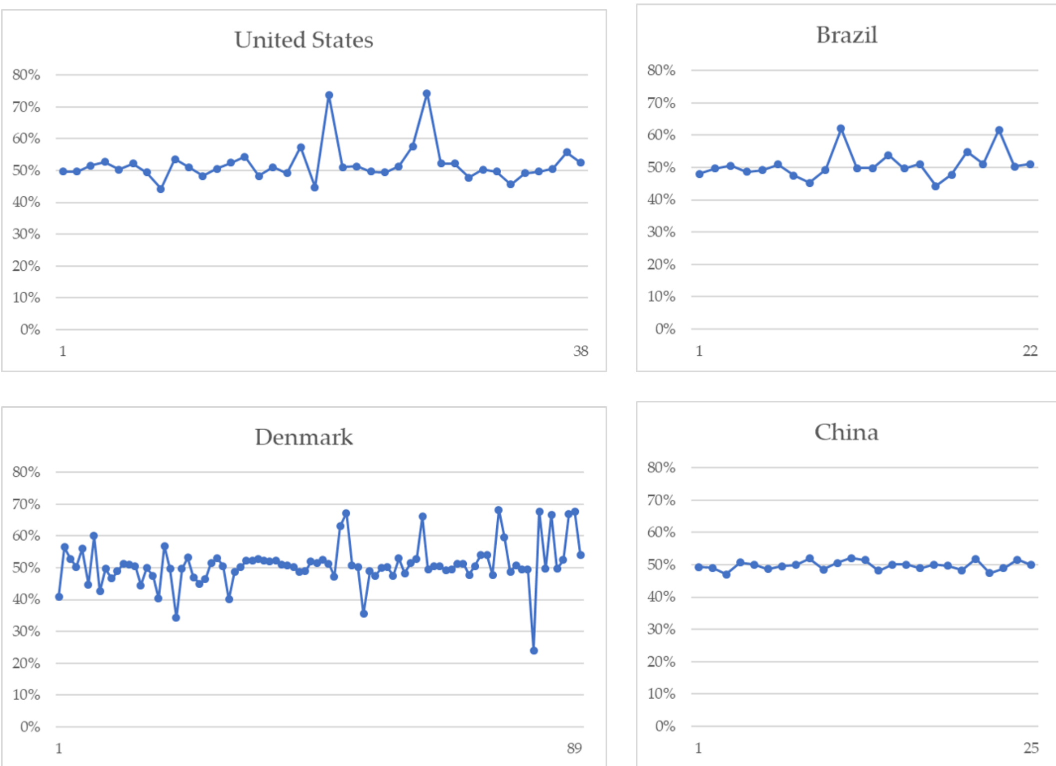


FIGURE 2.46: Average usage of the last truck capacity for each of the CDC to RDC connections.

Once the four charts are seen, averages of each channel information are obtained, helping to compare easily all of them. The averages of each of the four channels are the following:

US: 51.98% | Denmark: 51.05% | Brazil: 50.77% | China: 49.77%

It is checked that all values are very close to each other and around half capacity use.

The similarity between all of them can show that this factor does not have a critical effect in the existing margin of optimization.

The concordance between the number of routes and margin of optimizing the network seems to be clear. Also, those routes that have a higher demand will have a smaller optimization perceptually but not necessarily in terms of total savings.

To finalize the research and study of the transportation connecting CDCs with RDCs, and once the optimized case is designed, it is going to be analyzed the effect of both the market needs and dimensions and the number of routes starting from each of the central centers.

Firstly, data showing the number of trucks needed from each CDC to its related RDCs is comparing the initial case and the optimized case it has been done.

Table 2.24 shows the number of trucks that are not being used any more to supply products in the CDC to RDC phase, the one where most of the expenses are paid.

It can be seen that the reductions achieved are very oscillating and there is no special trend within channels. Maximum reductions raise up to almost 30% (e.g. Copenhagen) while in others the reduction does not even represents 1% (e.g. Chongqing and Beijing).

TABLE 2.24: Initial case and optimized model comparison of transportation units used between CDCs and their linked RDCs.

CDC	Trucks needed		Reduction	
	Initial Case	Optimization	[*Trucks*]	[%]
Seattle	8718	8162	-556	-6.38%
LA	8746	8162	-584	-6.68%
Denver	8349	8163	-186	-2.23%
St. Paul	8544	8162	-382	-4.47%
Madison	8721	8162	-559	-6.41%
Austin	9607	8161	-1446	-15.05%
Columbia	8907	8162	-745	-8.36%
Boston	9086	8160	-926	-10.19%
Aarhus	6649	5306	-1343	-20.20%
Skagen	18511	16800	-1711	-9.24%
Aalborg	16484	13751	-2733	-16.58%
Esbjerg	18442	17346	-1096	-5.94%
Abenra	9151	7548	-1603	-17.52%
Odense	13956	12242	-1714	-12.28%
Roskilde	14770	11427	-3343	-22.63%
Copenhagen	2926	2089	-837	-28.61%
Brasilia	46209	44872	-1337	-2.89%
Porto Alegre	10767	8613	-2154	-20.01%
Chongqing	329126	328572	-554	-0.17%
Guangzhou	32512	29999	-2513	-7.73%
Beijing	285425	283971	-1454	-0.51%

In order to find explanations for the variations of optimization percentages achieved, Figure 2.47 and 2.48 have been created.

The first figure (2.47) combines the total reduction in the numbers of trucks used by percentage and the volume and the importance of the market channel. The reduction is shown with the column chart and the left vertical axis, while the total number of trucks used is shown with the line graph and the right vertical axis.

Regarding truck usage reductions, we see that in most of the connections they raise above 5%, going up to 20-25% in some cases. Route importances are approximately the same in United States and Denmark routes, as well as one of the routes from Brazil, with a number of trucks used of around 10.000 per year. Other two routes use a number of trucks of around 30.000-40.000 per year (one of Brazil and one of China), and then the two connections left from China are much more demanding than all the rest with up to 300.000 trucks used or more.

With this graphic, it is possible to explain some tendencies but not all of them. For example, it is clear that the bigger need of trucks, the less reduction can be achieved. This fact can be seen easily in Brazil and China, where those CDCs that send many trucks could not optimize the transportation much, while the other two CDCs where the needs supply is lower the optimization is much more significant.

However, it is not possible to predict in this graphic why those CDCs that ship not that much high quantities (around 10.000) have very different reductions in number of trucks used.

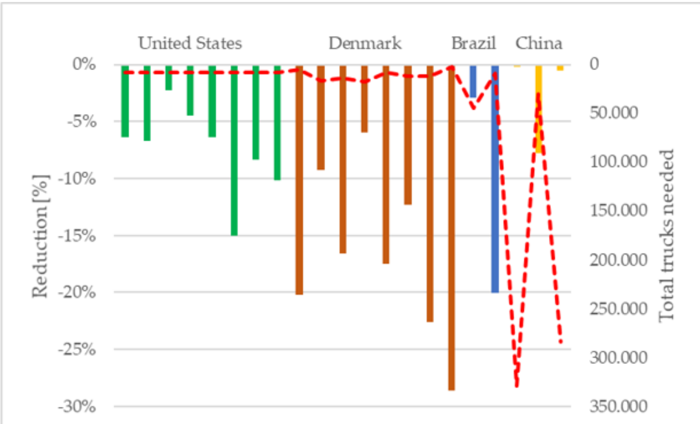


FIGURE 2.47: Total truck usage reduction and volume of trucks needed in CDC to RDC connections

Figure 2.48 differs from previous one, because now it is compared the reduction of total trucks used with the amount of routes that start from each CDC.

In this graphic, we are able to see a certain link between both parameters analyzed. It is seen how, in most of the CDC routes, there is a linkage in the sense that the more exiting routes, the greater the reduction there is.

It is known that the Danish channel has the biggest amount of RDC connections, and it is also visible in the graph that the biggest peaks in the routes are in the dark-red area.

There are, however, some cases where the parameters analyzed do not match, e.g. in Aarhus and Copenhagen where the reduction is much higher than what we would have expected based on the trend. In Table 2.3, where it was shown the total demand of each of CDCs in a year, we could see how both of the mentioned CDCs had the lowest needs of units. Figure 2.45, in the section of Denmark, also shows how in the zones related to Aarhus and Copenhagen, the respective percentages of truck fully loaded are lower than in the rest of the chart.

A possible explanation to these differentiated results might be the fact that the daily demands are too low to load even one truck in many of the cases. Therefore, as the system was performing before, many extra payments were done by sending most of the trucks unfilled. As now, there is no problem if there is no shipment everyday, there are bigger savings in proportion than in other CDC routes.

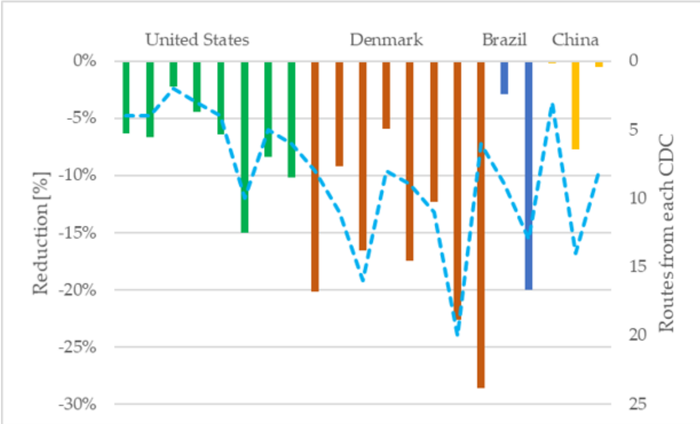


FIGURE 2.48: Total truck usage reduction and number of existing routes from CDCs to RDCs

From these last conclusions, trends analysis and general results obtained during this experiment, we have realized that there are some KPIs that provide the most relevant information. They can be summarized into the following list:

- Loading use of transportation units
- Distance of transportation routes
- Importance and demand of transportation routes

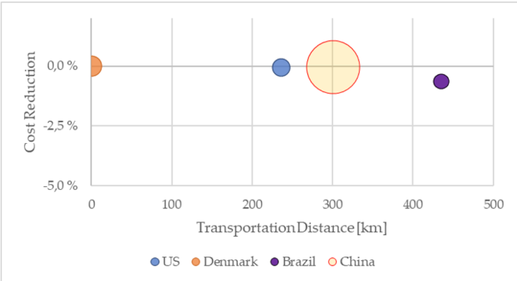
With this new management system, it is proved that better solutions can be applied in the transportation model. In each of the existing connections within centers we have achieved certain reductions in terms of trucks/ships needed and, therefore, in cost investments.

In Figure 2.49 and Figure 2.50, we aim to establish a link between two of the parameters mentioned below (Routes distance and demand rates) and the relative transport reduction obtained after applying this methodology.

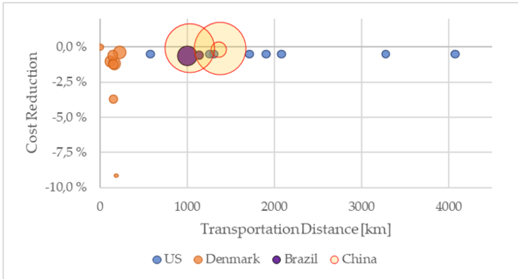
Both graphics show in the X-axis the route distance, in the Y-axis the cost variation (reduction since they are always below the actual values) and finally, in the size of each circle, the demand according to each connection.

To clarify which will be the most determinant and important routes when optimizing the transportation system, we will focus on certain parts of these following graphics:

1. The more demand existing in a connection, the harder it is to reduce its cost perceptually. The net values can be as big as in other connections but the reduction in percentage quite low.
2. A route with the same cost reduction than another but with larger transportation distances will save much more money in total than the other.
3. The optimal route in terms of cost-saving solutions will be the one with a large distance, big cost reduction and high quantities of demand (right bottom corner of the graphics).



(A) *PC to MW connection* .



(B) *MW to CDCs connection* .

FIGURE 2.49: Cost reduction, routes distances and total number of trucks needed comparison in PC to MW and MW to CDCs routes respectively

Figure 2.49, shows in the left the four existing connections (one for each channel) between manufacturing centers and main hubs. The size of the points is, in this case, directly related to the total demand in each of the channels. This is why, as expected, the point representing the China area is much larger than the other three. Another particularity is the fact that the point referred to Denmark has no reduction and no distance. This is because both centers are located in the same area (Aarhus) and therefore, no modification/ reduction has been carried out. The only connection where reduction is significant is in Brazil, because of three reasons already explained in other parts of this section: 1.Very low filling of last truck (Table 2.16) 2.Not very high total demand (Table 2.3) 3.Longer distance of the route (Figure 2.16).

The graphic on the right represents the information obtained from MW to CDC connections. Again, two of the connections from China channel have a much higher volume of products supplied and, although their respective reductions are quite low in percentage, they would have the biggest net reductions. In all connections of United States the reduction (in %) is the same, because demand rates are equal and shipment procedures are as well - the longer the routes are they most total money reduced they will represent. Danish connections are the ones with the biggest cost reductions (in %), but they are also considerably shorter than all the others, so the perceptual reduction is not transformed into a bigger net reduction than in the other routes necessarily. Lastly, while one of the connections of Brazil is not very significant (low demand), the other has a good combination between long distance, noticeable reduction and big demand volume so it will lead to quite significant cost savings.

Proving numerically the deductions from the graphics, the net cost reductions are written below.

PC to MW routes:

- United States: -7229 €
- Denmark: -
- Brazil: **-91279** €
- China: -45040 €

MW to CDC routes:

- United States: **-50408, -43524**, -25584, -33431, -18907, -18493, -12610 & -24047 €
- Denmark: 0, -26022, -49784, **-78045, -106910**, -27985, -52483 & **-74714** €
- Brazil: **-122175** and -24639 €
- China: **-179076**, -21922 and **-94488** €

Figure 2.50 shows the information regarding CDC-RDC routes in each of the channels.

The biggest reductions in percentage are obtained in Denmark. Distances are longer in China and Brazil, followed by Denmark. Required demand is very high in certain hubs located also in Brazil and China.

In general, it is not as easy to predict the absolute cost reduction in these transportation stages. However, it can be guessed that the biggest savings will not come from the United States routes.

Depending on which parameter influences the most the results, Denmark will bring the highest improvements if reductions in % are also relevant in net values and China will lead to the biggest savings if the distances are a decisive indication.

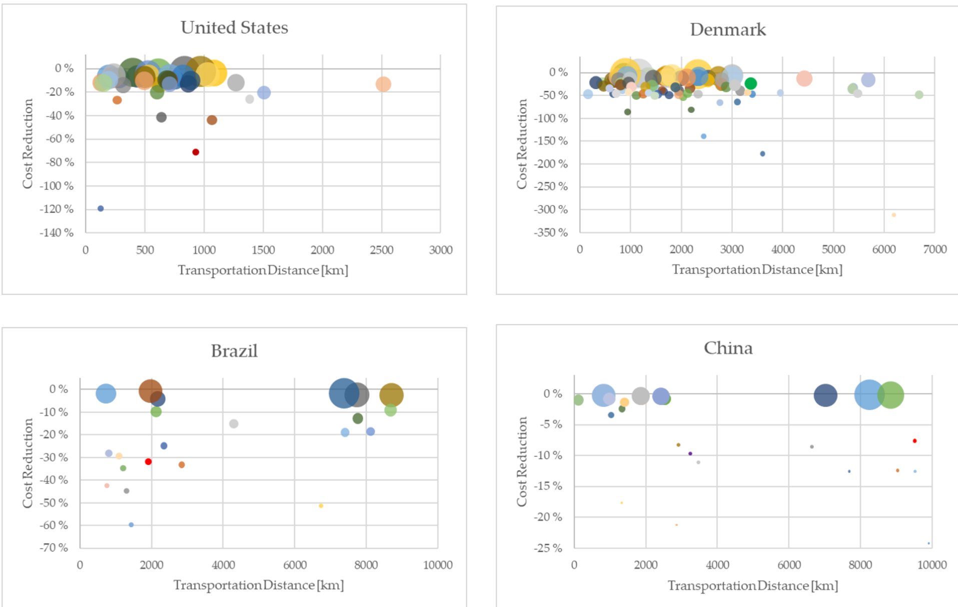


FIGURE 2.50: Cost reduction, routes distances and total number of trucks needed comparison in PC to MW and MW to CDCs channels respectively

Calculating the average of the absolute reduction for each of the four channels we come to the conclusion that reductions from Denmark are so big in comparison with the current model status that this channel has a bigger impact in cost reduction per route than any other.

<u>CDC to RDC routes:</u>

- United States: -48359 €
- Denmark: **-245105** €
- Brazil: -160000 €
- China: -126007 €

To give a visual understanding of the cost reduction that this new transportation management system would bring, two figures (2.51 and 2.52) show a comparison of MW to CDC and CDC to RDC routes transportation expenses in a year basis.

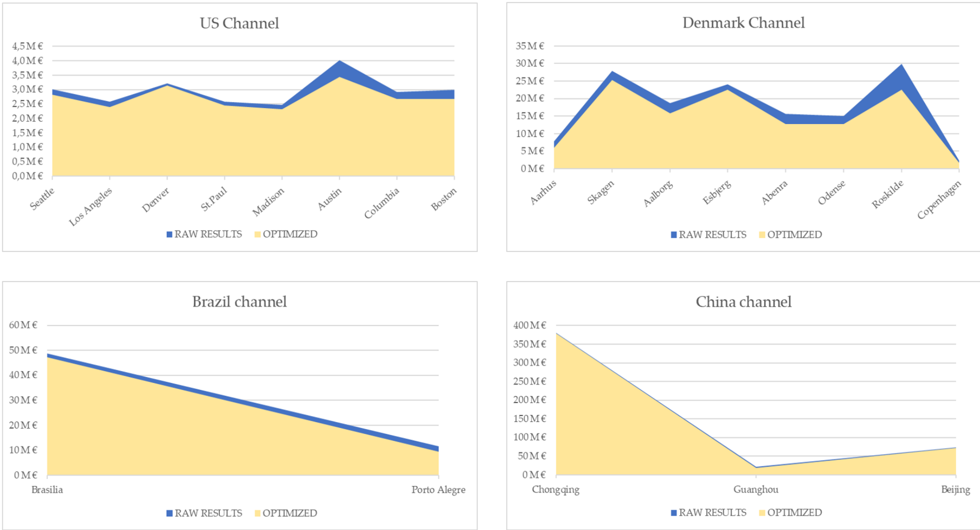


FIGURE 2.51: Total transportation expenses in MW-CDC routes in optimized and current business model.

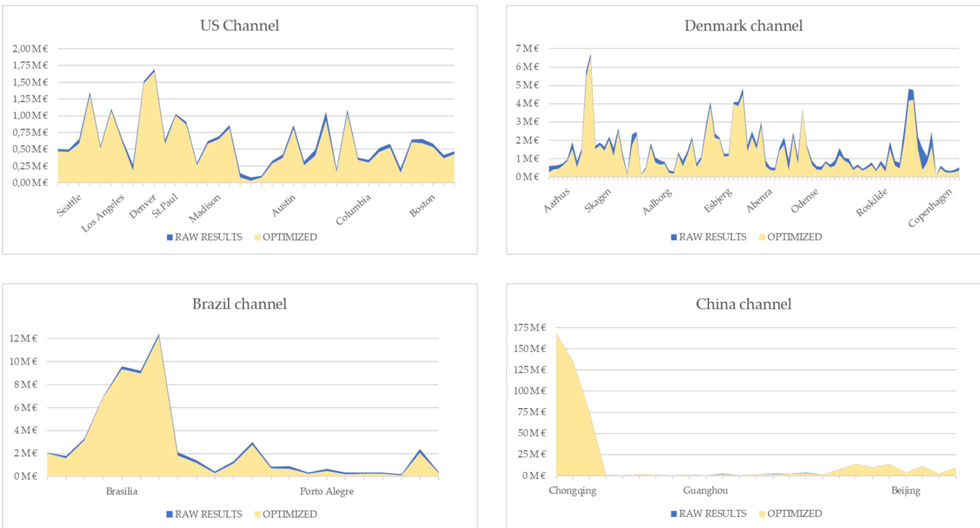


FIGURE 2.52: Total transportation expenses in CDC-RDC routes in optimized and current business model.

For these two previous figures, the more blue shade there is, the bigger the cost reduction is in that transportation route. In can be checked how, for China, compared to the big amounts of money spent in transportation in a year the reduction achieved is almost non-existent. On the other hand, we see again how most of routes in the Denmark channel are optimized quite a lot.

At the end of this optimization scenario, dividing the cost comparison in the three transportation stages that take part of the logistics transportation activities, the total cost variations from the current network status are stated in both Figure 2.53 and Table 2.25.

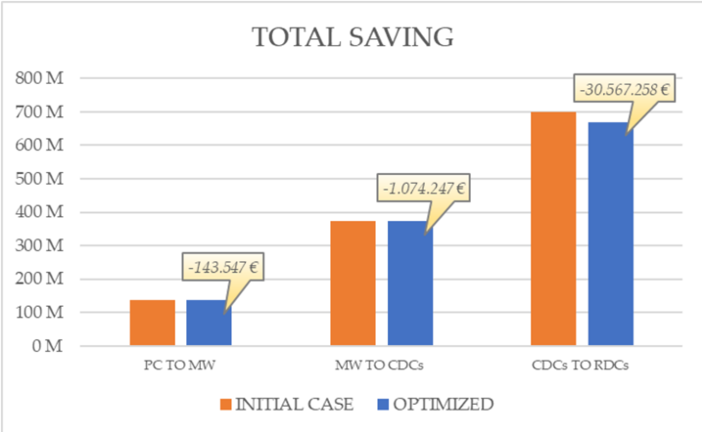


FIGURE 2.53: Total cost reduction thanks to the transportation optimized model.

TABLE 2.25: Transportation cost comparison with the current network status.

Channel	**Initial case**	**Optimized**	
		Reduction [€]	Reduction [%]
PC→MW	136.435.251	-143.547	-0.11 %
MW→CDC	373.609.995	-1.074.247	-0.29 %
CDC→RDC	700.090.765	-30.567.258	-4.57 %
TOTAL	1.210.136.011	-31.785.053	-2.70 %

As we explained during this section, this new transportation scheduling method would influence the performance of the storage centers such as Main Warehouses and Central Distribution Centers. This will modify the costs of doing this activity. The variation is so little that it can almost be neglected in contrast with the remarkable variation (reduction) that is achieved thanks to the new transportation concept.

· MW storage costs: + 24.119 €
· CDC storage costs: + 25.347 €
· Total variation: + 49.465 €

The total expected investment that the company would need to do if applying this new business model would be: **3.802,4M €**. This means a reduction of **31.7M €** from the current status of the global network. In percentage, these savings would represent **-0.83 %** the investment that needs to be done annually right now.

The hypothetical application of this new methodology would be beneficial, since the modification of the transportation shipping planning can be easy to implement, getting in return a considerable amount of cost reduction.

MAIN CONCLUSIONS FROM THE RESULTS:

Transportation takes up to 31.65 % of the yearly total expenses of the company as the network performs in reality, as it was seen in Figure 2.30. The aim of this study scenario was to reduce the total transportation cost without changing any of the routes or transport systems.
Analyzing the information collected from transportation activities, it was realized that many trucks and container ships were used without being totally filled up. This fact is leading the company to pay for services that might not be needed.
Our objective in this section was to convert the daily based transportation adjusted model to another which could guarantee a continuous supply but not matching the demand exactly everyday (very closely).
Only full loaded transportation services would be used in this model, resulting in considerable reductions of the shipping units number. This improvement is specially relevant in the last stage of transportation - from CDCs to RDCs- where the larger number of routes and lower amount of units shipped were causing large cost expenses.

- Full loaded shipping → Feasible ✓
- Reduction of Transportation investment → Possible ✓
- GENERAL IMPROVEMENT → ACHIEVED ✓

2.5 Production channels differentiation by product

This new scenario combines modifications in the production schedules and in the transportation needs and routes.
In this case, based on the information summarized in Section 2.2 and the general information collected from the current state and performance of the network, we will discuss if it is beneficial to modify some supply routes and production activities.
More specifically, based on the data collected from Figure 2.10, where it is represented the usage levels in every line and PC, and also from Table 2.7 and Figure 2.23, where every unitary cost derived from production is specified, we considered applying some changes in the global channels to see if they could lead to lowering costs in the network.
The aim of this study is to find out if moving some manufacturing volume from one PC to another where production is cheaper could be beneficial besides the expected increasing in transportation costs. Pointing this out, since the network is designed to supply to final customers from the closest PC, if we ship products from another center routes will be longer and, therefore, transportation activities more expensive.
After a deeper analysis of which channels could have greater potential to improve the results, it was decided to focus in the channels from America (both United States and Brazil). The explanation of why we came with this decision will be explained below these introductory paragraphs.

United States channel ⇔ Brazil channel

Moving on now to the explanation of why focusing just on North and South America channels, we can state the following:

- The global network is composed by four main production channels. Each of them cover large areas and many customers and are strategically positioned to supply their assigned clients. Supplying to customers assigned to a channel from another one it is not an easy task as route distances can become extremely long and time-consuming.

  For this reason, not every combination between the four channels seems to be feasible since some of them are too far from each other or simply have routes that make transportation much harder (See Figure 2.7).

  Regarding this aspect, we have discarded at this point certain combinations of channels like the one combining Denmark ↔ China: Transportation from Europe to Australia and New Zealand seems to be too long and costly.

  ✗ Denmark ↔ China.

- If it is desired to do a total differentiation of product lines in two different channels, China can not be a possibility. This is because the demand of all three products types in this channel is much larger than any combined capacity of all the other three PCs from other channels.

  The only possibility would be to add some RDCs of the other three channels to the supplying list from China. With this, we would reduce the manufacturing cost since producing in China is cheaper. However, the margin of increasing production here is so small (see Table 2.5, that very few extra customers could be added to its production network. Since transportation costs would clearly increase because of larger distances and production volume would not be very relevant (not big savings), this possibility was discarded.

✗ United States ↔ China.

✗ Brazil ↔ China.

- For this scenario, it is desired to reduce the production cost as much as possible. Therefore, it is desired to exchange production from a channel where manufacturing is more expensive to another one where it is cheaper unitary.

  In this sense, and reminding the information previously shown from Figure 2.23 and Table 2.7, it is know that generally the order is Denmark, United States, Brazil and China from more expensive to the cheapest respectively.

  Since China is not possible to combine, Brazil seems to be the most interesting channel where to produce the most, exchanging supplying activity with any of the other two channels.

  ✗ United States ↔ Denmark.

- Last but not least, we decided which channel matches better with Brazil with the purpose of taking advantage from this scenario.

  Regarding the demand rates from channels, United States matches slightly better with Brazil as both have similar volume needs.

  In terms of geographical reasons, both continents are relatively as far from Brazil, although North America seems to be an easier supplier.

  However, there is a decisive factor that helped us to decide. Denmark channel is the one that covers a bigger area of customers, shipping all the way to the Middle East and countries like Kazakhstan. Sending products from South America could make routes extremely long and costly.

  In addition, as there are several customers located in Central America, we could get benefits because shipping from North or South part of the continent does not really make a difference in terms of time and costs.

  ✗ Brazil ↔ Denmark.

  ✓ Brazil ↔ United States.

TABLE 2.26: Feasible solutions based on the production capacities in both manufacturing centers involved.

Scenario	**Product type**			**Feasibility**
	Part A	Part B	Part C	
1	US	US	Brazil	✓
2	Brazil	US	US	✓
3	Brazil	US/Brazil	US	✓*
4	Brazil	Brazil	US	✗
5	US	Brazil	Brazil	✗
6	Brazil	US	Brazil	✗
7	US	Brazil	US	✗

Once it is clear that the production differentiation will be analyze within US and Brazil channels, it is necessary to find out which combinations are possible regarding the product types each of them will get in charge of. This is summarized in Table 2.26 and explained in the paragraphs below.

1. Capacities of both PCs are big enough to guarantee the manufacturing of the demand from each product assigned.
2. Capacities of both PCs are big enough to guarantee the manufacturing of the demand from each product assigned.
3. Although Brazil can not produce the total amount of products A and B, the rest units left of part B will be manufactured in United States.
   * *This scenario derives from the first two cases. It is analyzed with the aim of finding if it could be beneficial to produce full capacity in Brazil because of lower manufacturing costs.*
4. The maximum capacity combining the 3 Lines in Brazil does not fulfill the total demand of Part A and B.
5. The maximum capacity combining the 3 Lines in Brazil does not fulfill the total demand of Part B and C.
6. The maximum capacity combining the 3 Lines in Brazil does not fulfill the total demand of Part A and C.
7. The maximum capacity combining the 3 Lines in United States does not fulfill the total demand of Part A and C.

IMPORTANT CONSIDERATIONS:

- By not using at all certain manufacturing lines over the year, the company will avoid having to pay any Activation costs in some cases.
  As a reminder, that type of costs is the amount that the company pays for activating the production line of a product at any point during a day. However, although the number of lines is reduced, the amount of time that the others are used increases since they are working now closer to full capacity in general. This fact will increase the Fixed cost of the production system, which is the one that the company pays regarding every hour a machinery line is producing.

  This means that, although it is expected to obtain higher production costs in Cases 1 and 2 (because of the fact that manufacturing costs are all higher in United States than in Brazil) and lower production costs in Case 3 (from producing more quantity in Brazil), this will be affected by how many lines are involved and how much are each of them producing, so results can vary from expectations.

- Regarding transportation routes, we have done a simplification in certain situations. For those routes that combine road and sea transportation, we have skipped the costs of unloading trucks and loading sea containers and vice versa. Not only that, but these commented routes of combined transportation because of geographical reasons, are simplified in order to calculate their cost as if they were totally through the ocean, with their derived fixed and variable costs.

In this hypothetical optimization scenario, the company would take advantage again of the flexibility they have in their manufacturing processes. Production lines have not size enough to be capable to guarantee the demand of a product type from the two channels combined.

The new approach is to limit the number of product types in each PC to 2 or even to 1 but getting in charge of the entire production of these part for both Brazil and United States.

It is important to explain each scenario of study in detail. As a punctuation, case 3 is an excision of the case 2 - we have found that this last one allowed us to achieve better results than the first option and thought of possible ways of progressing a bit further. Our wish was to reduce the manufacturing cost by scheduling greater amounts of production in Brazil, where the unit cost for each product is cheaper. However, as it will be explained later on this section, this was not successfully because although the production was improved, we incurred into higher expenses in transportation activities.

CASE 1:

<u>PART A:</u> All manufactured in United States and shipped to both North and South America RDCs.
<u>PART B:</u> All manufactured in United States and shipped to both North and South America RDCs.
<u>PART C:</u> All manufactured in Brazil and shipped to both North and South America RDCs.

CASE 2:

<u>PART A:</u> All manufactured in Brazil and shipped to both North and South America RDCs.
<u>PART B:</u> All manufactured in United States and shipped to both North and South America RDCs.
<u>PART C:</u> All manufactured in United States and shipped to both North and South America RDCs.

CASE 3:

<u>PART A:</u> All manufactured in Brazil and shipped to both North and South America RDCs.
<u>PART B:</u> Manufactured mainly in Brazil but also some parts in United States.

- Atlanta PC supplies to: Winnipeg, Fargo, Grand Forks, Milwaukee, Chicago, Indianapolis, Cincinnati, Oklahoma City, Kansas City, Toronto and Dallas*.
- Rio de Janeiro PC supplies to all South America, South Africa and the rest of RDCs not mentioned before in North America.

**It was decided like that considering their respective close distance to the PC and the fact that the their demand matches with the amount of units of product B that Brazil channel could not guarantee the supply.*

<u>PART C:</u> All manufactured in United States and shipped to both North and South America RDCs.

Once the main aspects of the study are described, it is time to show numerically how that new activities would be carried out and which results would they bring with to the company.

Again, all of these scenarios are possible thanks to the flexibility of all manufacturing centers, where lines can be adjusted to produce one part or another. Without doing any modification, lines are not capable to fabricate the amount of products demanded from both North and South America.

At this point, not every product is made in every PC, leaving their respective lines available for increasing the production of the parts that they are in charge from now.

In Table 2.27, 2.28 and 2.29, the restructuring of the production for the three analyzed possibilities is explained. These tables have two well-differentiated parts: The first one related to the products manufactured and the comparison between their line capacities and the demand, and the second one showing the available extra capacity from adjusting the other lines to gain more production rates. The complementary lines can be needed or not, and also once needed can be barely used or used quite a lot, and this is all detailed in the tables.

As a remark, the row "Extra need" shows the demand that could not be supplied by the PC without modifying its lines parameters. Lastly, the two final rows "Needed" and "% Used" provide information about the lines initially designed for products that they are not manufactured now, and detail if it is needed to redesign them and how much of their capacity would be used.

TABLE 2.27: Case 1 production restructuring in every line.

	CASE 1			
	Unites States		**Brazil**	
PART	A	B	C	
LINE CAPACITY	12.5M	11.8M	9.4M	
DEMAND	19.8M	17.2M	19.0M	
EXTRA NEED	7.3M	5.4M	9.6M	
NOT FABRICATED	C		A	B
MARGIN	13.1M		14.0M	10.4M
NEEDED	Yes		No	Yes
% USED	96.95%		-	92.31%

TABLE 2.28: Case 2 production restructuring in every line.

	CASE 2			
	Unites States		**Brazil**	
PART	B	C	A	
LINE CAPACITY	11.8M	13.1M	14.0M	
DEMAND	17.2M	19.0M	19.8M	
EXTRA NEED	5.4M	5.9M	5.8M	
NOT FABRICATED	A		B	C
MARGIN	12.5M		10.4M	9.4M
NEEDED	Yes		No	Yes
% USED	90.40%		-	61.70%

TABLE 2.29: Case 3 production restructuring in every line.

	CASE 3			
	Unites States		**Brazil**	
PART	B	C	A	B
LINE CAPACITY	11.8M	13.1M	14.0M	10.4M
DEMAND	3.2M	19.0M	19.8M	14.0M
EXTRA NEED	-	5.9M	5.8M	3.6M
NOT FABRICATED	A		C	
MARGIN	12.5M		9.4M	
NEEDED	No		Yes	
% USED	-		99.73%	

Summarizing the necessity of activating every line over the total available capacity to be compared within the three scenarios, Table 2.30 has been included below.

TABLE 2.30: Manufacturing lines usage rates for every scenario.

Scenario		**Case 1**		**Case 2**		**Case 3**	
Location		US	Brazil	US	Brazil	US	Brazil
Capacity Used	Line A	100%	-	90.4%	100%	-	100%
	Line B	100%	92.3%	100%	-	77.1%	100%
	Line C	96.9%	100%	100%	61.7%	100%	97.6%

Reducing the sum of production costs from United States and Brazil is the final objective of this section. Once achieved, it will be time to find out if it really compensates the extra costs derived from transportation. From now on, the explanation will be divided into the two areas mentioned: Production and Transportation. Their individual performances in comparison with the actual state will be analyzed individually and then as a whole, in order to provide more detailed information.

Production processes comparison

Focusing just in the manufacturing process now, Case 1 and 2 results in terms of production expenses are not easy to guess. By producing more units in United States the company will incur in higher unitary costs. However, some lines are now stopped, so activation costs will disappear from one line all year long. On the other hand, case 3 maximizes production in Brazil, so variable unit costs will be reduced. Theoretically the total production costs should be lower than the current status of the network.

TABLE 2.31: Production costs comparison between the three scenarios studied in this section and the current network state.

Scenario	**Production costs**			**Variation**
	Unites States	Brazil	Total	
Initial Case	273.4M	163.1M	436.5M	-
Case 1	349.8M	110.3M	460.1M	+23.6M
Case 2	330.2M	105.1M	435.2M	-1.2M
Case 3	166.9M	251.5M	418.5M	-18.1M

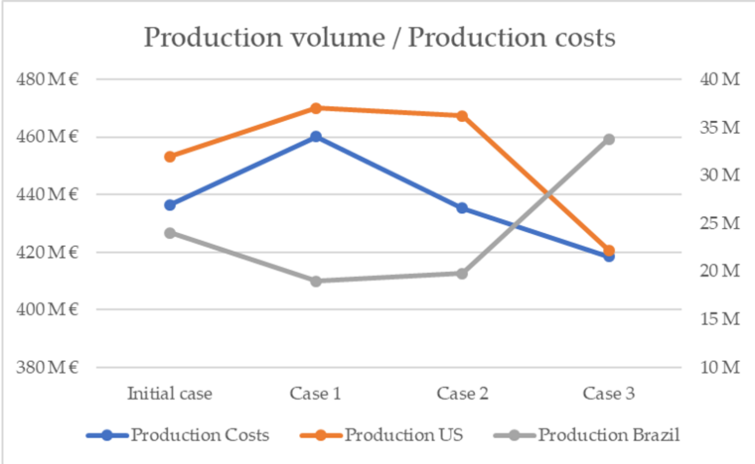


FIGURE 2.54: Relation between the production volume relative to United States and Brazil in comparison with the total manufacturing costs.

Table 2.31 and Figure 2.54 show the comparison between the three analyzed cases in this section and the current state of the network regarding United States and Brazil channels.

Thanks to them we can see that the more beneficial scenario to reduce manufacturing costs is Case 3. Case 2 leads to slightly lower costs than the initial case and Case 1 is not near improving the current situation of the network.

The figure adds some valuable extra information. It shows the evolution of the total production costs in comparison with the amount of products made in each of the two channels.

In general, for those cases where the production in United States is increased and lowered in Brazil (Case 1 and 2), the results do not show an improvement, whereas in the third scenario, by maximizing production in Brazil, there is a considerable cost reduction in the manufacturing process.

TABLE 2.32: Comparison between manufacturing processes: Lines involved and fixed/activation costs.

Scenario	**Lines used***		**Fixed**	**Activation**	**TOTAL**
	Unites States	Brazil			
Initial Case	3 (3)	3 (3)	51.5M	66.7M	128.2M
Case 1	3 (3)	2 (2)	70.1M	57.2M	127.3M
Case 2	3 (3)	2 (1)	55.8M	56.4M	112.2M
Case 3	2 (1)	3 (3)	64.1M	54.1M	118.2M

* *In brackets, those lines that are used more than 90% out of their total capacities*

To understand the influence of stopping certain manufacturing lines in case full production is not needed, we have added the Table 2.32. In it, number of lines used in each PC, total fixed and activation costs, as well as the sum of both are represented.

Focusing first on the number of lines needed in the process, it can be seen that every new scenario requires at least one less line to fulfill the demand. More specifically, current case uses all 6 lines, while every other studied case would need only 5 of them. There is also a remarkable detail which is that for cases 2 and 3 only four lines are used over 90% of capacity, whereas in the first scenario we would need five of them.

Theoretically, the lower usage rates of the lines, the less expenses of Fixed costs that will be payed. Also, the less lines used, the less money it will be expended in Activation costs. However, this predictions can be varied because of the differences in the costs set-up by product and channel shown in Section 2.2 of this Chapter.

Summarizing the results obtained in terms of just production activity, from the cheapest to the most expensive:

Fixed + Activation:	Case 2 → Case 3 → Case 1 → Initial case
Variable:	Case 3 → Initial case → Case 2 → Case 1
Total:	Case 3 → Case 2 → Initial case → Case 1

Transportation activities comparison

In relation to the transportation between both continents, there are some remarkable facts that definitely pay a role in the results obtained and, therefore, need to be explained before presenting any results.

1. **Position of the Production Centers**

   It is not part of this project to analyze which benefits or disadvantages have the locations of the manufacturing centers, nor to try to find the reasons why the company decided to place them there. However, it is obvious that they are there for a reason and, since we are considering new purposes and designs for the network, this location can be hard to adapt to this new activities.

   The PC of Atlanta is quite near the east coast and relatively close to the southern part of the continent. It is not a bad location for this new scenario of shipping to South America at all.

   On the other hand, the PC of Rio de Janeiro, it is not in a very great location. Although it is on the coast, ships have to round almost the entire coast of Brazil to go northern. It could have been better if it was closer to Central America in this case.

2. **Infrastructures and geographical influence**

   This company's global activity covers so much area and so many customers all around the globe. The complexity of some routes is a big challenge, and finding the optimal solutions can be very time-consuming. In this case, there is a clear difficulty in South America because of the natural geography of the continent including the Amazon covering a very large area of Brazil and surroundings, but also, the large mountain chain in the western part.

   In addition, South America is, in general, not a very developed territory. Roads and infrastructures are not the optimal ones, and transportation times are generally longer than in other places comparing the same distance.

3. **Location of all customers**

   As we said previously, there is a very large area covered by the company's activity. In this case, the optimal case would be to have the higher demand possible in coastal and close-to-equator locations. In North America there are several important customers in inner cities and even in Canada (much northern), whereas in South America most of the RDCs are near the sea.

> Our task is to find a satisfactory transportation plan and to achieve the lowest time and cost consuming solution possible.

Connecting United States and Brazil channels in terms of supply-demand would clearly modify the transportation channels, bringing to us the task of finding the optimal routes and shipping methods.

The connections between PC-MW-CDCs-RDCs within the same channel would not be modified from the real status. This means that all routes which start and end in North America will have the same procedures as before, and same with South America.

However, we had to find a way of shipping from/to both continents. To do so, we divided the connections which ship from United States depending on East and West locations. This means that the packages to RDCs located in the East part of South America where sent from CDC in Columbia (Charleston Port). The ones going to customers placed in the West side would be shipped from CDC in Los Angeles.

Packages sent from South America do not follow the same trend. Since CDC in Brazilia is located in a very inner side of Brazil, it was thought that it would be more beneficial if that one only supplies to the RDCs from that same continent. In general, the transportation would be by road, but some to some centers located in Central America, it would be by the ocean from Fortaleza port, since it is cheaper.

CDC in Porto Alegre would be in charge of shipping to North America, since it is very close from the MW and it is a coastal city - no need to move products from trucks to containers after they are stored in CDC.

For this optimization and, based on the possible modifications of sea shipping sketched in Figure 2.69, the ocean transportation will start from only two ports in both North and South America. This means that the company would not ship the lot from the closest port (from many ports), and will concentrate their operations in very few loading ports (Modifications 1 and 2 from Figure 2.69).

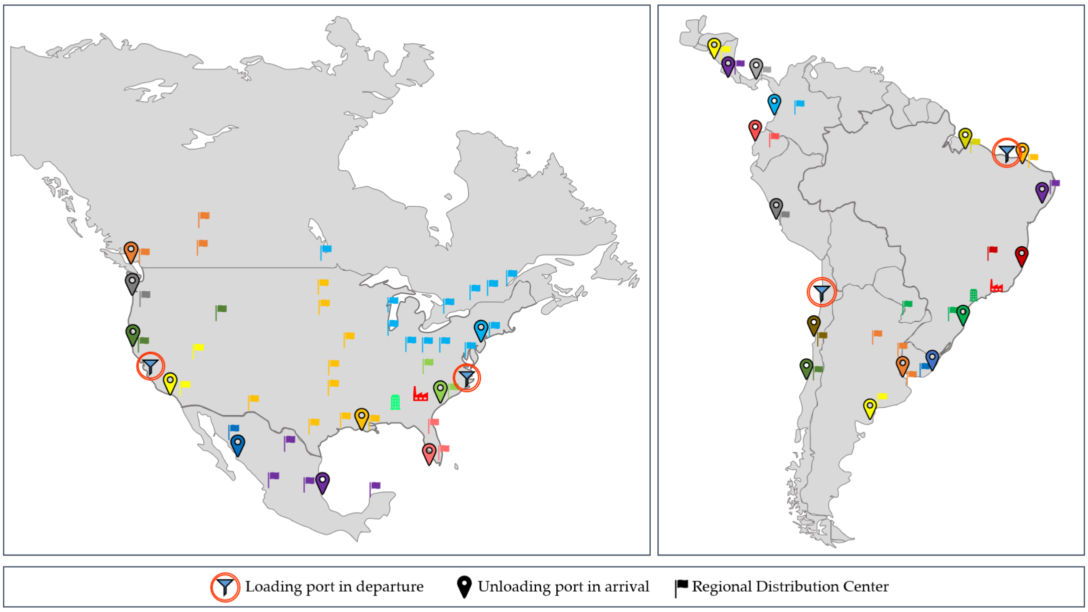


FIGURE 2.55: Loading and unloading ports for the shipping routes with final RDC destinations

There is a little detail in Case 3 that needs a bit of explanation. In this hypothesis, Part B products are not only elaborated in one PC, so their production is combined.

However, the amount of units made in United States in quite low and can supply to a few number of RDCs only. These mentioned RDCs were chosen by their proximity to the MW, by the fact of not being close to the coast and by fitting the demand to the production of Part B in the PC in North America. Choosing interior RDCs will lead to cost-savings as if the shipping from Brazil would have to be sent there, a exchange from containers to trucks would be needed.

Figure 2.56 shows in orange those RDCs where Part B is supplied by Atlanta PC and, in purple, the ones in which this product's type is provided from South America.

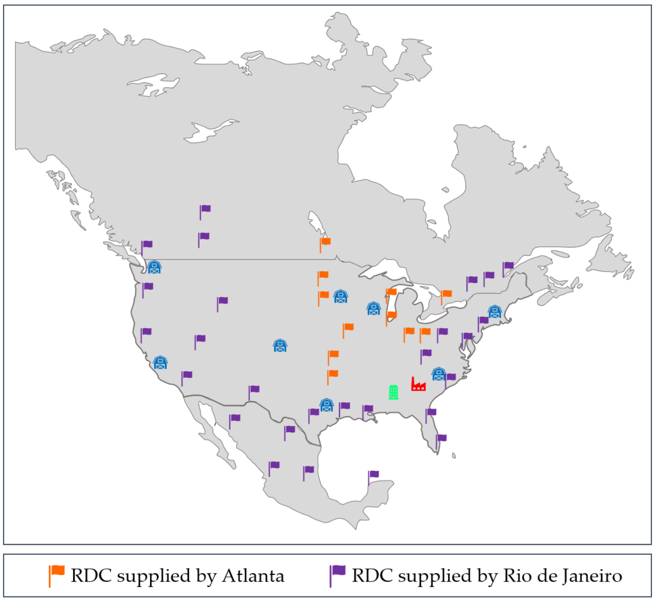


FIGURE 2.56: Part B RDCs that are supplied by PC of Unites States or Brazil in Case 3 hypothesis.

With all descriptions of the routes and shipping activities explained, it is time to analyze the data and results from all three scenarios in terms of transportation.

The results from transportation are not favorable at all. Routes are so long time consuming and the investment that would need to be done it is extremely high, as it can be checked in Table 2.33. The final column shows the increasing in million of euros that would carry putting these hypothesis into practice, which is clearly very significant.

TABLE 2.33: Transportation costs comparison between the three scenarios studied in this section and the current network state.

Scenario	**Transportation costs**			**Variation**
	Unites States	Brazil	Total	
Initial Case	82.7M	99.4M	182.1M	-
Case 1	142.9M	124.0M	266.9M	+84.8M
Case 2	134.8M	122.8M	257.6M	+75.5M
Case 3	86.0M	191.8M	277.8M	+95.7M

To help us describe the trends and performances of the company's transportation activity between the three new cases and the current one, Figure 2.57 has been included in this report.

The graphic compares the evolution of production rates together with transportation investment for all four cases.

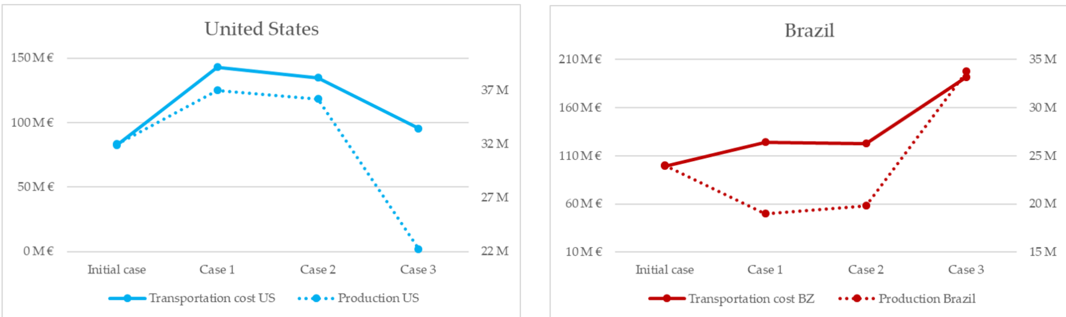
This combined graphic of United States and Brazil transportation investments is been done in a way in which both parameters match for the current state. This makes the comparison with the other three situations easier and more clear to comprehend.

The first notable fact is that transportation cost do not match any more with the production rates. The transportation line is above the other one in every cases except in Case 3 in Brazil, where they coincide again.

The second and very determinant evidence is that, for those cases where the demand has increased in the PC (Case 1 and 2 for United States and Case 3 for Brazil), transportation costs line is just a bit above the other one, or directly matching as it is the case of the one in Brazil. For the cases where the production rate in being lowered (Case 3 for United States and Cases 1 and 2 for Brazil), the proportional relation within parameters does not exist anymore. In all three situations, although the production is much lower than the current activity one, the transportation expenses are higher.

It is thanks to these graphics where we could understand the unexpected not satisfactory results from this scenarios.

Production $\Uparrow \rightarrow$ Transportation costs increase proportionally to production.
Production $\Downarrow \rightarrow$ Transportation expenses are not lowered from current status.



(A) *Detailed for United States .* (B) *Detailed for Brazil .*

FIGURE 2.57: Comparison between transportation costs and production rates in both countries involved in the study for each of the 4 scenarios.

Lastly, we compare the total expected annual expenses for the three new scenarios and the real activity in Figure 2.58 and Table 2.34.

As a summary, meaning by $\Downarrow$ worst results and by $\Uparrow$ improved results:

	Production	Transportation	Total
Case 1:	$\Downarrow$	$\Downarrow\Downarrow$	$\Downarrow$
Case 2:	$\equiv$	$\Downarrow\Downarrow$	$\Downarrow$
Case 3:	$\Uparrow$	$\Downarrow\Downarrow$	$\Downarrow$

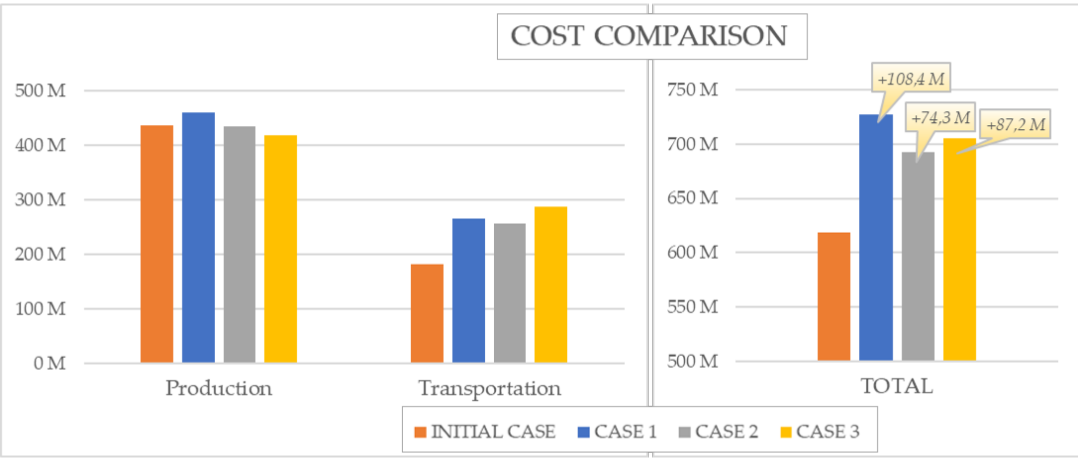


FIGURE 2.58: Cost comparison regarding production and transportation activities between the current status and the three studied scenarios

TABLE 2.34: Summary of total investments expected for each three analyzed cases and the current status of the network.

Scenario	**Total expenses** [€]	**Cost variation**	
		Difference [€]	Difference [%]
Initial Case	3.834.120.520	-	-
Scenario 1	3.942.819.310	+108.4M	+2.84 %
Scenario 2	3.908.634.746	+74.3M	+1.94 %
Scenario 3	3.911.267.589	+87.2M	+2.01 %

At the end, comparing the total costs (production, storage and transportation) and, although in storage activities there is barely no change in the invested sum, the three scenarios would increase between 2 and 3% the annual budget of the company.

MAIN CONCLUSIONS FROM THE RESULTS:

Before starting the analysis of this scenario in detail, it was known that the company would incur in considerable extra costs in terms of transportation activities.
Our goal was to minimize as much as possible the manufacturing costs by converting Production Centers into specialization. This means that in this hypothesis, instead of fabricating every product type in every center, each center would be in charge of only one or two parts as maximum.
After an initial pre-study, it was decided to focus in the channels from America, where the implementation of this structural change of the performance seemed to be feasible and could bring beneficial results.
However, the intention of improving the current business activity was not fulfilled in this scenario - although we managed to reduce considerably the production expenses (in case 3), the large increasing of transportation costs made these scenarios not profitable and, therefore, their hypothetical implementation not considered anymore.

- Production differentiation → Feasible ✓
- Reduction of production investment → Achieved ✓
- Transportation costs → Extremely high ✗
- GENERAL IMPROVEMENT → NOT ACHIEVED ✗

2.6 Production channels optimization

This scenario aims to find a new manufacturing scheduling model which could be implemented by the company helping them to reduce the total expenses.
In this case, there will not be any adjustments or modification between lines - the changes will be done in the planning of every line in particular.
In Section 2.2, it was explained that manufacturing lines were not working at full capacity. Some of them like the ones in China are closer to the production limits while lines from Brazil have larger margins to maximize their production (Figure 2.10).
It was also mentioned that the system was set to make production rates constant all over the year - the total expected demand was divided by the number of days in a year and, every day, manufacturing lines were assigned to produce the same amounts.
This last consideration is to be changed in this new approach. Activation cost type is paid in a daily basis, so no matter if the line is used during one hour or the entire day, the amount to pay is the same for that day. Instead of producing all days below total capacity, the system would work fully some days and then totally stopped during others while fulfilling the same total demand.

As in previous scenarios, the explanation starts with the understanding of the system's work-flow within all stages of the network.

The main modification is, of course, in the first stage related with production. Before, the fabrication was a straight horizontal line as it was constant, but now it evolves as a periodic chart (sometimes full capacity, others totally stopped).

When it is said that production will be periodic, we mean by line but not by Production Center. This means that units to be shipped from PC to MW will not be periodic, since each line has its own periodic charts and the transportation is done regardless the product types. Transportation is therefore varying randomly.

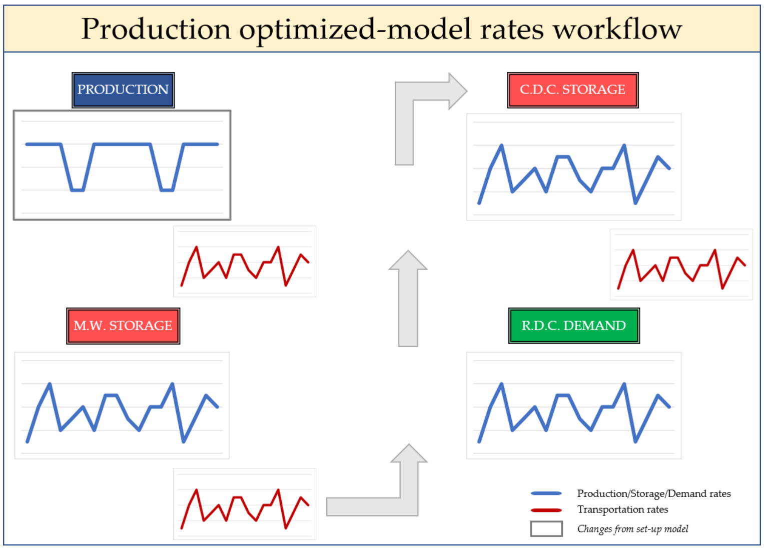
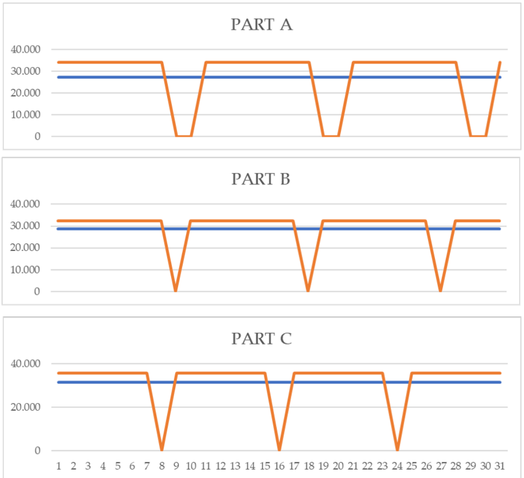
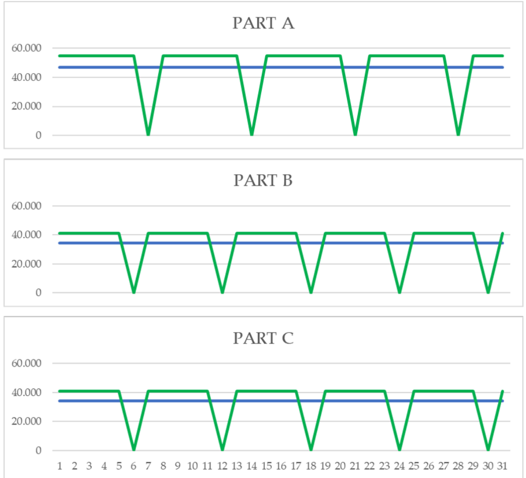


FIGURE 2.59: Work-flow rates performance in the distribution process once the production is optimized

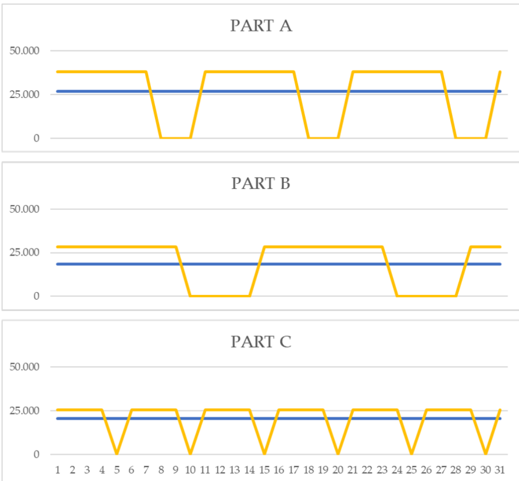
To illustrate how production operations would change in this new scenario, Figure 2.60 is added below these paragraphs. There is one chart for each manufacturing line in every PC.



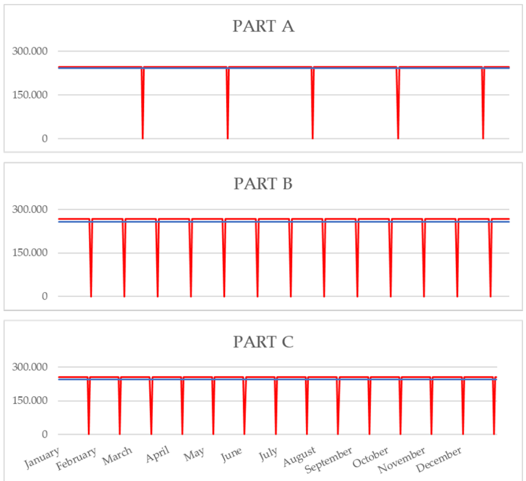
(A) *United States production modification.*



(B) *Denmark production modification.*



(C) *Brazil production modification.*



(D) *China production modification.*

FIGURE 2.60: Comparison between current constant daily production and new proposed production activity performance.

In blue, the actual production activity is represented (horizontal/constant chart). The other line represents how it would look like the production rates in this new studied optimization. It can be seen how lines would work above the capacity there is right now (up to full capacity), and then they are completely stopped for other shorter periods. These periods where designed to match the production of both scenarios in a year basis.

To make the graphics easier to understand, United States, Denmark and Brazil charts have been detailed in a monthly basis. These trends do not vary during the year and, by shortening the x-axis, the modification of the production is easier to see.

On the other side, in China, since the production of the real model is already very close to full capacity there is no much margin of improvement. The daily production is very high and the margin of increasing production very thin, leading to a very little reduction of days in which the manufacturing lines can be stopped. This is why, for this last channel, the charts have been designed in a yearly basis instead, so we could appreciate the difference between both models a bit more clear.

To find out numerically the benefits in terms of days stopping the lines, Table 2.35 is been added. In it, we can read and compare number of total days in which each line is totally stopped, together with the percentage that those days represent over the total days in a year.

The lines can be stopped the most days in Brazil (up to 20-30%), whereas in China these days do not represent more than 5% of the total days in a year.

TABLE 2.35: Total number of days in which manufacturing lines are out of use.

Location	Production Stopped	Part A	Part B	Part C
Atlanta	Days	72	40	45
	% in Year	19.67%	10.93%	12.30%
Aarhus	Days	52	45	61
	% in Year	14.75%	12.30%	16.67%
Rio de Janeiro	Days	108	130	73
	% in Year	29.51%	35.52%	19.95%
Shangai	Days	5	13	14
	% in Year	1.37%	3.55%	3.83%

Changing some production planning parameters and procedures has some consequences in other stages and activities of the network such as transportation and storage tasks.

Regarding transportation, the only main difference in this new scenario would be in the stage from the PC to the MW, since it is the only connection in which shipping schedules and quantities would be affected. Trucks needed would change according to the production amounts - bigger needs when full production and no trucks required when PC fabrication lines are stopped.

From the Main Warehouse to the customers, transportation activities would not be modified from their current status. The shipping planning remains unchanged from this stage of the network and, with it, all the related activities (transportation and storage).

The current network performs in a way in which, except unexpected circumstances, Main Warehouse usage rates do not vary among the year - the same volume of products is sent from the PC to the MW and from this one to the respective CDCs. However, in this new scenario, the situation would no longer be like this. The demand from the distribution centers will remain constant every day but the variations in production would lead to little peaks in the MW storage levels.

Figure 2.61, shows the variation of the MW levels for this new network model in comparison with the existing one. It can be seen how, although at the end of the year the occupancy levels are approximately in the same levels, the charts are considerably different. Besides that, the peaks do not differ much from the constant rates the network has right now - no variation is greater than half of a million units - so this aspect would not affect much the process, since there is still a large margin to increase the occupancy levels in MW at every moment of the year. In the following Figure:

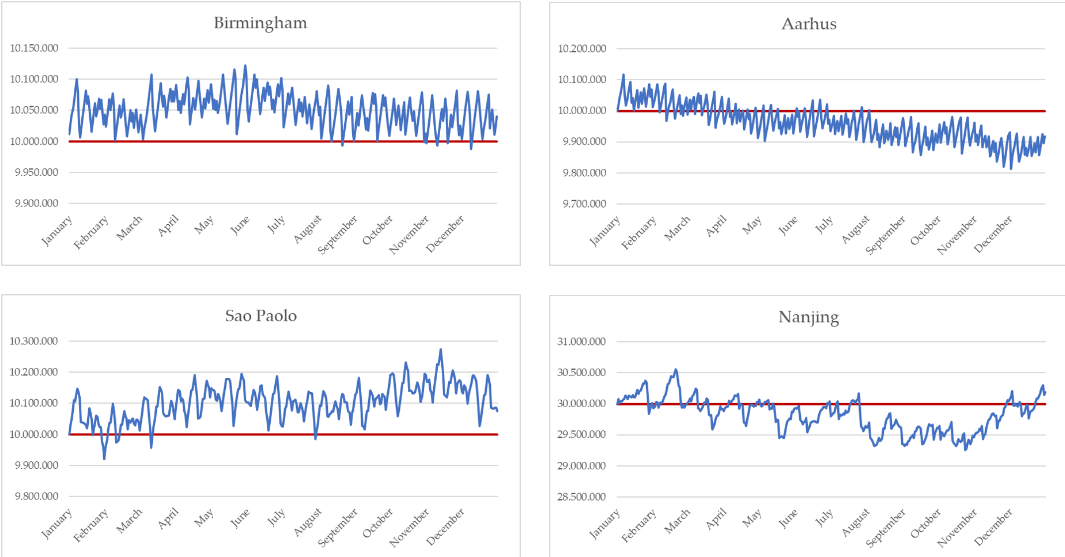


FIGURE 2.61: Comparison between Main Warehouses usage rates before and after the production planning optimization.

To find out which would be the real consequences of applying this new model in terms of cost savings, we compare the respective variations in the activation cost expenses in all four PCs in Table 2.36.

TABLE 2.36: Total activation cost reduction.

Location	**Part A**	**Part B**	**Part C**	**Total**
Atlanta	-2.473.200	-1.922.000	-1.302.300	-5.697.500
Aarhus	-2.390.960	-2.694.150	-2.439.390	-7.524.500
Rio de Janeiro	-2.818.260	-3.646.500	-1.226.400	-7.691.160
Shangai	-199.500	-644.475	-406.700	-1.250.675

The table shows how this modification provides the biggest improvements in Denmark and Brazil with savings of approximately 7.5 million, followed by United States with up to 5.7 million of cost reduction and, finally, China with a much lower upgrade (1.2 million reduction).

Same results are also showed graphically in Figure 2.62. The orange area represented refers to the cost investments of every product type regarding activation production expenses. The blue area, shows the same costs summary for the new analyzed scenario. Therefore, the margin within both upper limits, shows the cost reduction that this hypothetical case would give to the company.

In the figure, it is even more clear that there is barely no cost reduction in China (very thin margin), whereas in Denmark and Brazil (specially Part B) we can achieve much better results.

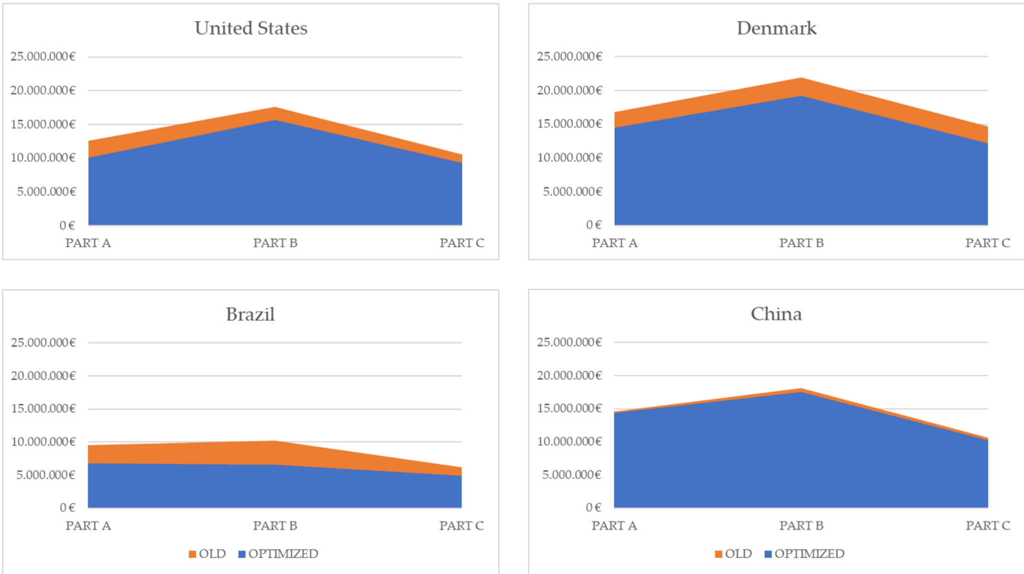


FIGURE 2.62: Comparison between expenses regarding activation costs.

However, it was a bit surprising when analyzing the results that we get approximately the same savings in Denmark and Brazil. In the first table of this section (2.35) we saw how manufacturing lines could be stopped much more time in Rio de Janeiro PC than in Aarhus.

After a deeper analysis, we figured out that the result had to do with how much it costs to use a product line in each of the channels. For example, for those PCs where the expenses are quite high, stopping the line one day could be equivalent of stopping it two days in other centers.

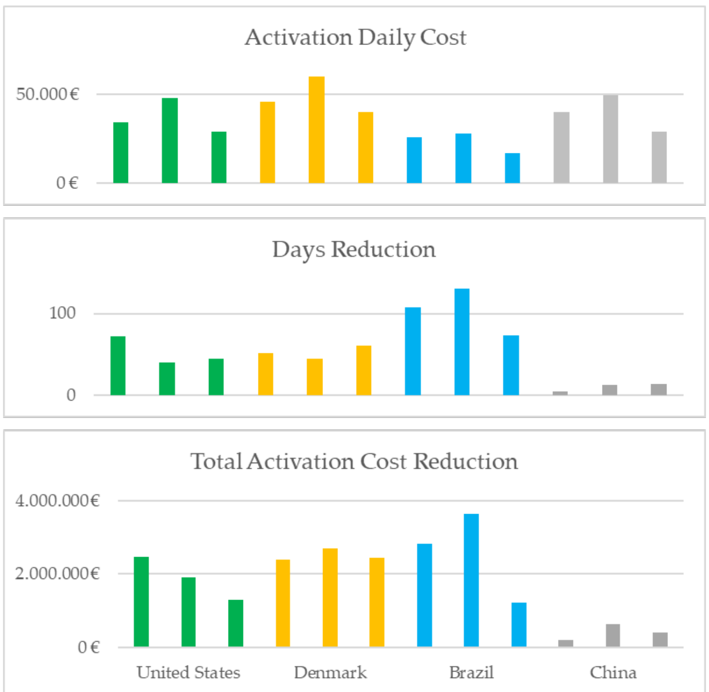


FIGURE 2.63: Activation cost annual reduction in comparison with the total expenses and daily cost.

To see the relation between the unitary activation costs explained in the beginning of this Chapter and the reductions obtained in this scenario, Figure 2.63 is added.

The graphic is a combination of three different charts which, each of them, show a specific parameter. The first one shows the amount that the company pays as Activation cost daily when they use one of the manufacturing lines at any moment during a day - this was already shown in Table 2.7 and Figure 2.23 of the introductory Section. The second part represents graphically the number of days that each production line will be stopped now thanks to this new approach. Finally, the last part shows the total savings for each line if this new manufacturing strategy would be implemented.

So, thanks to this figure we can clarify and understand better the results that we obtained in Table 2.36.

By looking at the activation daily costs that the company pays for each product line in every channel, we see that these ones are very similar in United States, Denmark (a bit higher) and China, whereas in Brazil these costs are considerably lower.

If we focus on the number of days where lines are stopped, Brazil is clearly the place where bigger improvements (in terms of reduction of the total number of days) are obtained, followed quite far by United States and Denmark.

Combining the information of the first two charts we can understand the last part of the figure. Starting with China, although the activation cost is similar to other locations, since the total number of days in which the PC lines are working is barely reduced, the total manufacturing savings are very little. In United States and Denmark, the days in which lines are stopped are almost the same number (157 in US and 158 in Denmark - not all three lines stopped, just any of them). However, the activation unitary costs are greater in Denmark, leading to a bigger reduction of total expenses in Denmark PC. In Brazil, unitary costs are much lower than the others but the reduction of days in which lines are working much higher, leading to very similar results in total cost savings than in Denmark.

Before showing the final results from this case studied, a last punctuation regarding the new hypothetical manufacturing scenario should be mentioned. The design of the cycles in which centers should be operating at full capacity or stopped was done considering an optimal fit of the demand that the network requires. However, this numbers were rounded, since there is not an exactly combination that produces the same amount unless there is one day in which the factory would not operate at full capacity. Because of that, there a very little variation in the variable total cost because of tiny differences in the total number of units produced. Reductions in the activation cost are therefore not exactly the same ones as in the total manufacturing process, although the difference could be obviated.

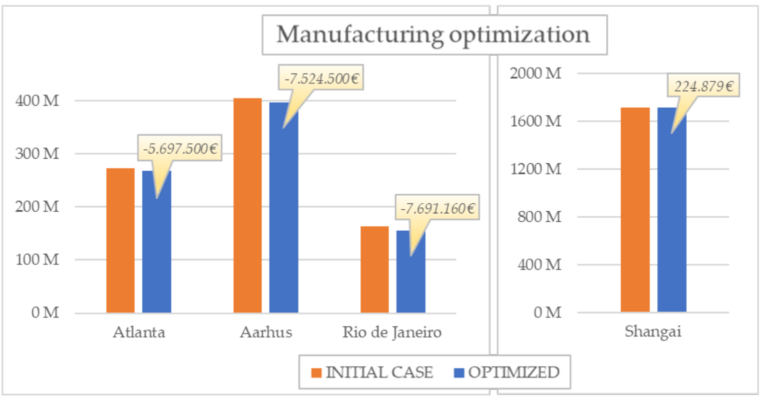


FIGURE 2.64: Production annual cost reduction by manufacturing channel.

To sum all up and do the conclusion of this optimization scenario, we have made Figure 2.64, where the cost reduction in terms of manufacturing is presented for all four channels.

In Table 2.37, the sum of every cost variation is presented. The total saving raise up to 21 million euros of reduction, which represents a percentage of 0.8% of the total annually expenses of the company's activities.

TABLE 2.37: Production cost comparison between initial case and optimized model.

PC	Initial case	Optimized	
		Reduction [€]	Reduction [%]
United States	273.412.350	-5.441.425	-1.99 %
Denmark	405.241.742	-8.560.639	-3.13 %
Brazil	163.082.461	-7.284.539	-2.66 %
China	1.717.987.787	224.879	0.08 %
TOTAL	2.559.724.339	-21.061.724	-0.82 %

The last remarkable note from this scenario is that, by changing the manufacturing scheduling system, other activities can be certainly affected. Being more precise, transportation from Production Centers to Main Warehouse would definitely change from the current case - more trucks would be needed for those days where all lines are working at full capacity, and less or even no transportation units would be used when the lines are stopped.

Apart from that, production rates do not match 100% with the previous ones. However, the difference is so small that would have no influence in the previously mentioned transportation connection and also in the following activities.

Variation of the rest of activities within the network:

- PC → MW transportation: + 119.858 €
- MW storage: + 25.287 €
- MW → CDCs transportation: -
- CDCs storage: -
- CDCs → RDCs transportation: -

It is proved that, although this modification in the production system influences two other activities of the process, it is so small that can be totally neglected for the overall analysis.

The total investment that would need to be done by the company annually if this case would be implemented would be: **3.813,2M €**, which would reduce by **20,9M €** the current expenses. This improvement represents a reduction of **0.55%** of the total costs.

It is, therefore, a satisfactory approach. The modification that represents for the manufacturing process is not hard to implement at all - it would only require a more precise management task and a good planning to be followed for every employee in the production center.

MAIN CONCLUSIONS FROM THE RESULTS:

Production centers have been designed to guarantee fabrication rates greater than the ones they are carrying out in the current network model.
Besides the oversized manufacturing centers, the organization of the process is still distributed over every day during the year. Logically, as it can be intuited, opening the factory all year long leads to high maintenance and operation costs.
This scenario was analyzed with the main objective of restructuring the production schedules to reduce the total costs.
No changes in the units made or in the supply channels was done in this section. The only and main transformation was producing near full capacity during certain days and stopping the production in other periods, leading to considerable cost savings from Activation costs in factories.

- Intermittent production → Feasible ✓
- Lower manufacturing costs → Achieved ✓
- GENERAL IMPROVEMENT → ACHIEVED ✓

2.7 Production and transportation combined optimization

Once several new scenarios have been analyzed and their hypothetical implementations compared, it is already known which of them can be profitable for the company and which are not a good option.
Converting the current constant production rates into an intermittent and cyclic manufacturing planning was proved to bring benefits mainly because of the savings derived from totally stopping some lines certain days and not having to pay line activation costs for those periods of time.
On the other side, modifying the transportation shipping management and ensuring the fully filling of every transport unit, was proved to be another more efficient possibility.
This section's objective is to ensure the viability of implementing in reality both modifications, as well as to check if both costs savings would be summed proportionally. In case this is possible, we are expecting this approach to be the best solution out of all that have been analyzed in this report.

In general terms, this section could be understood as the combination of the following sections:

$$Section\ 2.4 + Section\ 2.6$$

As in other sections, a work-flow collecting each of the activities that take part of the network is shown (Figure 2.65). Of course, it a bit of a mix between the ones added in the transportation and manufacturing optimization studies separately.

Production is cyclic regarding each product line, since they would be either working at full capacity or stopped but always in the same repeated periods among the year.

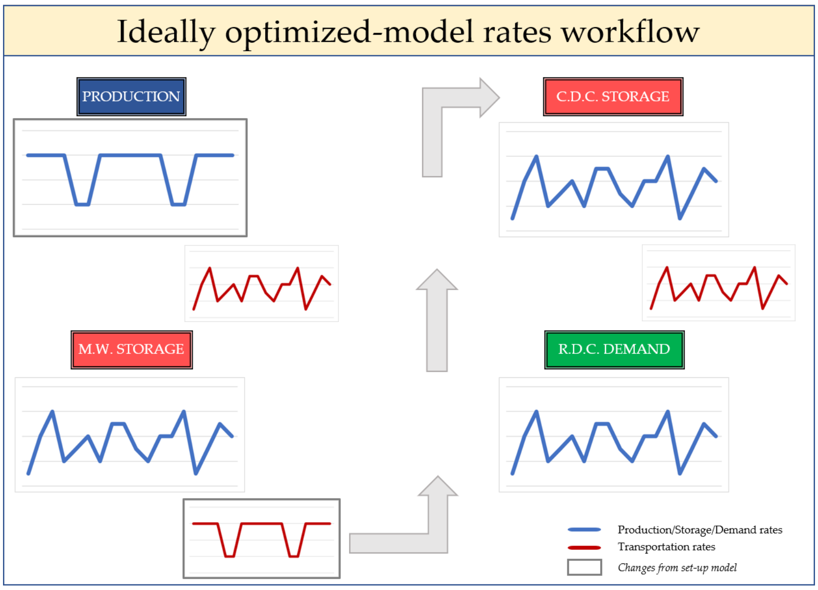


FIGURE 2.65: Work-flow rates performance in the distribution process once the entire channel is optimized

In relation to transportation, this activity is done periodically in only one stage (from MW to CDCs) and without any specific pattern in the first and last connection (between PC and MW and from CDCs to RDCs).

In the first one, although lines are scheduled to produce in periods, each of them work individually and the combination of the three lines of every center results in alternative shipping amounts over the year. Since the PC does not have a relevant storage capacity, transportation needs to fit quite close to the production rates, meaning that will also vary randomly.

The second connection is the one that can be fully cyclic because of the fact that there is storage margin in both the initial and final nodes (MW and CDCs). Both of them have plenty of free space which can be used so transportation can be adapted to the most optimal way we can find regardless if the shipping rates fit or not in any other time basis that is not yearly.

Derived from the modifications carried out in the transportation activities, every storage center has variable usage rates among the year - the biggest change takes place in the MWs where the use is constant in the current model and would no longer be if applying this new scenario.

In order to combine the processes developed in both scenarios involved, it is important to understand which performances studied before can be directly exported to this new case and which ones have to be analyzed again but following the same patterns. There are 6 major activities which are: Product manufacturing, PC to MW transportation, MW storage, MW to CDCs transportation, CDCs storage and, finally, CDCs to RDCs transportation. For each of them it will be explained below if they need to be recalculated or not and why.

1. **Product manufacturing:** *Can be exported from Section 2.6* ✓

2. **PC to MW transportation:** *Needs to be recalculated for this new scenario* ✗
   Since production rates in PCs are no longer constant during the year, the shipping in this connection can no longer be designed periodically. Instead, the design of the optimal transportation system is done similarly to the one developed to ship from CDCs to RDCs - only the amount of packages that makes all trucks full is shipped, the rest is stored and send the next day together with the next lots.

3. **MW storage:** *Needs to be recalculated for this new scenario* ✗
   The changes carried out in the transportation to this center will make that the rates of occupancy will vary in slightly different shapes and the total number of orders that will be controlled here could vary also (almost neglected).

4. **MW to CDCs transportation:** *Can be exported from Section 2.4* ✓
   From the MW on to the final customers the performance of the network will not be modified. The quantities sent to the CDCs would be cyclic (right now they are constant) because of the trucks fully loading optimization that was detailed in the previous section.

5. **CDCs storage:** *Can be exported from Section 2.4* ✓

6. **CDCs to RDCs transportation:** *Can be exported from Section 2.4* ✓

Tables 2.38 and 2.39 show the characteristic results obtained for the two new calculations carried out of the activities mentioned above.

In Table 2.38, the first two columns present the number of trucks needed to transport the produced units to the MW once the restructuring of the manufacturing system is added. The first one refers to when the transportation is optimized (Section 2.7) and the second one without optimizing the shipping (Section 2.6). We can see how reduction between 100 and 300 trucks approximately are achieved.

The third column shows the trucks that were used when transportation was optimized but production was not (Section 2.4). In general, it was possible to reduce even more the number or trucks that were used in this stage.

TABLE 2.38: New PC to MW transportation optimization for the manufacturing process management approach.

Channel	**Trucks needed**		
	New manufacturing		**Old manufacturing**
	Optimized	Non-optimized	Optimized
United States	64.080	64.298	64.020
Denmark	84.317	84.650	-*
Brazil	48.200	48.333	48.007
China	546.629	546.714	546.207

Table 2.39 compares the expenses derived from ordering tasks between the real model and the one that is developed in this section. There are differences but they are very small perceptually and not really have an influence in the final results. These little variations derive from the adjustments of filled trucks - depending on the margin left at the end of the year between exact demand and supplied.

TABLE 2.39: MW ordering cost expenses variation for each of the four channels in comparison with the current status of the network.

Channel	**MW Ordering costs**		
	Current Status	Optimized case	Variation
United States	2.748.126	2.753.528	5.402
Denmark	4.731.007	4.729.334	-1.673
Brazil	1.390.218	1.394.837	4.618
China	9.819.144	9.835.455	16.311

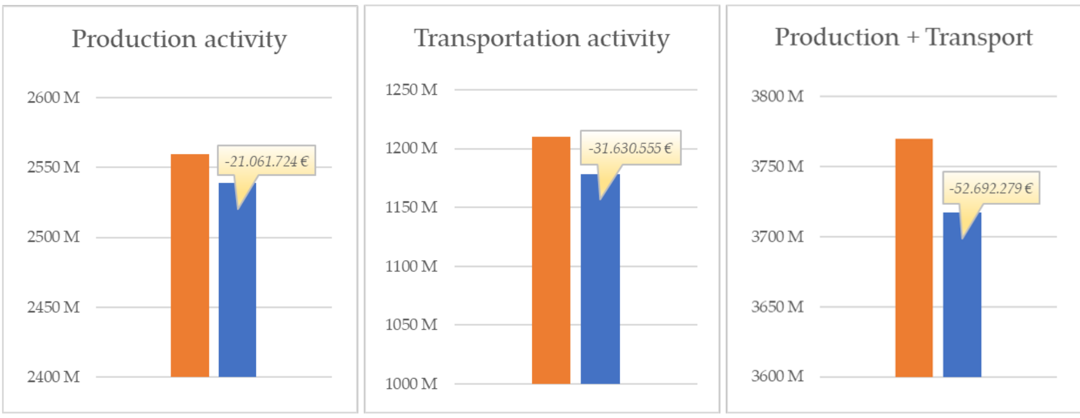


FIGURE 2.66: Cost reduction in production and transportation activities and the combination of both.

Once the two stages left were recalculated, it is possible to describe the results and analyze the benefits from the hypothetical implementation of this model.

Figure 2.66 shows the improvements in terms of cost savings respect the current real model obtained in the production activity and in the transportation one, both individually and combined. Then, in Figure 2.67 Storage activity is also included so we can see graphically the very little influence that this new model would have in this ambit in comparison with the current status.

As a conclusion, this scenario is very beneficial in terms of cost reduction (**52.6M € less**). The total sum of expenses goes up to **3.781,4M €** which represents **-1.37%** the actual investment of the company annually.

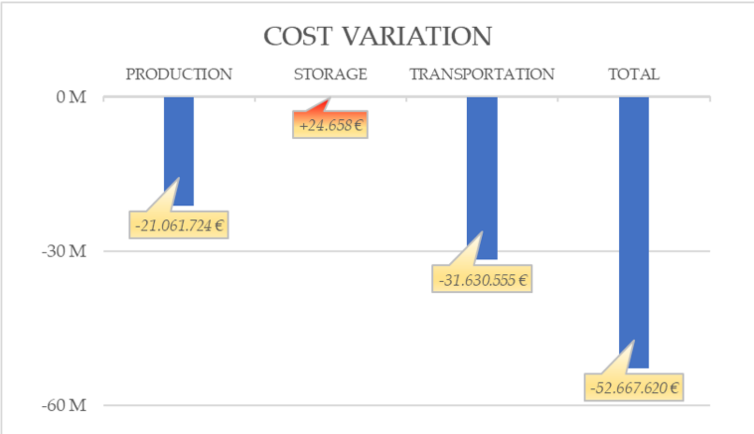


FIGURE 2.67: Cost expected investments by activity and variation of them from current network status.

MAIN CONCLUSIONS FROM THE RESULTS:

It was previously presented in this document how the biggest percentage of the annual investments of the company were related to manufacturing and transportation activities.
As they are the areas in which the margin of optimization is wider, two solutions - one for each of the fields - were described in Section 2.4 and 2.6 respectively.
The purpose of this section was to combine both improvements and connect them into one new methodology that improves both production and transportation systems.

- Intermittent production → Feasible ✓ *[Already proved]*
- Lower manufacturing costs → Achieved ✓
- Restructured transportation → Feasible ✓ *[Already proved]*
- Lower transportation costs → Achieved ✓
- Combination of both system modifications → Feasible ✓
- GENERAL IMPROVEMENT → ACHIEVED ✓

2.8 Costs comparison and feasibility study

Once the experimental scenarios have been described and analyzed individually, this section aims to present a general comparison between the results of all studied cases.

The first phase of this chapter was to fully describe the current status and business performance of the global logistics network analyzed. To do so, all areas of the chain were covered and explained (transportation+storage+production). In the introduction, the set-up of the network, the location of each of the units that compose the network and also of every customer were detailed. Then, the characteristic parameters and rates such as production capacities and current rates, transportation routes distances and warehousing storage evolution and occupancy rates were included. The last part of it was explaining how are the cost analysis consequent decisions that managers of the company take into account when estimating and forecasting the investments the company will need to do in order to ensure the satisfactory performance of all stages of the network.

To understand how would the network respond to variations of the demand in each of the four channels, an hypothetical case which proposed certain potential increases of the demand was analyzed. The objective was to decide if the company would be ready to put up with that changes without modifying the system at any level.

From that point on, a total of 6 scenarios to restructure the network model were designed in detail. One regarding transportation shipping management, other three considering the specialization into less products manufacturing lines of certain PCs, another case in which a different strategy of managing the production was developed, and the last one in which both transportation and manufacturing optimization changes were applied and combined into the network.

KPIs and the most significant parameters for each of the studied cases were already shown in each of their individual process explanations. However, in the lines below they will be compared in terms of costs from every activity and global cost of the whole structure.

TABLE 2.40: Cost summary for each of the optimization models and comparison with the current status of the network.

SCENARIO		PRODUCTION	STORAGE	TRANSPORT	TOTAL
2.2 Current Model		2.559,7M	64,26M	1.210,1M	3.834,1M
2.4 Transport. Optimization		2.559,7M	64,28M	1.178,3M	3.802,4M
		-	≈ 0%	-2.70%	-0,84%
2.5 Manufact. Differentiation	Case 1	2.583,3M	64,51M	1.294,9M	3.942,8M
		+0.91%	+0.39%	+7.01%	+2.84%
	Case 2	2.558,5M	64,47M	1.285,7M	3.908,6M
		-0.05%	+0,33%	+6.24%	+1.94%
	Case 3	2.541,7M	63,76M	1.305,8M	3.911,3M
		-0.71%	-0.78%	+7.91%	+2.01%
2.6 Manufact. Optimization		2.538,7M	64.28M	1.210.2M	3.813.2M
		-0.82%	≈ 0%	≈ 0%	-0.55%
2.7 Final Optimization		2.538,7M	64,28M	1.178,5M	3.781,4M
		-0.82%	≈ 0%	**-2.61%**	**-1.37%**

Table 2.40 summarizes the results obtained from each of the scenarios carried out during this chapter, including their perceptual variation from the expenses derived

from the current status of the network.

As it was mentioned in each of the previous sections, not all the new business models analyzed have satisfactory results. In fact, the only ones in which their implementation would lead to an optimization of the network are the ones that modify the transportation and production management in terms of scheduling and programming (Sections 2.4 and 2.6).

Of course, since Section 2.7 combines the improved systems from these last two mentioned scenarios, its results are even better and would lead the company to the biggest cost savings.

To comprehend graphically the variation in terms of total costs that every described scenario would represent, Figure 2.68 is included.

In it we can see how the three scenarios in which the modification of the production and transportation channels between South and North America was performed, would increase quite significantly the investments.

On the other hand, the cases in which we focused on the modification of both manufacturing and transportation planning seemed to be favourable (2.6 and 2.4). As mentioned before, the possibility of combining both improvements would clearly be the optimal solution out of all 6 scenarios (2.7), leading to savings that could raise up to 52 million of euros.

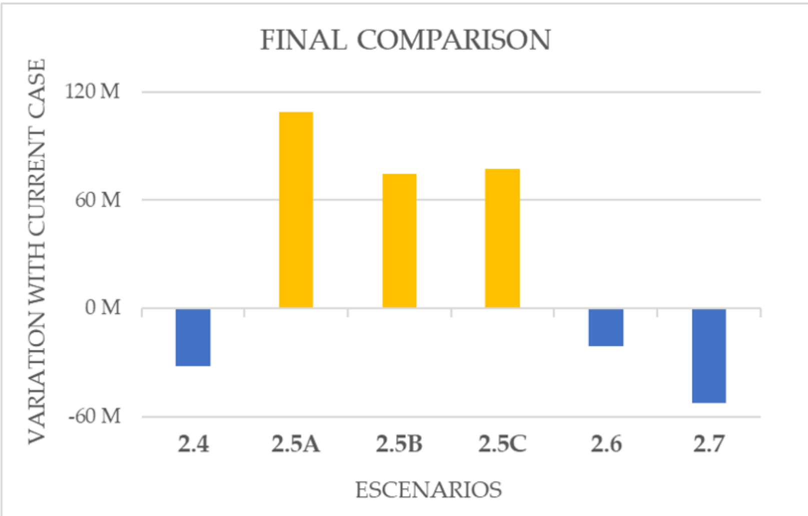


FIGURE 2.68: Total cost variation comparison between every scenario analyzed and the current status of the global network.

All of the cases that have been studied would clearly affect the way the company's business performs in the current model. However, not every hypothetical modification of the system would make the same impact in the whole logistics network chain. In the following lines, it will be explained which will be the circumstances under each of the new models could be developed and in which area they will make the bigger impacts.

* 2.4 *Transportation channels optimization:*

  As explained in the introductory section of the experimental optimization case, the company does not carry the transportation activity itself, but subcontracts it to another company.

  Furthermore, the modification of the system is only in relation to the shipping programming task. This means that it is only planned to be changed when to ship and how full the transport units will be sent. Channel routes, connections from PC to RDCs and transportation units (trucks and ships) would not be changed at all.

With all this said, the feasibility of this system alteration seems to be quite likely to be perform. This is because of the lack of any structural modification of the supply chain structure, which could have been quite expensive to be performed.

Anyway, the agreement between our studied company and the one that is in charge of the transportation tasks will have to be readjusted.

Theoretically, our company is in charge of forecasting the demand trends in all areas of the network and also of calculating and programming the shipments of products and, therefore, the transportation needs. They will need to communicate with the transport company with some days in advance so they can provide the units that will be needed.

The first two shipping stages (from the PC to the CDCs) are much easier to manage than the final third one (from CDCs to RDCs). The fact that transportation follow cyclic trends allow the companies to prepare in advance the infrastructures they will need. The last one, however, evolves randomly and transportation needs can not be predicted as easily. For this one, once the company receives the order, they should automatically calculate the trucks that will be needed based on the accumulated variation between shipping and demand rates and send the message to the transport company so they can provide the units needed.

∗ 2.5 *Production channels differentiation by products:*

Non of the three studied possibilities seemed to be beneficial in terms of invested money. Assuming that the results would have proved that these were cost improving solutions, they do not seem to be as simple to implement as the one explained above.

The task would be to do a whole restructuring for two of the channels, regarding production, transportation, storage, shipping and demand forecasting in these areas of the network.

Theoretically, the implementation of this big impact modification would only make sense if the cost savings that the company would obtain annually were very significant. In that case, in a time frame of certain years, the invested money of this restructuring could be redeemed and from that moment on, bring benefits for the company.

However, new channel routes should be found and analyzed, huge modifications of the manufacturing processes in terms of product specialization and working rates would need to be done, updated transportation needs and agreements with shipping companies would be required, a big number of employees would need to be relocated depending on the needs, and some other big changes make these scenarios unlikely to be feasible.

∗ 2.6 *Production channels optimization:*

In this studied case we focused on the production scheduling inside the PCs. In the same way as in the transportation one, no big structural changes are meant to be performed in this scenario.

It was previously explained that in the current network production rates are constant among the time. There is no modification on the manufacturing lines unless an unexpected failure or big demand variation occurs. Another fact that was described was that all the production lines that take part of the global network are working below their maximum capacities.

The objective is to maximize the resources and to benefit from the cost set up structure as much as possible. To do so, the planning system is modified into new periodic charts for each manufacturing line, where some days they will be working at full capacity and others totally stopped.

The implementation of this new production concept seems to be quite affordable by the company. The only areas and activities that will be involved are, of course, the production, and then the transportation from the PC to the MW and the storage levels of this mentioned hub.

This stage's transportation activity will be affected in the sense that the units needed are no longer constant. Since each of the lines for every PC will have their own production cycles, the total packages that need to be sent every day will vary randomly. This makes the transportation activity of this connections similar to the one between CDCs and RDCs. To put this into practice, the company would need to establish a good communication system with the one in charge of the transportation, in order to guarantee the supply needed at every levels o the network.

On the other hand, since manufacturing centers (PCs) are totally controlled and supervised by our own company, the modification would only imply a new management and planning system. There would be a higher need of a detailed surveillance because of the modification from a constant production to a different cyclic scheduling for each line.

Possible further analysis and optimization studies

This experimental part of the thesis had certain limitations mainly because of the lack of detailed data that would have allowed us to track the evolution of every parameter at all levels of the network in a more precise way.

It is therefore quite challenging to really propose solutions that focus very in detail on certain specific behaviours of our analyzed system.

Besides that, this case has helped us to understand how important is to continuously develop every little activity that takes part in a global logistics network as it is this one. There are so many areas with huge volumes of work that every little detail can have a considerably good impact in the overall performance.

With all that said, working together with this case study and analyzing it quite in detail has given us some ideas to continue developing the network in the future.

1. Reducing the number of warehousing stations or lowering their storage capacities.

   It has been proved that Main Warehouses have capacities of 20 million of units in Brazil, United States and Denmark and up to 60 million in China. It is such a unique case, since usually world-wide logistics networks as this one include many more main storage centers but with lower usable areas. In this case, every lot goes through only four hubs and they do have a very big capacity to store.

However, they are not really being used in a very optimal way since their usage rates do not vary from half of their capacity at any point of the seasons.

Always assuming that there are not very big expected increasing of demand in the close future, our proposal would be to either rent to other companies up to one third of the centers total capacity or to fully move the activity to new and smaller centers that could fit better with the needs. Both solutions would reduce the fixed costs of maintaining the centers. This will not make a very big impact in the total investments since storage activity has much lower total costs than the two main areas: transport and production.

2. Exploring the possibility of new transportation methods.

   It is unknown if the company has already carried out a detailed recent study with the optimal transportation operation in terms of shipping methods and routes. However, it seems to be a way to lower the costs from transportation.

   This is because there are so many customers to supply to and only four production channels that for some specific routes the distances are extremely long. Not only distances but also time spend, leading to the fact that very big amounts of money are spend in these routes.

   A new proposal from us would be to explore the possibility to introduce partially or totally new transportation operations by the use of railway or air shipments. These methods, specially shipping through the air, would be more expensive comparing the same time basis. However, shipments that take now up to 10 or more days could be done within a few hours.

   For routes where road infrastructures are very good and for those where distances are relatively short, this hypothetical modification would not really make any sense. This is why, in principle, the objective would be to compare their behaviours in the long distance and bad communicated channels.

   Although we can not really predict the results of implementing new transportation method for certain routes, it could be an interesting new scenario to study more deeply.

3. Modifying the sea shipping routes procedure.

   Based on the research explained in Chapter 1, where different sea shipping configurations generally used in global logistics networks were explained, we can propose the implementation of a little modification of ours.

   In the existing sea shipping methodology (**Current work-flow** in the Figure 2.69), once the lots are stored in the CDCs, the shipments are divided into different transportation units and sent to the loading ports that seem to be optimal regarding the destiny of those lots. This has the advantage that routes are optimized in terms of finding the shortest and easiest paths. However, there is a need of developing infrastructure in many ports, as well as to pay the taxes of very different agreements with port operation companies.

   In fact, in many cases, concentrating the lots in just one or very few ports which are close to the CDC and ship all lots to destinations from there seems to be another very reasonable solution. By doing this, some routes will take a bit longer distance and time, but will make the management task of this kind of transportation much easier and will reduce the payments of using many ports into paying just in one but higher amounts. This solution itself is the one represented in the graphic as **Modification 1**.

In other situations, mainly in only a few specific cases, this practice could be extended to the unloading port. In cases where shipments are being unloaded in different ports but that are quite close to each other, the operations could be unified into only one port and from there carry the rest of the transportation by road. This would be the solution represented in the **Modification 2** and, again, would only make sense for a few cases in which geographical circumstances would make this change beneficial.

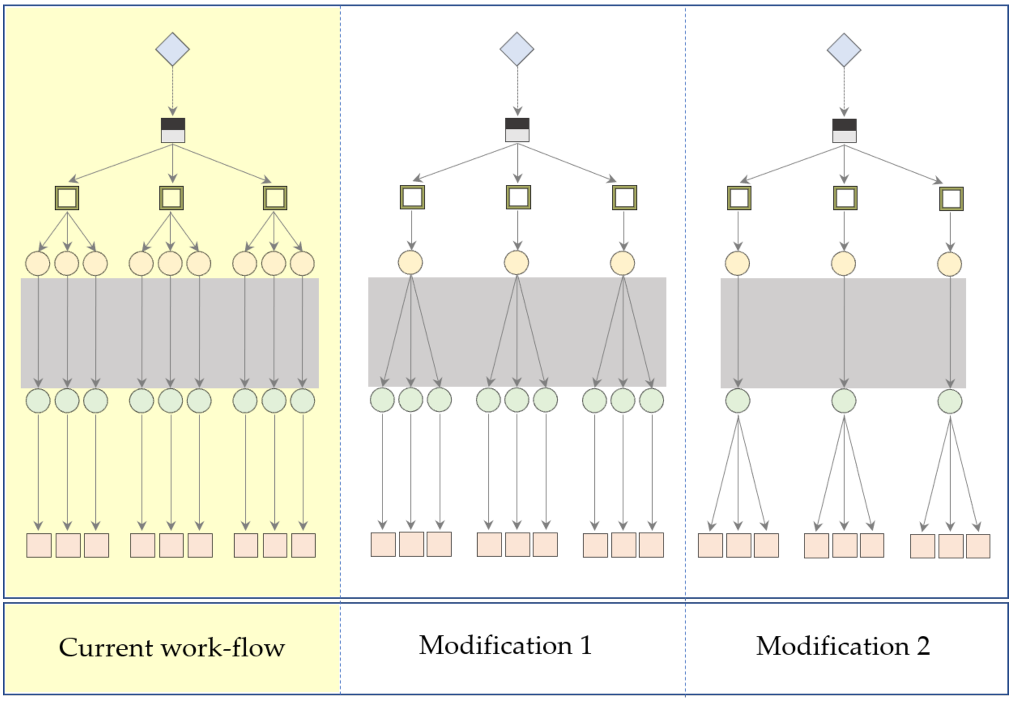


FIGURE 2.69: Hypothetical changes to carry out in the logistics network analyzed

Chapter 3

Industry 4.0. and smart warehousing solutions

3.1 Industry evolution and transition to the 4.0 environment

As stated in (Barreto, Amaral, and Pereira, 2017), the evolution of the cyber technologies and their impact and connection with the digital systems already existing throughout the entire chain has led to the appearance of what it has been named as "Industry 4.0". This term was used the firth time back in 2011, in the Hannover Fair of Industrial Technologies. From that time on, several companies have been studying, analyzing and preparing their businesses for this new environment.

Mainly in Europe, North America and Japan, companies from different sectors have been developing several solutions that can have a huge impact in the way industry works nowadays. Some governments have also taken part supporting their respective sectors in industry, in order to take advantage of these new opportunities the industry will bring. This new concept is seen as a great chance to position their markets and, therefore, it is viewed as very strategic by both industrial powers and players.

Regarding previous industrial impacts comparable to this one, there have already been three "revolutions".

Back in between 1760 and 1840 approximately, the first industrial revolution took part. The introduction of big and heavy mechanical systems and the development of the steam engine brought a new and unique scenario never seen before in manufacturing industries.

The second revolution, sometimes called as the technological revolution, occurred from 1850 until 1914 approximately and it was known by the use of electricity, the building of railroads, the big rates of steel and iron production and the impact of the telegraph.

In the third place, in 1969, it took place the automation of manufacturing processes mainly because of the extended and crucial use of electronics. Information and communication channels experienced also an amazing and differential change. The appearance of a new type of energy production as it was the nuclear one had a huge impact, mainly because its potential surpassed the already existing energy sources.

The fourth revolution introduces the Industry 4.0 concept, which refers to the integration, development and improvement of the communications and information technologies in industry. This new industrial revolution aims to propel the appearance of digital manufacturing, often know as “smart” factory, which means the development of networking, flexibility of operations, integration with customers and suppliers and new innovative business models.

The purpose is now to create intelligent networks of both products and processes among the value chain. More efficiently designed processes and the creation of goods and services that can be adapted to customer requirements and wishes is the main differential aspect of this new industry environment. In other words, as defined by (Liu et al., 2018b), the ultimate objective of Industry 4.0 is to facilitate a flexible and customized manufacturing process at the lower cost of mass production. They also remark that cloud manufacturing is the concept that aims to deliver manufactured products and services on-demand to the clients.

Internet of Things (IoT) which is the concept of connecting any device with an on/off switch to the Internet has affected the way Cyber-Physical Systems (CPS) interact, are controlled and monitored and managed. IoT encompasses everything from mobile phones, headphones or wearable devices. . .

As written in (Wang et al., 2016), with the implementation of the Industry 4.0 concepts, almost all the working environments will get fully automatized using the appropriate combination of Cyber-physical systems and also with the Internet of Things, while the data will be processed now online by the use of Cloud Computing.

However, the purpose of industry is to have as many interconnected systems as possible, as this is contributing to a better communication and cooperation within all the network components in a new smart way: new production strategies, provision of services and logistics and resource planning in a more optimal way, with cost reductions consequently.

In smart systems within the Industry 4.0 and cloud manufacturing perspective, processes for different customers may be held by their own structures, so that flexibility of the stations enables to execute contrasting functions subject to individual sets of operations within the tasks, (Ivanov et al., 2018b), (Ivanov et al., 2018a) .

The decisive use of technological applications and the development of wireless embedded sensors and actuators is leading to new applications in several areas like manufacturing, transportation, logistics services, autonomous services, machine learning and smart structures, and consequently helping to improve the already existing systems such as Supervisory Control and Data Acquisition (SCADA) systems.

Improvements achieved from a technological point of view are provable and evident. Shorter production cycles, customer needs incorporation in real time, automatically performed maintenance and self-regulated order shipping and dispatching are some of the areas where this new era is to become revolutionary.

On the other hand, regarding an organizational structure perspective, Industry 4.0 combines both horizontal and vertical integration in different areas. Between networks there is a horizontal integration, which allows a better internal cooperation. Vertical integration is performed within the subsystems of the factory, creating adaptable and more flexible production systems. Finally, there is a integration both horizontally and vertically across the whole value chain, which allows to the customization all products.

The German National Academy of Science and Engineering puts in the center of the organizational chain the Smart Factories, (FuE-Themen., 2014). They explain the fundamental role that the new manufacturing centers will have and the need of analyzing deeply the opportunities and challenges of digitalization in machine-human-system communications in the production factories. As it can be seen schematically in Figure 3.1, apart from Smart Factory development, Industry 4.0 will also bring other digitalized and smart dimensions such as Smart Mobility, Smart Logistics (Smart Warehousing), Smart Buildings, Smart Products and Smart Grids.

This new concept of industry and its innovative level of organization and control of the entire value-adding system, that considers the complete product life-cycle with the objective of fulfilling the individual customers needs is the characterization of Industry 4.0.

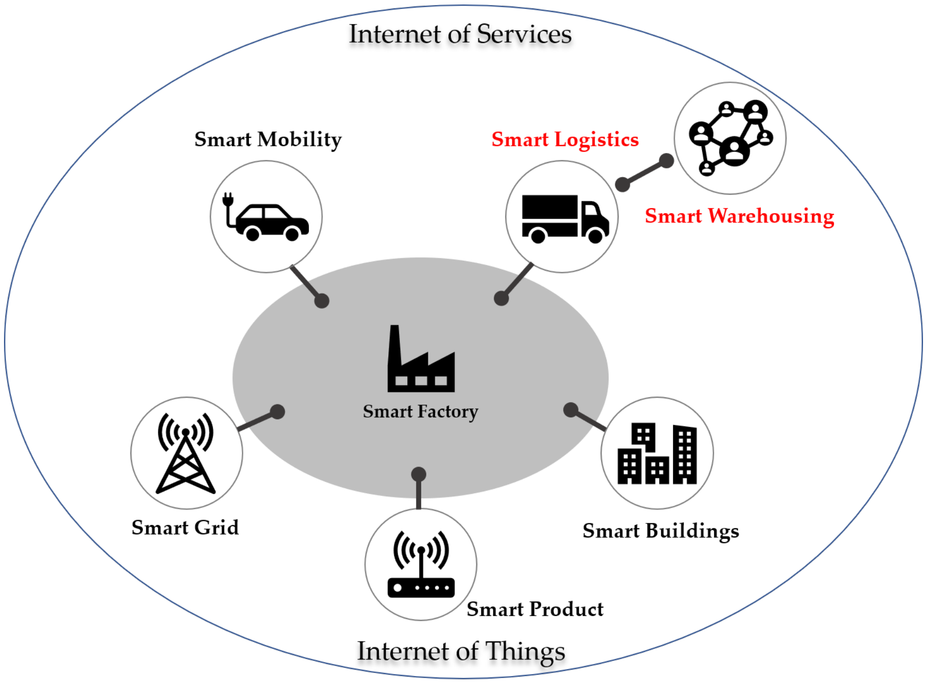


FIGURE 3.1: Industry 4.0 and smart areas involved

(Landherr, Schneider, and Bauernhansl, 2016) focuses on the application of Industry 4.0 in the production activity. It is stated that Application Center in industry 4.0 is an advanced environment for industry-driven research, development and testing of CPS. They offer the possibility to create innovative solutions and to verify their feasibility in an specific environment which is oriented towards the real industrial environments. It allows the strategic cooperation between industry and research in industry 4.0, acting as a test-bed for future CPS.

The Application Center Industry 4.0 is developed and created based on three pillars that provide a wide range of opportunities for the implementation of CPS.

1. *Smart Objects / CPS Technologies:*
   The first area is based on the development, testing and feasibility of the implementation of solutions in the cyber-physical field regarding systems for manufacturing.

2. *Additive Production Technologies:*
   This pillar focuses on the further development of additive production technologies such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS) or Fused Deposition Modeling (FDM), which will make production faster and cheaper once optimized, by developing, for example, an inline quality control.

3. *Near Real-time Simulation Technologies:*
   This pillar aims to develop new ways of connecting physical objects digitally, so they can be used in communication and simulation processes. Because of the diversity of the objects involved in manufacturing, this IT platforms will need to be flexible and powerful so they can meet the future requirements in the field of CPS.

However, besides the many advantages that this new industry scenario will bring, there will be many challenges and difficulties for a big number of industries from every business area, specially SMEs which have lower potential to apply changes.

One of the main professions that will be highly modified and will get to another dimension in the Industry 4.0 environment is the process planner. As stated in (Cummings and Worley, 2001), traditional and past process planning activities, mainly in SMEs, were based on a very individualized knowledge and expertise from only one person or a small team of a few co-workers. In most of the cases, their education was based on traditional approaches without the concept of life-long learning and without the use of modern systems such as CAPP.

These employees are not easy to convince when carrying out such a big scale change in their tasks as the one it would be implementing the Industry 4.0 methodology. Together with the very big investments needed in modern equipment and digitalization systems, these aspects represent important obstacles that make the transition to a 4.0 industry ambient a very big challenge.

3.2 Logistics networks adaptation to the Industry 4.0 era

Concepts like "Smart products", "Smart services" or even "Smart logistics", which refer to systems that do those tasks that would have been carried out by human beings. This new horizon changes drastically the way in which humans are useful in the value chain. The fact that machines are now capable to ensure the fulfillment of certain tasks initially done by human, leads to the point in which employees need to focus and work on that processes that require intelligence instead of automation and also in taking the most of these new smart systems.

As stated by (Barreto, Amaral, and Pereira, 2017), greater flexibility, easier adaptation to the market trends and a deeper knowledge of customer needs are some of the characteristics of "Smart Logistics". The main benefits of these new scenario are the optimization of production, the lower costs of both manufacture and storage systems and the bigger adaptation to the customer specifications.

This new industrial scenario, known as the digital revolution, has an enormous dependency on the technology as it uses the very new techniques to continue its progress. Defining the state of the art of the technology it is important for the better understanding of the concept "Smart Logistics". The fundamental role that Internet plays in this new paradigm, facilitating the communication channels between artificial systems and humans in real time and the advanced digitalization are two of the main aspects that make this new environment unique and potentially very powerful.

(Kawa, 2012) defines the SMART model as the one which is Specialized, Market-driven, Applicable, Reactive and Technologically-oriented for Logistics Chains.

They also explain that cooperation between companies will be decisive as it will play a big role in these new smart chains environments. Single company's intelligence does not imply necessarily the system's intelligence, and by cooperating with other partners, companies should rationalize their logistics activities, reduce the number of empty shipments and lower costs. Companies that continue their managing task as if they were "family enterprises" will have a limitation in their ability of getting potential opportunities offered by collaboration with others actors in the market.

There is an increasing need of creating an online/electronic platform that makes this cooperation within SMEs possible. Thanks to it, they could gain access to updated data about logistics services and supply capacities. A good solution to this challenging process seems to be creating what it is called Cloud Computing. Its implementation would avoid cost investments in hardware, software and services to third-party providers that make individualized solutions to each of the SMEs.

The main advances and benefits that companies would get by implementing this Cloud computing system are:

- ✓ Filtering services
- ✓ Aggregation services
- ✓ Optimization of logistics costs
- ✓ Rationalization of logistics processes
- ✓ Harmonization of logistics services and supply capacities

(Fleisch, Christ, and Dierkes, 2005), gives an informal definition about what logistics networks and logistics processes really offer: they enable us to have the right product at the right time at the right place in the right condition. The article also explains how these mentioned requirements are getting harder to fulfill, since the logistics environment is changing very fast and dynamically. Long-lasting business activities are converted into short-therm connections and, therefore, new methods, products and services are needed to help companies to the adaptation to these new challenges. It is also commented how, from their point of view, an optimal definition of these new logistics technologies known as Smart logistics, is still missing. However, the definition is based on an analogy to terms such as Smart Products and Smart Services.

(Uckelmann, 2008) describes that these Smart tools enable humans to dispense some of their control activities. In other words, these products and services are used by humans to delegate the kind of work tagged like "unnecessary" work.

Smart Products and Services generally evolve from new technologies in a technology driven approach, offering additional functionality based mainly on increased visibility which has been achieved through ubiquitous computing technologies.

Smart Services offer the ability to measure what could not be measured before - enabling operating, pricing and trading of previous non-tradeable services. (Jonkers et al., 2001) defines two relevant elements of the usage data acquisition - metering and collecting. Metering is in charge of registering the usage rates of resources in real time basis, whereas collectors aggregate data from one or several meters and send this data for accounting.

(Fleisch, Christ, and Dierkes, 2005) describes the most important types of Smart Services:

- **Control Services:** Enabling to delegate the traditional activities such as tracking, tracing and reordering, previously carried by humans.
- **Leasing Services:** Conversion of the basis of calculation from owner based information to usage based data thanks to the high visibility.
- **Risk Services:** Allow to change the pricing model of companies by using based fees instead of estimated ones.
- **Information Services:** Instant online access to ubiquitous computing related information.
- **Complex Services:** They are a combination of the others mentioned above.

In the article by (Barreto, Amaral, and Pereira, 2017), they also state the following technologies that can make Logistics 4.0 an efficient and strong network if they are developed and enhanced throughout the entire process.

- Resource planning
- Warehouse management systems
- Transportation management systems
- Intelligent transportation systems
- Information security

Resource planning

New resources planning in the Industry 4.0 environment and the introduction of CPS are meant to upgrade the productivity, flexibility and agility of the system to the internal or external changes that the supply chain is exposed to. An entire integration and optimal connection between every actor of the supply chain, as well as a higher level of transparency and visibility, can provide the management department more precise and secure forecasts. By analyzing and comparing a bigger number of parameters from the logistics network, a much more efficient network that only uses the amount of resources that it needs (employees, materials and machinery) can be developed.

As mentioned previously, the human action in the value chain is about to change. The degree of specialization and the IoT technology will lead to a higher level of sophistication required. Data management, computational and analytic skills and technological integration will be abilities that good Industry 4.0 actors will need .

Warehouse management systems

Warehouses have always played a decisive role in supply chains. They influence the flow of goods and determine whether a shipping of goods is feasible or not. However, their functionalities are about to change as the "smart" management of these hubs is introduced. Warehouse Management Systems (WMS) should now be adopted and implemented into the new idea of warehousing. The higher levels of integration between every actor and stakeholder of the supply chain can guarantee and deeper understanding of every movement in which warehouses are involved.

In this new 4.0 environment, transportation actors will carry GPS sensors that will facilitate the management system keeping track of their movements and predict arrival times much more precisely. This is a big advantage, as enables the system to prepare a docking slot and human and machine resources just for the right time and use them for other purposes when the ship is not yet nearby. These procedures derive into optimized ways of Just-in-Time (JiT) and Just-in-Sequence (JiS) deliveries. Radio-Frequency IDentification (RFID) devices will give information about what was received in the hub and quantity of it, sharing the track-and-trace with the entire supply chain. Warehouse Management System (WMS) decides where the packages will be stored depending of the characteristics of them and will notify which actors (mainly artificial systems) will need to be involve moving the goods to the location assigned autonomously.

The WMS will also receive real-time signals of the inventory levels, avoiding with so having out-of-stocks situations that are highly cost wasting for the company. The information is also useful for the management decisions, as they can adjust the system to enhance clients' service level.

Transportation management systems

A Transportation Management System (TMS) facilitates the connection between an Order Management System (OMS) and the storage centers either Distribution Centers (DC) or warehouses. TMS is an essential element in Logistics 4.0 environment.

As 4.0 concept uses real-time and inline data to gain effectiveness in a logistic process, TMS is a much-needed system providing information accurately of their fleet of vehicles thanks to GPS technologies. This enables the company to monitor routes and study different transport trends, that they can use later to negotiate with carriers, consolidate shipments methodologies and use platform's advanced functionalities.

Remarkable fact is that, since there is a high increase of developed cloud services and tools, most of TMS solutions are being moved to the cloud. This helps to reduce substantially the number of on premise installs on the future.

Transportation of goods through the entire supply chain (production, shipping, storage and distribution) is meant to be monitored in real-time by transportation and logistics companies thanks to the introduction of bar codes, RFID tags and sensors in the physical actors of the chain.

Intelligent transportation systems

Some new technologies as they are computing hardware, positioning system, sensor technologies, virtual operation, telecommunication and some others have helped to the development of Intelligent Transportation Systems (ITS). ITS is a new solution that improves transportation systems in all its areas such as management, control, infrastructure, operations and policies. These systems bring many important advantages like safety and reliability, increasing of travel speeds and traffic flows, reduction of risks and accidents and lower pollution and emissions.

But regarding how do these systems work, ITS uses real time data obtained from VANET Systems, sensors, drone points and business intelligence systems to increase the decision-making quality and to become more flexible and efficient in the near future, leading to a higher efficiency of logistics with the adaption of Machine to Machine (M2M) communication and cooperative systems technologies.

Some ambits in which an ITS can be totally useful and highly valuable are, for example, to promote intelligent truck parking and delivery zones management, to do an emission footprints estimation and to synchronize the different transport modes during the several logistics operations.

Information security

The increasing reliance on technology from companies to achieve a more successful business model has also brought a big challenge that all actors involved in Industry 4.0 must face. Every technological solution always carries vulnerabilities in security and protection areas and, therefore, developing a surely protected system in which their technological advantages, IT infrastructure and information is safe has been one of the main aspects in which companies have been focusing on.

Cloud-based systems such as Internet of Things (IoT), Big Data and, of course, Industry 4.0 deal with an enormous amount of data and information that is clearly confidential, since it is potentially differential for a company to help them to get a market advantage with their competitors. The rise of on-line transactions, new systems hypothetical potential third-party access and sometimes the lack of computer security awareness are sufficient motivations to exploit vulnerabilities of both software systems and humans.

In general, society tends to dismiss their vulnerabilities when using new technologies if they get benefits from them. Organizations aim to achieve solid levels of security to be closer to their business goals by encouraging and fostering a culture of security and accept that every technological advance has to be treated carefully so it does not become a risk factor to the system.

The purpose of every organization that wants to be protected from digital attacks should be to identify, implement, monitor and evaluate the optimal set of controls, provide high levels of security and ensure the progress of their business. Anyway, security requirements and needs must be specified in the information security policy, and this one dictates the set of controls that ensure the aimed protection.

In (Trstenjak and Cosic, 2017), it is stated that system security it is part of the further research, because of cloud platforms enabling access to many diverse and different users. Every company should put a big effort on keeping their intellectual property, because it is their knowledge what will make them have a strategic advantage in the market with other competitors. Knowledge is the main factor for the process optimization, which will imply bigger incomes in the future.

In the article (Mousheimish, Taher, and Finance, 2015), a proposed framework of what it is the methodology that every Smart Logistics process should follow is explained. The sketch of the framework is shown in Figure 3.2.

The first step when generating a logistics process is the *Plan* component, an external module that allows the process to be created. Then, the *Execute* component, which is in charge of the execution of the previously detailed plan. Afterwards, the *Monitor* task controls the ongoing process with respect to certain identified events called the events of interest. *Predict* step is the one responsible of drawing anticipations about the state of the process in the future - if any future violation is predicted, it will make the *Recommend* component to be triggered, creating an alternative solution dynamically and suggested to the user. If the user rejects the proposal, the system loops again to the *Recommend* component and try to find a new solution. If it is approved, the system advances into the *Adapt* component, where the initial process is proactively updated at run-time to avoid the predicted violation. Of course, the system can query the planner again, however, once the processes is once fully performed, the last three phases (Predict, Recommend and Adapt) will be the ones focusing on how to predict violations and mitigate them.

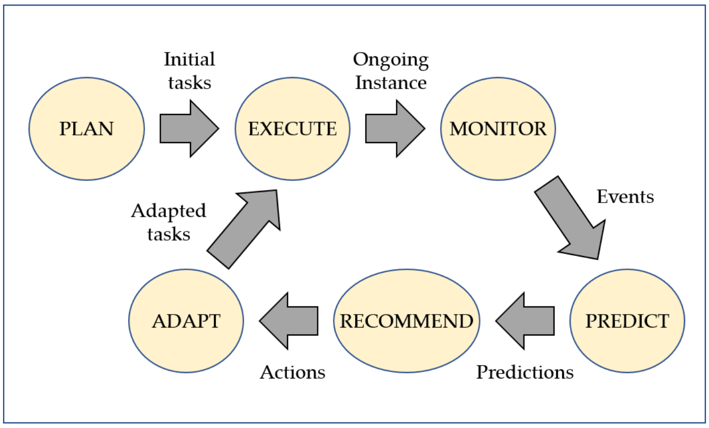


FIGURE 3.2: Smart logistics process framework

Although technical components and processes of the activities that compose Smart Logistics networks would evolve among the years, (Uckelmann, 2008) explains that there will always be certain phases and components that foster Smart Logistics. These technical components of Smart Logistics that they refer to are: Identification, location, sensing, processing and acting.

Identification

As said in (Gershenfeld, 1999), things have a right to have an identity. Real and virtual world visions are continuously moving together, that is why it is claimed that logistics items that can not be identified are not existent for the processes. If identification can not be carried out, no controlled action is possible to do. Identification is therefore a decisive stage and must be developed for every Smart Logistics process.

RFID seems to be the optimal way to identify logistics objects. RFID can easily check the "right product" logistic requirement, together with the "right time" and "right place", which are confirmed with the identification number. All three main logistics requirements are easily fulfilled by this automatic identification systems and, although there are other technologies that can carry out this automatic recognition, radio-frequency identification offers certain advantages in comparison with them:

- Bulk-reading
- No line of sight required
- Robust compared to barcode
- Large memory
- Re-writable/changeable data storage
- Ease of use
- Speed of data entry
- Cheap solution

Locating

Locating and identifying tasks are often confused. Real-time locating systems (RTLS) offer locating close real-time with continuous sub-minute updates. While RFID is progressing to be ubiquitous, RTLS are still hard to find and this is mainly because of the high cost of developing their infrastructures.

Radio frequency based identification systems have a good acceptance in markets but their functions are still limited to branch-specific approaches such as healthcare management, car yards or container terminals. The implementation of a real-time locating system can bring the possibility of developing a better supply chain visibility at all levels - RTLS combine functions of identification of objects and to located them within short time frames.

According to (Hightower and Borriello, 2009), real-time locating systems have two different ways to describe the positioning of the objects. They can provide the physical position, as it is the case of the well-know GPS system, or refer to to symbolic locations based or relative distances to other objects.

GPS system send information about the absolute position, which is unique worldwide. However, for some special logistics activities, relative positions may be of importance (e.g. the distance to a workstation may provide very useful information for managing a production line). Mainly for locating systems indoors, relative location systems are the optimal ones to be used. Transmission media could include radio frequency, infrared, ultrasound together with magnetic and optical technologies. The following location methods and combinations for RTLS are popularly known:

- Cell-of-origin
- Amplitude (RSSI: Received Signal Strength Indicator)
- Time of flight ranging systems
- Time difference of arrival (TDOA)
- Angle of Arrival (AoA)

Sensing

The last but very important requirement of every logistics chain is to make sure that every product/good is supplied in the "right condition". Although shipping all products to customers in the optimal status is always the objective when managing a logistics network, there are some business activities where this phase is even more sensitive and needs to be consider in very little detail. This is the case of, for example, cold chain and fresh food logistics processes, where temperature and humidity sensors are a fundamental part, since they are the ones that will ensure that the products arrive to customers in their best shapes, (Jedermann et al., 2010). Sensors may be based on active RFID systems, thus facilitating the use of the main battery to power the sensors.

The whole performance of Smart logistics networks can be therefore controlled by the proper combination of RFID, RTLS and sensors, communicating between themselves with a state-of-the-art IT infrastructure.

Networking and Data Processing

Every object that takes part in a Smart logistics chain is meant to be able to communicate with all other actors of the network and also with its environment. The data-processing activity can be performed both centralized or de-centralized, and this leads to a fusion between material flow and information flow, enabling every actor to manage and control its own logistics process.

Regarding the de-centralized data-processing and management, it can be supported by software agents. However, nowadays, these software agents have not achieved a relevant market share within logistics processes. In many cases, they fail to fulfill the defined criteria of being available in the market. They do have a long way to be fully efficient and plenty of potential to develop their functionality, but surely they are expected to be a common technology in the future.

The Internet of Things is another technology that is growing quickly over the last years, although it has not reach a fully efficient and developed status to be commercially available. There are still many questions uncompleted and that is why it is not implemented in industry yet.

Billing

The main problem that exists nowadays with Smart products and services is that a return-on-investment can not be achieved from a single stakeholder, as there is a trending move from closed technology environments to open loop ones. These Smart products/services need to pay off for both the customer and the manufacturer, that is why new concepts to share benefits and costs need to be implemented in the close future to make these solutions feasible in quality and cost.

The "Internet of Things" concept provides most of the required infrastructure to overcome this problem - with this new methodology products will be individually identified thanks to automated identification from RFID systems. It is therefore a matter of time, but the IoT horizon is to be able to handle location and sensor-based information in real-time, using an Internet-like infrastructure and linking product and information throughout the network.

Since the value in individual pieces of information such as best-before date or storage conditions during shipment is very small, micro-payment solutions are suggested so all those tiny payments can be accumulated into billable amounts. However, existing solutions usually tend to fail to scale and are not very reasonable for micro payments. Yet, thanks to the fast growing of the ubiquitous computing, the transferred amount of information per transaction decreases thus requiring tiny payments on usage basis.

More familiar with ubiquitous computing are online-payment services, although these service providers are not yet ready to handle micropayments in business to business relations, as stated by (Jonkers et al., 2001).

In the article (Schuh et al., 2008), they also describe how the production monitoring and information framework will be held in Smart logistics network approaches.

As mentioned in the previous lines, Smart logistics approach requires that information is generated instantly and electronically, while the system should be able to be easily operable by staff and to provide safety concepts in which a non-electronic control mode is usable.

Traditional Kanban monitoring system will also evolve to adapt to this new smart environment. (Baerwald et al., 2007) remarks how conventional Kanban system is too slow to react to the individual material demands. In contrast with the common electronic Kanban systems which work with a push-bottom instead of Kanban cards, the smart concept uses ordinary Kanban cards equipped with RFID tags. This composition guarantees safety if the system has an unexpected failure. The required adaptability of the production systems to changing product lines, the logistics networks also need to be adaptable in regards to the layout and place of the RFID-Kanban boards, (Tönshoff and Schnülle, 2001).

Some initial implementations of this system have been put into practice, but for now they use the electronic information only for visualization purpose instead of using it for event-driven triggering of further processes.

Creating these boards is such a technological challenge - they must be adaptable to different functional areas of the working centers and also adaptable to the size of these mentioned areas. This adaptability is a requirement in order to obtain a cost-efficient installation in every area of the factories. Apart from that, the boards should be capable to work and fully perform in real-life production conditions. This means being ready to deal with external agents such as dust, magnetism, temperature, etc. This is why especial antennas and control components have been developed and tested, according to (Baerwald et al., 2007).

In regards with the information framework, the Kanban-Boards equipped with RFID tags are included into a communication infrastructure of a wireless network (WLAN). The main challenge of using this communication solution is its reliability - disturbances by machines in terms of shielding and electromagnetism fields can affect the behaviour of these wireless networks, (De La Cruz, Veeke, and Lodewijks, 2007).

To ensure the proper communication, compensate the hypothetical connection issues and ensure the exchange of data in a secure way, network managers are generally implemented. Its task is to coordinate and facilitate all data exchanges within the components of the network. In other words it aims that no critical data is ever affected by secondary flows of information.

3.3 Smart warehouses solutions

According to (Taliaferro et al., 2016), Industry 4.0 aims to provide companies a lot of useful and powerful information. Technologies and automatized processes themselves, are set in a way in which organizations can reach their objectives and challenges. However, not only an adaptation of the automation process needs to be carried out, but also the organization must evolve and renovate their chart to maximize the benefits from automation. This is a restructuring in every range, including a challenging progress to find professional talent with data management abilities.

While in many areas of the industry total automation and digitization is the final objective, in the Distribution Centers environment seems yet unlikely. The challenge appears mainly when processes and operations vary during everyday's activity. Nowadays does not seem feasible to automatize peak inventory and throughput periods, as well as sporadically value-added tasks or product replacement intervals. So from now, in the upcoming future, the total automation will probably not be achieved yet, and the human intervention will be needed for certain specific tasks.

Collecting so much data is not as easy task to carry out - more precisely, the way this information from the system is studied and used. Data must be saved, aggregated from several sources, stored, analyzed, well secured and finally used in a way that gives added value to the process. Designing a system which combines both traditional and industry 4.0 machinery is such a challenge as it is difficult to ensure that systems and devices can inter-operate between them. After all, collected data should be shareable, easy to operate with and ready to be analyzed and updated efficiently. All combined with an essential need of guarantying the security so the access to the data is well monitored and spread to whom it may pretend.

When focusing on the transition towards the implementation and construction of smart warehouses systems, (Liu et al., 2018a) explains that there is a big challenge of a magnitude probably as never seen before. Over the years, warehouse operations consisted of pickup, delivery and bookkeeping were carried out by storekeepers. This is not only a highly time consuming method because of storing and fetching ships in and out the centres, but also a highly wasting way of human resources.

Smart Warehouses are automated, unmanned and eco-friendly (no existence of account books) solutions. The transition from traditional to smart warehouses lies in the use of Cyber-Physical Systems (CPS) that can get track and creates in-time virtual copies of the entire chain of the industry processes. This enables to make in-time decisions while gathering information from the virtual and physical worlds, analyzing the communication between smart objects.

The main benefits potentially gained by using these new systems are both time and energy efficiency, process accuracy, cost and error rates reduction and lower levels of waste. Radio-Frequency IDentification (RFID) and Near-Field Communication (NFC) tags, CPS devices like Wi-Fi access points, BLE (Bluetooth Low Energy) and cameras and finally robots, are settled all around the environment strategically distributed for specific reasons. Therefore, it can be stated that there exist four main components in a smart warehouse environment:

- CPS devices
- Inventories
- Robots
- Human beings

For each of them, there are some considerations that need to be well performed to ensure their correctly operation and to take the most profit from the system. A large number of CPS devices can be operating at the same time and that is why their communication should be scheduled efficiently. Status and location of every inventory needs to be known so it can be compared with the data reported by the attached devices. Robots will carry out those tasks that are repetitive and harmful to human beings. Finally, humans have the very important task of recognizing their gestures and activities to perform in the operation of the warehouse.

However, the integration of these mentioned CPS techniques into smart warehouses in an Industry 4.0 is not an easy task to carry out with. While the human interaction it is going to be needed only for sending precise instructions to the warehouse (and monitoring if needed/wanted), the need of digital and technological systems is a fundamental aspect. Over the last years, customer trends have been requiring high-individualized products and the demand of customized services are increasing quite a lot. This new environment in more complex than the existing a couple years ago and no longer can inbound and outbound logistics systems be handled with traditional and ordinary planning and control techniques.

Focusing now deeply into the smart warehouses (CPS based), there have been considered four main issues.

1. Efficient communication scheduling
2. Accurate and robust location
3. Multi-robot collaboration
4. Human activity recognition

Efficient communication scheduling

In a smart warehouse, there always exists what it is called a Local Area Network (LAN). This network is simply the combination of all hundreds or thousands of CPS devices that are used for the smart performance of the warehouse. These devices are used to provide information and data, but this can not always be collected too often, as there is a limited wireless communication bandwidth and it may not be enough to support real-time data of every single device that takes part in the LAN. This is the reason why there is a need of investigate which are the most efficient ways of communication scheduling from every device existing in the network, always while considering energy-savings and eco-friendly solutions.

Every little component of the future smart warehouse systems (products, tools, machines...) is going to have, more certainly, some kind of sensor attached to it to help with tracking inventory at all levels. This is clearly a benefit because of the very detailed and accurate information it will be received from the entire system. However, since communication channels are not limitless and there will be a huge amount of sensing devices, achieve a methodology that ensures the efficiency communication scheduling strategies when collecting all types of data from the CPS devices is yet not easy.

The existing automatic identification mechanisms are basically based on barcodes, sensors and Bluetooth. RFID has a unique advantage which is being able to identify simultaneously multiple objects, while all the others have requirements of line-of-sight. That is not the only characteristic that makes this system so powerful, RFID have almost unlimited service time of operation, so they can be closely be considered as battery-free systems. Lastly, they are small-sized systems, so their large-scale deployment is quite easy and feasible for smart industry.

A general solution for communication scheduling is identifying all tags IDs for inventory. Two different protocols for tag identification exist: *a*) Aloha-based and *b*) tree-based protocols.

As explained in the book "RFID Handbook-Applications, Technology, Security and Privacy", Aloha-based protocols reduce the occurrence probability of tag collisions. Each tag aims to transmit the ID at a randomly selected time. Nevertheless, these protocols cannot totally ensure no collisions, while they face the important issue known as "tag starvation problem" that a specific tag may not be detected for so long time. By contrast, tree-based protocols have this name because the concept of their tag identification forms a tree. These protocols split a set of tags into two groups at a time, attempting to recognize these two groups (subsets) one by one. This procedure is repeated until each subgroup has only one tag, in which moment the reader can recognize every tag in the reader's scanning time. Tree-based protocol does not cause tag starvation, however there are quite longer identification delays compared with the previously mentioned protocol.

The most comprehensive data can be gathered by using tag identification protocols, but it also brings some drawbacks considering time and energy efficiency. General solutions as the ones explained above may not be the better solution for a specific issue, e.g., missing tag detection or identification, unknown tag detection or identification... The reason is because the main purpose is to find which tags are not known or are missing and their respective positions and not necessarily their IDs.

Accurate and robust location

Having a consistent method where we can know the updated location of every different product stored into the warehouse is a very important factor that every smart hub should really develop. This has always been an important problem and, in this new digital era, several different techniques such as GPS, Wi-Fi, Bluetooth and RFID have been developed to solve it in the best way possible. Nevertheless, every different solution lead to particular disadvantages and considerations that need to be thought. As a shortly example, GPS is not a very precise system for indoor locations; Wi-Fi systems are only useful if a smartphone is included in every component; BLE systems have not a large battery power so their lifetimes are quite short; and the communication ranges of RFID devices are very small.

Therefore, the difficult task is not to add technology into our warehouses to obtain information related to relative locations of the elements, the challenge is to find the optimal combination of all the existing tools and ensure that the solution will be accurate, robust, fast and that provides a wide coverage.

Multi-robot collaboration

In this new industrial revolution, robots are meant to have a decisive role, as they are one of the main differential components that makes this era contrasting from previous concepts of industry. Smart robots are a combination of sensors, actuators and very powerful processors, components that enable robots to be sensible with the environment, to think with intelligence and to behave in a precise way.

Robots are designed with the purpose of carry out work that was previously done by humans or by humans using machines. There is definitely a promising and bright future for the smart robots in industry and in warehouses in particular, however, multi-robot systems (MRS) required a very precise planification and the work of tasks scheduling and local coordination are fundamental in order to get the maximum help and benefits from the use of robots.

Human activity recognition

No matter all the technological discoveries and improvement that have been done exponentially this last decades, human beings are still going to play the most important role in this 4.0 smart warehouses environments, since they are the main operators.

As written by (Gorecky et al., 2014), Industry 4.0 has brought a new horizon that will take the traditional way of working to a completely different level, professions will definitely change. People will need to learn new types of everyday tasks, together with a deep knowledge of high-tech gadgets which will became the most fundamental part of their works. They will need to rely on data given by machines, but also to realize when that data is correct and when it is not.

The education process in order to make the workers qualification evolve according to the needs of industry seems to be quite long and not very easy. As explained in (Mason and Lee, 2014), the transition to these new industry employment needs may seem feasible and not as challenging in young working force in developed countries. However, when we think in countries which are yet in transition, working force is generally older and not very familiar with new technologies, which leads to the fact that this new scenario would be very long in time to implement and will require a adaptation of many levels on society, not only in education.

If the physical and emotional activities could be recognized by the system, there would be more comprehensive inputs to control the performance of the smart warehouse. Human activity recognition can be definitely very helpful to achieve automated industrial manufacturing, transportation, storage and management of the hubs and, therefore, to develop the new industrial environment 4.0.

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