[211008] Horizontal integration of a Logistics System to the CP Factory Production System. Case Study: Javeriana University

Fabián Alejandro Calderón Jimenez [a,c] , Sofia Delgado Casallas [a,c] , Mayra Andrea García Soler [a,c],

Jose Fernando Jimenez Gordillo [b,c], Iván Fernando Mondragón Bernal [b,c]

[a]*Industrial Engineering Student*
[b] *Associate Professor, Project Director, Department of Industrial Engineering*
[c]*Pontificia Universidad Javeriana, Bogotá, Colombia*

Engineering Design Overview

As industry advances and shows significant growth, new challenges arise. Industry 4.0 has advanced significantly in integration issues, allowing data intercommunication between different areas of companies using these emerging technologies. The CP Factory of the Javeriana University (i.e. Colombia), is a didactic manufacturing system used for teaching and research. Nowadays, the CP factory has a manufacturing system in charge of controlling only the production processes. From this situation and being aware of the need to cover more relevant aspects in the CP Factory process, the following project arises. The main objective is to perform a horizontal integration between the current production system with a new logistics system.

First it was necessary to carry out an exhaustive review of the current production system of the CP Factory for the development of this research project. This is done in order to define which are the logistics aspects that are needed to carry out an effective productive and logistics control of the process. After its review and knowledge about the operation, it begins with the design of an architecture where the existing processes will be combined with the new needs of the module. Likewise, the design of the databases, the scope of the logistics system and the requirements to be met by the logistics module based on the revision of the ISO 25010 standard were stipulated for the development of the research project.

The integration was carried out by creating a graphic interface and processes that responded to the logistics needs that were found in the conceptual design stage, once all the requirements and limits of the module were theoretically defined. Likewise, the dashboards were designed in order to allow the user to keep informed of the operation. Finally, on the one hand, functionality and usability tests of the module were carried out. On the other hand, a focus group was carried out in order to validate the use of the module and its correct interaction with the current production system.

The tests conducted in the focus group showed that the integration with the MES 4 was successful, reflecting that the participants had a good experience in terms of understanding, use and speed of the MFS logistics module, as well as of the dashboards and logistical concepts that were intended to be covered in the development of the module.

Key words: Cyber-Physical System, Cyber-Physical Logistic System, Manufacturing Execution System, Real Time, Horizontal Integration, Logistics Module

1. Justification and statement of the problem

Throughout history, the economical and societal world has sought to satisfy their needs with the efficient use of resources. Certainly, industries have generated a wave of economic, social, and technological advances since the concept of industry was born when the transformation was done on a massive way. The evolution of industry has been subject to continuous interaction between supply and demand in a proportional way to maintain a balance in the market. Four industrial revolutions have taken place until today.

Technological advances have increased productivity and spawned three industrial revolutions from the late 1700s to the 1970s, which introduced mechanization, electronics, and information technology (IT) to lower production costs and increase efficiency. The fourth industrial revolution (Industry 4.0) is considered a significant upgrade of the third revolution. Industry 4.0 emphasizes the digitization and interconnection of all objects for manufacturing systems, such as projects, parts, machines, devices, etc. Compared with prior industrial revolutions, Industry 4.0 does not focus on the replacement of the existing assets and manufacturing technologies, but the creation of networks and interconnectivity among existing assets and technologies using mostly available information and communication technology (ICT). To ensure technology integration and inter-operability, technology standardization has become essential in Industry 4.0. Further, standardization has become a key driving force during development phase innovation. To achieve Industry 4.0, smart factories consisting of Cyber-Physical Systems (CPS) and the Internet of Things (IoTs) are built and integrated [1].

Industry 4.0 features several enabling technologies that potentiate the improvement of efficiency and productivity for a range of industries, such as Cloud Computing, the Internet of Things (IoT), Big Data and Cyber-Physical Systems (CPS). Cloud Computing is a model that enables ubiquitous, convenient, and on-demand access to shared and configurable computing resources that can be provided and released quickly with minimal administration effort. In addition, the Internet of Things (IoT) concept refers to an interaction between the physical world and cybernetic systems, allowing the exchange of information with minimal human intervention. Furthermore, Big Data is a technology that allows and facilitates the treatment and processing of data that collects enormous amounts of data to store, understand and convert them into knowledge [2]. These technologies can establish enhanced connectivity across the company systems infrastructure. Besides, this connectivity upgrades the capabilities for collecting data relevant to mapping the state of product and allows to monitor and analyze the operating performance [3].

The industry 4.0 revolution faces several challenges, such as security over information technologies, quality control based on Big Data, the great investment required for new technologies, and finally the intelligent automation of processes. Still, Cyber-Physical Systems (CPS) stands as it can manage efficiently the full set of technology enablers. CPS allow for the integration of physical and digital entities through data and information processing, making use of the internet that is used as a large-scale network [3,4]. Extending the definition, CPS can be characterized as physical and engineered systems whose operations are monitored, controlled, coordinated, and integrated by a computing and communicating core [5]. These systems are used in every field, i.e., engineering, medicine, transportation, industries, etc; making things smarter, easier, quicker, and efficient. Certainly, CPS create unparalleled business opportunities for redefining the nature of customer relationships, products, and services within and outside the enterprise by acting as boundary agents which connect the physical with virtual reality. The foregoing is obtained due to an increase in opportunities for service innovation that are achieved thanks to the application of CPS [3,4].

Cyber-Physical Systems can be found in different business processes and therefore, these systems have several types of approach. This study will focus on the intersection of Cyber-Physical Production Systems (CPPS) with Cyber-Physical Logistics Systems (CPLS). CPPS on one hand, is a kind of CPS that refers to the connection of autonomous and cooperative elements and subsystems in all production phases. These phases include processes through machines up to production and logistics networks [6]. On the other hand, CPLS is another kind of CPS that is defined as a system of systems (SoS) that monitors, controls, coordinates, and integrates information of agents in the Supply Chain (SC) [7].

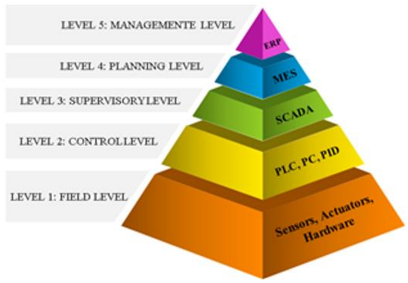


Fig 1. Automation Pyramid [Own author]

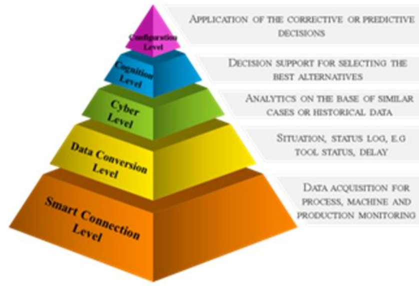


Fig 2. 5c architecture for implementation of CPPS [Own author]

The planning and control involved in the increasing industrial automation requires various production IT systems in order to cope with resulting challenges. These challenges arise due to the complex manufacturing systems of companies. The automation pyramid on one hand, is a widely accepted approach to classify these in-house IT systems in a functional and hierarchical manner [8]. Although Cyber-Physical Systems present a new approach, the hierarchical architecture of the pyramid remains. The levels of the automation pyramid are presented in Fig 1. On the other hand, the 5C architecture provides a step-by-step guideline for developing and deploying a CPS for manufacturing application from the initial data acquisition to the final value creation. The steps of this architecture are presented in Fig 2 [9].

The automation pyramid is made up of five different levels: the field level, control level, supervisory level, planning level and finally, management level. These levels will be discussed from a bottom-up approach. The field level includes devices related to the manufacturing process such as sensors and actuators. The function of these devices is to inform the control level about the production situation, as well as to control the physical manufacturing processes. Furthermore, the control level includes devices like PLC's, PC's and PID's which send orders to industrial actors to perform their functions. The supervisory level is responsible for creating an interface between the machine, the process, and the operator, facilitating their interaction. In addition, supervision of the process is carried out in real time. In other matters, the planning level includes the dynamic programming of works and the optimization of production processes such as data collection and distribution. These activities can be carried out through a Manufacturing Execution System (MES) which is a system that operates within one day or shift and must be capable of react to unexpected events like machine breakdowns at a reasonable time. Finally, the management level involves business and logistics planning. Some of the main activities at this level are material planning, logistics and stock inventory as well as resource management. In practice, an Enterprise Resource Planning (ERP) tool executes these actions [8].

The 5c architecture for implementation of CPPS is a 5-level structure such as: the smart connection level, data conversion level, cyber level, cognition level and configuration level. In the smart connection level, acquiring accurate and reliable data from machines and their components is the first step for developing a Cyber-Physical System application. The data might be directly measured by sensors or obtained from controller or enterprise manufacturing systems such as ERP or MES. In addition, data conversion level allows to obtain meaningful information from data. Currently, there are several tools and methodologies available to perform this conversion. The cyber level acts as central information hub in this architecture. Massive information gathered and specific analytics provide machines with self-comparison ability to predict the future behavior of the machinery. Furthermore, the cognition level generates a thorough knowledge of the monitored system. Since comparative information as well as individual machine status is available, decision on priority of tasks to optimize the maintaining process can be made. Finally, the configuration level is the feedback from cyber space to physical space and works as supervisory control. This stage acts to apply the corrective and preventive decisions, which has been made in cognition level, to the monitored system [9].

Industry 4.0 technologies are a tool that provides solution to several problems that arise in industry, such as the lack of communication between internal and productive logistic systems, low data analysis in the physical systems of the companies, bad information management due to human error, and the lack of reactive processes against production drawbacks. The lack of communication between internal and productive logistic systems is a problem that directly affects the processes as these systems work as a gear. Communication is essential for systems to function properly and smoothly. However, the low data analysis in the physical systems of the companies means that processes are not flexible and therefore, do not keep pace with demand. In addition, it hinders decision making in organizations due to lack of clarity of information. Moreover, the mishandling of information due to human error generates negative consequences such as difficulty in the processes and the generation of deviations from the expected result. Finally, the lack of reactive processes against production drawbacks involves delays in the process, compromising customer satisfaction [1].

Based on previous statements, the problem that is planned to be solved through this research project is the lack of communication between the internal and productive logistics systems. Logistics and production systems must operate in a synchronized manner. Technological changes in these systems are needed to improve the flexibility of the chain, optimize logistics activities, and adapt to global changes [4]. In addition, the creation of an intelligent logistics module is a fundamental step since this module controls and supervises logistic processes. Then, the horizontal integration between the created module and the MES of Javeriana University must be carried out in order to achieve the synchronization of both systems in the CP Factory. Product traceability allows to optimize the industrial activities, to track orders and resources, and finally, to obtain complete product information in real time [1]. Through the traceability of the product, the monitoring, control and planning of logistics and production processes are achieved.

This research project aims to propose an approach of a horizontal integration of the Manufacturing Execution System (MES) in charge of controlling the production processes, which are carried out in the CP Factory, located at Javeriana University (i.e., Colombia) with an intelligent logistics module. The logistics processes that will be considered in this research project are the supply of raw materials from the CP Factory and the dispatch of finished product to the warehouses. Based on previous statement this study seeks to contribute to the following research question:

"How should an intelligent logistics module be horizontally integrated with the Manufacturing Execution System of the CP Factory of Javeriana University?". For a complete understanding and contribution, the following sub-questions must be addressed: 1) What needs does the logistics module require to be integrated with the MES control module? 2) What parameters should be considered for the design of an integration architecture? 3) Which tools allow to validate the performance of the integration of the logistics module with the manufacturing module?

2. Background

Currently, the MES control module of Javeriana University does not have horizontal integration to a logistics module. It is important to integrate the logistics module to the production module since logistics services serve to provide greater precision and efficiency in logistics operations in Industry 4.0 [1].

For this research project, a literary review is carried out to learn about industry 4.0 methodologies and applications focused on logistics and production systems, thus knowing the purpose of the investigation, particular characteristics of the system, applied technology, results, and additional considerations. The keywords used to search for documents were logistics 4.0, production, RFID, Industry 4.0, smart factory, company, and technology. In addition, the review was carried out through databases such as Taylor and Francis, Springer Link, Science Direct, IEEE.

In addition, 45 papers were taken for the literary review. However, the selected papers were filtered into those using technologies similar to those proposed in this research project, and finally 21 papers were obtained. Then, the 21 papers were filtered according to the following criteria: papers less than five years old, papers with more than four pages, and papers that present proposals, methodologies or case studies related to industry 4.0. Finally, 13 papers were obtained. The literary review and the applied methodology are presented in Table I:

		A					B							C							D							E
	A) Purpose of the investigation B) Particular characteristics of the system C) Applied technology D) Results E) Additional considerations	Increase the efficiency of production and logistics systems	Collect and analyze data information in real time	Generate innovative planning and control methods	Get a system for smart decision making	Generate a prediction system	High system coverage	High transmission efficiency	Flexible system structure	IoT-based manufacturing	Cybersecurity of hyperconnected systems	Intelligent technical assistance	Understand customer behavior	Sensor technology	Information processing technology	CAD technology	Wireless communication technology	Manufacturing Execution Systems	RFID or QR technology	Positioning systems	Improve product quality	Improve system efficiency	Reduce operating costs	Reduce operating times	Improves the interaction between components	Facilitates future studies and research	Improve customer satisfaction	Additional Considerations
1	Nayak et al. (2015)	X	X	X			X	X	X						X		X		X			X	X	X	X			Use of technology in textile industries
2	Schuhmacher et al. (2016)	X		X					X			X		X	X		X		X							X		Use of decentralized control methods
3	Trappey et al. (2017)	X	X							X									X							X		It is based on finding a structure for logistics
4	Barata et al. (2018)	X	X				X	X	X					X	X		X	X	X			X			X			Combines technologies at different stages of the product life cycle
5	Chaudhary et al. (2018)	X	X	X	X	X	X	X	X	X				X	X		X					X			X			Vertical integration of logistics with the other systems of the company
6	Juhász et al. (2018)	X	X				X	X			X				X		X		X			X	X	X	X			Use RAMI 4.0 architecture to build an intelligent network model
7	Liu et al. (2019)	X	X	X	X	X	X	X					X	X	X		X	X		X	X	X	X	X	X		X	The system focuses on product customization
8	Park et al. (2019)	X	X		X					X					X	X						X	X		X			3D visualization services through the digital twin
9	Wu et al. (2019)	X	X	X	X	X	X		X					X	X		X		X	X	X	X			X			Use of a supply chain integration model with the IoT called SCoT
10	Zhong et al. (2019)	X	X			X			X						X		X					X	X	X	X			Use of a BP neural network
11	Liu et al. (2020)	X	X		X						X				X		X			X	X	X		X	X			Use of Dijkstra algorithm and artificial intelligence algorithm
12	Mörth et al. (2020)	X	X				X	X	X	X					X		X		X			X			X	X		Application in a laboratory environment
13	Wang et al. (2020)	X	X				X	X	X			X		X	X		X					X	X		X			Use of a wireless sensor network (WSN)

TABLE I. LITERARY REVIEW

The most relevant articles were chosen based on the results obtained in the search for information for the contextualization and solution to the problem. After reading the articles, a categorization was made by related topics. The articles were divided into three categories: design of digital models, Logistics 4.0, and industrial engineering in the age of Industry 4.0.

2.1. Articles related to the design of digital models

This set of articles contains those that carry out some architecture on a logistics or supply chain model, as well as the management of the database and the digital twin. All searches are focused on the design and theoretical study of the use of new technologies in an Industry 4.0 environment.

Wu et al. [10] propose a model that integrates the supply chain and the IoT, called SCoT, and the result is automated quality control, intelligent transportation, a system for decision-making and monitoring of traceability. Besides, Chaudhary et al. [11] propose a smart logistics framework to reduce human participation in decision-making. The authors model a vertically integrated supply chain, with the implementation of technologies present in Industry 4.0.

Wang et al. [12] set up a smart factory network and design a data acquisition and monitoring model to obtain high transmission efficiency, wide coverage, and flexible structure. The authors want to increase production and logistics efficiency, reduce operational costs, and improve the interaction of the components in their research. While Park et al. [13] designed and implemented a digital twin to solve problems of inefficiency in terms of cost and production through simulation, CAD technology and 3D printing in a micro smart factory. The results obtained are real-time monitoring, information tracking, cost reduction and improvement in system efficiency. In another way Zhong et al. [14], propose a general process of the implementation of an E-CPS to study the optimal energy control strategy in the energy system of a building. The strategy is designed through optimization algorithms, BP neural network, simulation and use of historical data. A 70% reduction in the rate of waste of renewable energy is achieved in addition to a proposal on the use of this process in the Supply Chain.

The results obtained from the articles presented in this category show digital models that can be applied to the supply chain, as well as in an intelligent factory to achieve better results through databases, it also shows digital software models such as the case of digital twins applied to solve inefficiency problems in terms of cost and production.

2.2. Articles related to Logistics 4.0.

This set of articles contains those that talk about the implementation of Industry 4.0 technology, with a focus on logistics. Analyzing business models, intralogistics in a case study and in a real case. The main focus is logistics and the relationship with other areas such as production. They show the advantages of using Industry 4.0 implemented in different cases.

Emmanouilidis et al. [15] introduce a conceptual approach to CPS in intra logistics by implementing a CPS demonstrator to monitor the performance of a real conveyor belt test bench. The developed demonstrator works as a small-scale (laboratory scale) implementation of the concept of an IoT-powered CPS system for performance monitoring analysis in intra-logistics that can be applicable to larger-scale facilities. The goal is to implement a system that can collect data that can be used to estimate benchmark performance and calculate eight Key Performance Indicators (KPI's) relevant to operational performance. Traceability technology was not implemented on the test bench, since vision cameras were used, which have hardware that is easy to obtain, install and administer.

In addition, Liu et al. [16] analyze business models for an intelligent and innovative production model of face masks to provide customers with a quality experience. Moreover, the authors generate an intelligent and efficient logistics module to monitor in real time. An AI-enhanced learning algorithm, a stochastic decision-making process, Manufacturing Execution Systems, sensor technology, and GPS (Global Positioning System) were used. The result obtained was a reduction in production time, transportation costs, delivery times and an improvement in customer satisfaction due to the quality of the product.

Trappey et al. [1], show the advantages of the implementation of technologies belonging to industry 4.0 in logistics. The authors show the ontology of intelligent logistics based on Systematic Layout Planning (SLP) which has four levels: distribution and warehousing, order management and inventory status, management consulting and purchase contracts, third party payment and monetary transactions. The proposed model is divided into five domains that include physical logistics services, value-added services, information integration, cash transactions and sales services. The study aims to visualize the roadmap for a patent for smart logistics.

Schuhmacher et al. [17], transfer an existing production system to a CPPS to develop new innovative planning and control methods for production and intra-logistics. Sensor technology, RFID and wireless communication are used. The result obtained is the decentralized planning and control of production in the Logistics Learning Factory of the University of Reutlingen to facilitate future research.

The results obtained in the presented articles show the ontology of intelligent logistics, the implementation of a CPS demonstrator to monitor a conveyor belt in a laboratory environment, an intelligent and efficient logistics module to monitor in real time and planning and control for production methods and intra logistics.

2.3. Articles related to Industrial Engineering in the age of Industry 4.0

In this set of articles, they are related to the use of location technologies such as RFID, belonging to industry 4.0 in different contexts, as well as the use of other technologies typical of this industrial revolution and that are applied in different fields of industrial engineering.

Juhász et al. [18] identified the supply challenges right in the sequence in the automotive industry from industry 4.0 solutions. The authors seek to improve the efficiency and availability of logistics processes and services. The study was carried out through JIS-based optimization algorithms, JIT strategies, simulation tools, RFID's technology, and interoperability systems. The result was cost control, risk reduction in the supply chain and third-party logistics support (3PL).

Some investigations were implemented in different fields such as the textile industry, the ceramic industry, and the laundry service. Nayak et al. [19] identify the implementation of RFID technologies in retail factories and manufacturers of clothing and consumer goods such as Tesco, Prada, Benetten, Walmart and P&G. The authors analyze the obtaining of potential benefits in the Supply Chain by reducing inventory losses, increasing efficiency, speed in processes and accurate information.

The use of RFID helps reduce labor. However, some disadvantages in the use of RFID are presented as the high cost of implementing these technologies, the damage of RFID tags and the alteration of their algorithms. Another application was seen in a study carried out by Barata et al. [7] where they carry out the traceability of the products of the ceramic industry. A model is obtained that combines technologies in various stages of the product life cycle and they are implemented in a cloud based MES prototype. The creation of cloud based MES supports the integration of the horizontal, vertical and technology tiers required for Industry 4.0. The cloud based MES aims to support the entire life cycle of tabletop and ornamental ceramic production, with distributed manufacturing and the integration of traceability technologies (barcode, QR code and RFID). The developed solution allows tracking the products, parts of national material products.

Finally, Liu et al [20] proposed an innovative business model for the next generation of commercial laundry services (cloud laundry) to demonstrate the theoretical and empirical feasibility of integrating manufacturing, industrial automation, and smart logistics management into the era of industry 4.0. The company uses advanced interdisciplinary technologies such as: big data analytics, route finding, AI, and integrated automated manufacturing to solve practical problems. The model focuses on routing for service and data security. The authors seek to obtain efficiency in the service, efficiency in the use of resources, improve quality and reduce automatic delivery times.

The results obtained in the articles presented show the application of the new technologies of Industry 4.0 in industrial engineering, especially in production and logistics. The articles mentioned above are case studies applied in the textile, automotive, ceramic and laundry industries.

3. Objectives

General objective

Create a logistic extension of a Manufacturing Execution System of the Javeriana CP Factory that, through the development of a logistics operation module, integrates horizontally the production and logistics process of the emulated manufacturing system.

Specific objectives

1. Identify the needs and specifications of the logistic extension module of the manufacturing system in order to determine the operations processes that integrate the production and logistics process of the supply chain.

2. Elaborate the conceptual design of the system architecture of the integrated production and logistic system, considering the components, structural organization, and modules behavior within the system.

3. Implement the logistic extension module with the Manufacturing Execution System of the CP Factory of Javeriana University, which allow exchange of information between both systems, monitoring of activities, interaction with the operator, and their presentation in a dashboard.

4. Validate the horizontal integration approach proposed by the integration the logistic extension module of the manufacturing system in order to evaluate the functionality and usability of the system.

4. Methodology development

The methodology contributes to the general objective and will be developed in four phases. Each of the phases that will be developed corresponds to the specific objectives mentioned above. The first phase will identify the needs and specifications of the logistic extension module of the manufacturing system. In this phase, the characterization of the manufacturing system will be performed, and the needs and specifications required will be determined. In the second phase, the conceptual design of the system architecture of the integrated production and logistic system will be elaborated. The main activities to be developed in this phase will be the construction of the architecture. The third phase seeks to implement the logistic extension module with the Manufacturing

Execution System of the CP Factory of Javeriana University. The activities to be developed in this phase will be the creation of the database to work with and progressive programming of the module. Finally, the last phase will validate the horizontal integration. The activities to develop in this phase will be checking the internal and the external functions of the module. According to the phases and activities described above, the following diagram is presented in Fig 3:

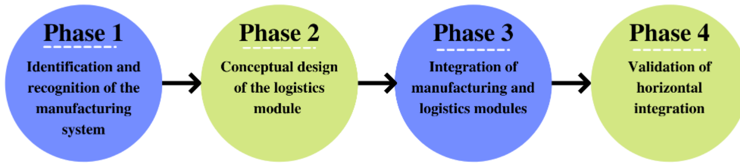


Fig 3. Methodology phases [Own author]

4.1. Identification and recognition of the manufacturing system

The first phase of this research project is identifying the needs and specifications of the logistic extension module of the manufacturing system in order to determine the operations processes that integrate the production and logistics process of the supply chain. The current process of the CP Factory, the scope and the processes involved in the supply chain for the horizontal integration of the production and logistics module proposed is fundamental to fulfill the first specific objective.

The description of eight factors includes the characterization that must be carried out to know the current manufacturing system of the CP Factory. The supply chain to be developed for the process is proposed knowing the aforementioned factors and based on the supply chain, the logistic needs for the module are determined.

Characterization of the Manufacturing Execution System

The CP Factory of Javeriana University is controlled by MES 4, a software developed by Festo. The MES 4 allows to control the current production systems in the CP Factory. It also allows the creation of different products that require different resources or machines, workplans, raw materials, and others. The manual of how the MES 4 is composed is in the Appendix I. The resources and processes available in the MES 4 are delimited for the development of this research project.

A specific characterization is carried out in order to delimit the functions offered by the MES 4, including information related to the eight factors: finished goods, raw materials, bill of materials, resources and operations, work plans, layout and current process. Appendix I contains details of all the factors mentioned. The finished goods, raw materials, design, and current process are shown below.

Finished goods

Two finished goods are produced in the CP Factory under a simulated environment in CIROS and Manufacturing Execution System (MES 4). Additionally, finished goods produced in the CP Factory are shown in Table II with their respective manufacturing code, their name, and their image.

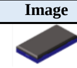
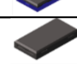
Manufacturing code	Finished good	Image
10	Blue cell phone	
20	Black cell phone	

TABLE II. FINISHED GOODS

Raw materials

Direct materials are the physical items incorporated in the final product. Table III shows the direct raw materials required to produce the finished goods in the CP Factory, their manufacturing code, and their image. The black back covers are endless for this case study.

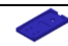
Manufacturing code	Direct material	Image
111	Black back cover	
410	Blue front cover	
210	Black front cover	

TABLE III. DIRECT RAW MATERIALS

Layout

The current distribution of the CP Factory manufacturing system has two production lines. Each production line has the purpose of manufacturing each finished good. Fig 4 shows the layout of the simulated production plant, the location of the mentioned resources and the product flow of each production line.

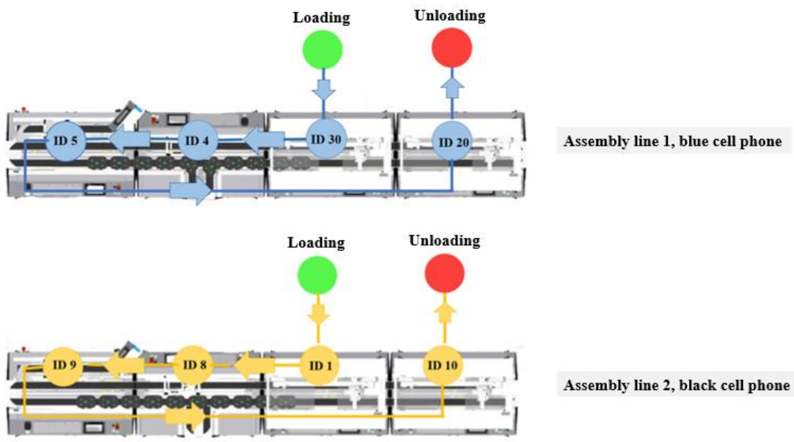


Fig 4. Current layout [Own author]

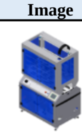
Type of resource	ID resource	Description	Image
ASRS32	1	Black raw material warehouse	
	10	Black finished good warehouse	
	30	Blue raw material warehouse	
	20	Blue finished good warehouse	

TABLE IV. ASRS32 warehouses

The resources offered by the MES 4 have a nomenclature, ASRS refers to Automatic Storage and Retrieval System, is equipped with a cartesian robot for automatic storage and retrieval of pallets. Up to 32 pallets can be stored and retrieved [21]. Table IV shows the resources required to produce, their ID code, their description and their image.

Current process

The MES 4 has an Access database where all the software information is stored, for example: the status of the raw material and finished good warehouses (ASRS32), the production orders created and finalized, the processing time of each cell phone, and others. Additionally, the characterization of the MES 4 database can be found in Appendix I.

The process starts when the production operator fills the ASRS32 warehouses with raw material for each cell phone with the MES 4. Next, the production operator must enter a production order in the MES 4. The production order is received by CIROS, and the production process of each cell phone starts. The process continues with the release of the front covers, where each one is placed on a carrier. The front covers are transported to feed the back cover from magazine operation. The back cover is placed on top of the front cover in this part of the process. Then, the carrier transports the product in process to the next operation whose function is to press the back cover with force regulation. Finally, the finished goods are transported to the ASRS32 warehouses for storage. The current cell phone production process is presented in Fig 5.

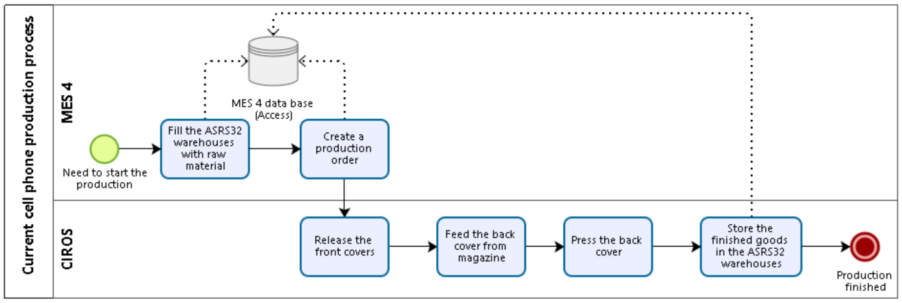


Fig 5. AS-IS diagram of the cell phone production process [Own author]

Finally, the identification of the needs and specifications of the logistics module based on the characterization of MES 4 can be found in the results section of this research project.

4.2. Conceptual design of the logistics module

The second phase of this research project is elaborating the conceptual design of the system architecture of the integrated production and logistic system, considering the components, structural organization, and modules behavior within the system. For this phase it is important to delimit the scope of the proposed logistics module, which is called MFS logistics module, based on the needs and specifications required of the previous phase, define the variables and parameters associated with the inputs, outputs, and restrictions for the development of the module. Finally, the relationship between the variables and their functionality must be defined.

4.2.1. Architecture

In order to create the architecture diagram proposed in Fig 6. it is important to consider the results obtained in phase 1 "Identification and recognition of the manufacturing system", since there it is possible to identify through the supply chain (Fig 10.) for the cell phone sales process the logistic needs for a logistic module called MFS that will be integrated to the existing manufacturing system in the CP Factory.

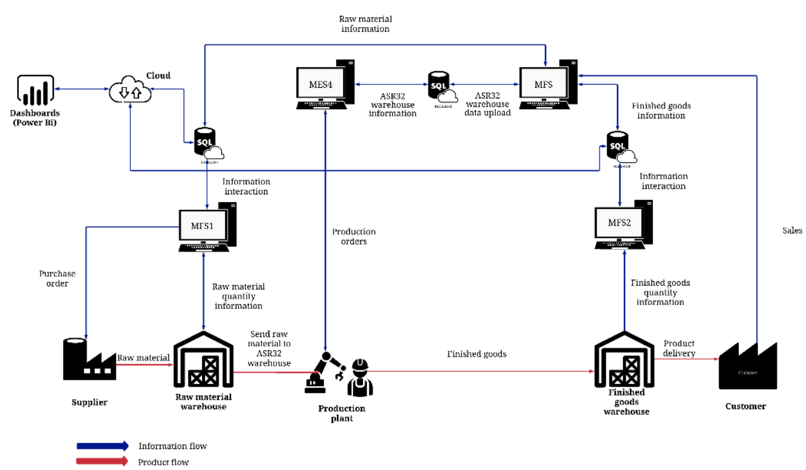


Fig 6. Architecture diagram [Own author]

Currently the CP Factory is controlled by MES 4, where all the cell phone production orders are managed. Fig 6. shown that the MES4 is at the same level of the MFS and they are intercommunicated through a database, likewise, the MFS is divided into two systems. The first one will oversee controlling the flow of raw material, from its reception to its supply to production and the second one will oversee the flow of finished goods from supplying the finished good warehouse to its delivery to the customer. The MFS logistics module has a database to store the information collected during the process, however, the database was divided into two to facilitate the visualization of both systems in the diagram. The MFS logistics module generates purchase orders to suppliers in a timely manner through inventory policies. Finally, MFS databases are connected to the cloud to know information in real time.

4.2.2. Layout

Based on the above it is important to generate a new plant layout, including raw material and finished good warehouses for each assembly line, with double the capacity of the existing ASR32 warehouses. The new plant layout is shown in Fig 7 and the presentation of the logistics warehouses in Table V.

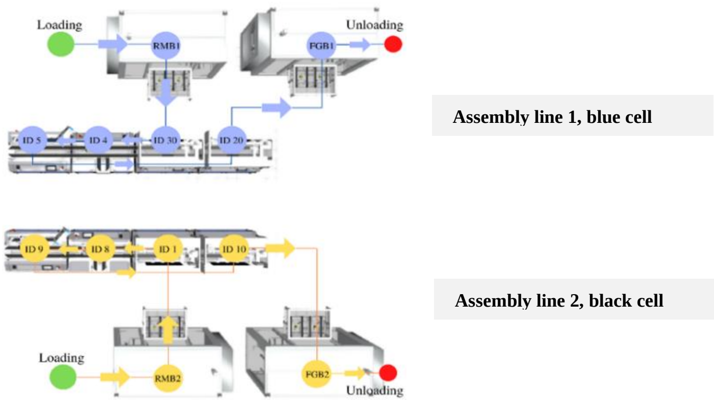


Fig 7. Proposed layout [Own author]

Type of resource	ID resource	Description	Image
ASRS64	RMB1	Blue raw material warehouse	
	FGB1	Blue finished good warehouse	
	RMB2	Black raw material warehouse	
	FGB2	Black finished good warehouse	

TABLE V. ASRS64 warehouses

4.2.3. Requirements

The ISO/IEC 25010 standard must be considered for the creation of the MFS logistics module. Additionally, functional and non-functional requirements are derived from the definition of this standard to ensure the quality of the software to be developed [22]. The characteristics of ISO/IEC 25010 are evaluated by means of checklists where the functional and non-functional requirements to be satisfied by the MFS logistics module are established. The lists of functional and non-functional requirements are presented in Table VI and Table VII.

FUNCTIONAL REQUIREMENTS	
Functional adequacy - Process requirements	
Allow the simulation of cell phone sales to customers.	Update the production warehouses (ASRS32) of raw material and finished product when a transaction is made.
Store information of a sales or purchase order generated.	Update the logistic warehouses (ASRS64) of raw material and finished product when a transaction is performed.
Store information of a sales or purchase order generated with empty fields.	Communicate the MFS logistics module database with the MES 4 database.
Store customer and supplier information.	Store information to create dashboards.
Inform the customer about the status of the order.	Visualize dashboards from the MFS logistics module.
Know the status of the logistic warehouses (ASRS64) of raw material and finished good.	Know the status of the production warehouses (ASRS32) of raw material and finished good.

Redirect to other applications such as Ciros, MES 4 and Power BI.	Allow the modification of estimated demand values from an interface.
Allow the simulation of purchase of raw material from suppliers.	Facilitate the search of purchase and sale orders made.
Notify the operator when each batch finishes the production process.	Generate details of each production batch to the operator.
Allow the creation of suppliers.	Assign each sales or purchase order a unique identifier.
Generate quantities to request to the supplier in the purchase order.	Display the sales or purchase orders generated in an interface.
The supply process includes the following steps: selection of the supplier, request of the quantity required and generation of the order.	The sales process includes the following steps: entering customer information, requesting the quantity required by the user, validating the status of the order and delivering finished goods.
Functional adequacy - Graphical interface requirements	
Amount fields accept only numeric values.	The name fields accept only alphabetic characters.
Address fields accept alphabetic, numeric, and special characters.	The city field is populated with a drop-down list.
The supplier field is populated with a drop-down list of the created suppliers.	The date field presents the current day, month, and year.
Functional adequacy - External interface requirements	
The MFS logistics module works without the need to install additional software, with the exception of MES 4.	The MFS logistics module can be used on Windows and Mac Os operating systems.

TABLE VI. FUNCTIONAL REQUIREMENTS LIST

NON-FUNCTIONAL REQUIREMENTS		
Product requirements		
Efficiency	Each action performed with the MFS logistics module must not take more than 5 seconds to be executed.	The database information must be updated for all users in less than 2 seconds when any transaction is performed.
Reliability	Database can only be modified by the administrator.	
Usability	The user is able to operate the MFS logistics module after reading the manual.	Provide messages or informative elements to the user during the process.
	The MFS logistics module has a user manual with all the necessary information to know and use it.	The MFS logistics module has a visually pleasing design for the user (color, font, font size, images).
	Have a help system in case the MFS logistics module fails.	The MFS logistics module can be used in different languages.
	The graphical interfaces are organized in such a way that the information in each one is easily understood by the user.	The time to start the MFS logistics module is no more than 1 minute.
Portability	The MFS logistics module does not occupy more than 3 GB of disk space.	
Security	Control and allow access to the "worker" window only to authorized users.	Users must log in with a username and password to the worker window.
	Send alert messages when unexpected events occur in the sales, production, and supply processes.	
Organizational requirements		
The information stored with the MFS logistics module allows the creation of KPI's to know the status of the CP Factory.		
External requirements		
The MFS logistics module does not disclose personal customer information to external entities.		

TABLE VII. NON-FUNCTIONAL REQUIREMENTS LIST

4.2.4. Definition of variables and parameters and their relationships

The definition of variables and parameters is a fundamental activity to develop the conceptual design of the MFS logistics module. The variables and parameters needed in this research project, their type and description are shown in the tables in Appendix II. In addition, the relationship between variables and parameters must be established to know the connections that exist in the process. The UML class diagram designed to show the relationship between the variables and parameters determined is shown in Fig 8 [23]

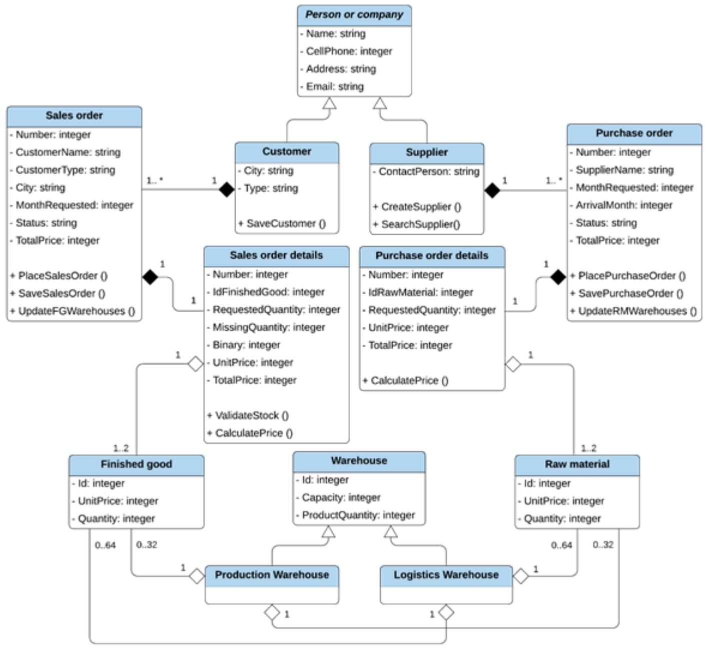


Fig 8. UML class diagram [Own author]

4.2.5. Case Study

The case study for this research project is shown in Appendix III. Finally, the conceptual design of the MFS logistics module based in the previous specifications and requirements can be found in the results section of this research project. Additionally, the case study contains inventory policies, but these are parameterized in order to facilitate the development of the module but are not optimal during the process.

4.3. Integration of manufacturing and logistics modules

The third phase of this research project is implementing the logistic extension module with the Manufacturing Execution System of the CP Factory of Javeriana University, which allow exchange of information between both systems, monitoring of activities, interaction with the operator, and their presentation in a dashboard. For this phase will describe the database of the MFS logistics module and will also show the software developed, its characterization and manual are important to understand the development of this phase.

4.3.1 Data base description

Azure is a platform that offers cloud services from Microsoft. The creation of databases is done through the Azure SQL Database service. Azure allows storing information in a secure and intelligent way. With Azure SQL Database, a highly available and high-performance data storage layer can be created for the applications and solutions in Azure. In addition, Azure SQL Database is based on the latest stable version of the Microsoft SQL Server database engine. Advanced query processing features can be used, such as high-performance in-memory technologies and intelligent query processing [24].

A database in Azure was created for the development of the MFS logistics module. The database stores the status of logistics warehouses, customers, suppliers, purchase orders, sales orders, inventories and demands. To access the information in the database, it is necessary to log in to a server in Microsoft SQL Server Management Studio. In addition, the data is stored in the cloud, allowing the dashboards to be viewed in real time.

Additionally, the variables and parameters presented in the Appendix II are organized in tables presented in Table VIII in order to visualize the information easily. Furthermore, the characterization of the Azure database with the detailed presentation of each table created is shown in Appendix IV.

Table name	Description
Customers	Store customer information
Demands	Store estimated and real demands by month
FGBlack	Store quantity of blue cell phones in finished good warehouses - ASRS64
FGBlue	Store quantity of black cell phones in finished good warehouses - ASRS64
IPFGBlack	Store black cell phone inventory
IPFGBlue	Store blue cell phone inventory
IPRMBlack	Store black front cover inventory
IPRMBlue	Store blue front cover inventory
PurchaseOrders	Store purchase orders placed with suppliers
RMBlack	Store quantity of black front covers in raw material warehouses - ASRS64
RMBlue	Store quantity of blue front covers in raw material warehouses - ASRS64
SalesOrders	Store sales orders placed by customers
Suppliers	Store supplier information

TABLE VIII. TABLES THAT COMPOSE THE AZURE DATABASE

4.3.2. Implementation of the MFS logistics module

The MFS logistics module is intended to be integrated with the current production module (MES4), production module that controls the CP Factory of Javeriana University, considering this, the MFS logistics module seeks to supply logistical needs required in the process of selling cell phones.

The MFS logistics module has two main components: the graphical interface and the source code in charge of the whole operation of the module. The source code on the one hand, was written in the Python programming language, which allows a simple interaction with the databases regardless of their origin from specific libraries that this language has. On the other hand, the graphical interface was developed in QT Designer. This program allows the execution of the module either in Windows or MacOS, have a simple integration with Python and a programming focused on easy-to-use objects for the design of the module windows. The programs used for the creation of the module were chosen based on their versatility and convenience at the programming moment and for the use of the final product by the user.

4.3.3. Dashboards

Dashboards aim to organize and present the information stored in the Azure database. In addition. The KPI's chosen to group the information stored in the MFS logistics module were based on the variables collected during the logistics and production process. Therefore, the dashboards are visualized in Power BI because this is a tool that allows to connect to a wide range of data sets. In addition, Power BI works to turn the unrelated sources of data into coherent, visually immersive, and interactive insights. Power BI connects to the Azure database in order to visualize and discover what is important, and easily share the information with anyone [25]. The information storage mode used is Direct Query, which allows KPI's to be updated in real time. Finally, the results of the MFS logistics module and dashboards can be found in the results section.

4.4. Validation of horizontal integration

The fourth phase of this research project is the validation of the proposed horizontal integration between the MFS logistics module and the production module. For the development of this objective, on the one hand, tests must be performed to ensure that the functional and non-functional requirements have been mostly fulfilled. On the other hand, a qualitative study should be carried out through a qualitative observational study in order to know the opinion of a specific group of participants about the functioning of the MFS logistics module.

4.4.1. Software testing

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On the one hand, two of the most important software testing techniques were used to validate functional requirements: white box testing and black box testing [26]. On the other hand, the non-functional requirements were validated from the final features of the MFS logistics module since they were easily detectable.

The white box testing is defined as a technique that investigate the internal logic and structure of the code. Additionally, this type of testing can detect implementation errors as each part of the code is tested for functionality [26]. The code developed was tested with a concatenated loop test, because if two loops are independent from each other then they are tested by using simple loop test. However, for two concatenated loops, if the loop counter for one loop is used as the initial value for the others, then the two loops are not independent [27].

Whereas the black box testing is defined as a technique that examines the fundamental aspects of the software without considering the internal logic structure of the MFS logistics module [26]. Some important types of black box testing techniques are used: equivalence partitioning, boundary value analysis, fuzzing, cause-effect graph, orthogonal array testing, all pair testing, and state transition testing [26]. However, the technique that will be used is equivalence partitioning. The validation of functional requirements is in the results section. In addition, the white box and black box tests developed to support the validation of the established functional requirements can be found in Appendix V.

Non-functional requirements are tested through abstraction of the basic module features. No validation test is necessary in this research project for the verification of the non-functional requirements since the stated requirements are basic and can be corroborated at a glance. The validation of functional requirements is in the results section.

4.4.2. Qualitative observational study

It is required to test the MFS logistics module different from the software tests, in order to avoid biases in the study and to be able to conclude about the performance and purpose of the MFS logistics module. Quantitative data collection is not necessary to validate the usability and functionality characteristics of the software. The qualitative study should be developed in order to have a previous approach to a group of people and to know their opinion regarding the MFS logistics module. Focus group discussion is often used as a qualitative approach. This method aims to obtain data from a selected group of individuals. The focus group discussion consists of four major steps as shown in Fig 9. The steps are research design, data collection, analysis, and reporting of results [28]. The description and development of each step is shown in Appendix VI.

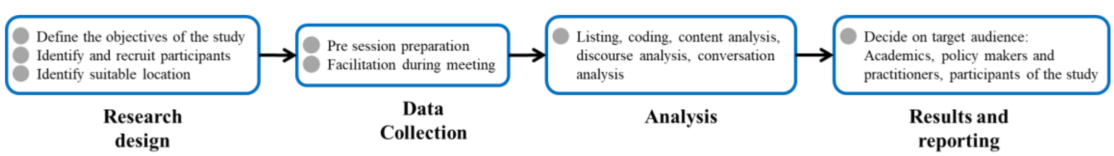


Fig 9. Focus group discussion steps [28]

To realize focus group the number of respondents to be invited for discussion is an important consideration. Generally, six to eight participants are accepted because they are sufficient [28]. Likewise, six people were invited to the focus group to validate the MFS logistics module. Additionally, the participants must be students of industrial engineering at the Universidad Javeriana with emphasis in technology and/or logistics because of the topics developed in this research project. Finally, five of the six people selected are students and the last person is an expert in technology-related topics.

5. Results

5.1. Identification and recognition of the manufacturing system

Based on the specifications that constitute the MES 4, it is necessary to identify needs so that it can be integrated with the logistics module. The supply chain for the commercialization of cell phones is shown in Fig 10. The purpose of developing this diagram is to identify the links in the chain with their processes in order to extract needs of the logistics module.

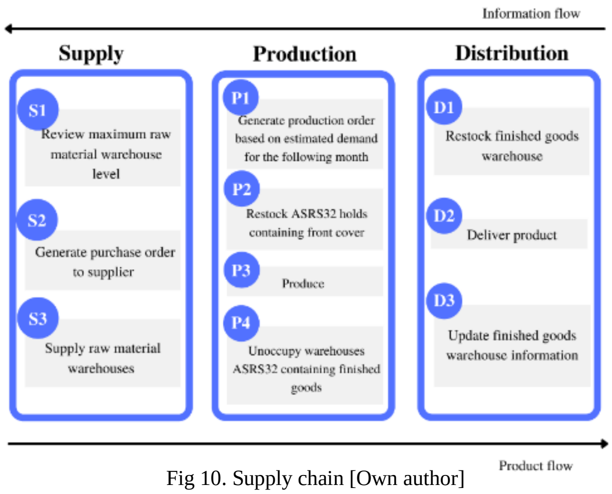


Fig 10. Supply chain [Own author]

The supply chain is composed of three links: supply, production, and distribution. Fig 10 shows the supply chain for the sale of cell phones. Nowadays, cell phones are manufactured in the CP Factory, the production orders are generated through the MES 4, however, there is no control over the supply of raw materials or the distribution of the finished goods.

The supply chain presented in Fig 10 shows the need to create logistics warehouses for the control and handling of raw materials. The logistics warehouses allow having enough stock to supply the ASRS32 warehouses present in the assembly line that contain the raw materials to produce cell phones. Additionally, in the supply link, it is necessary to control the inventory of the logistics warehouses through inventory policies to generate purchase orders to suppliers in order to supply.

Furthermore, it is proposed to create a month-by-month production plan based on estimated product demand. In addition, the ASRS32 warehouses on the assembly line dedicated to storing finished goods must be emptied to fill the logistics warehouses with finished goods once production is finished. In the distribution link, the finished good warehouses must be restocked because the finished goods units stored in the logistics warehouses will be available to the customer. Also, the constantly update information on the proposed warehouses is an important aspect throughout the chain.

5.2. Conceptual design of the logistics module

5.2.1. Process description

It is necessary to implement two new processes in the supply chain, supply and distribution, to develop the MFS logistics module. Additionally, the current production process must be modified in order to integrate, manage and automate the logistic flow of material and information. Each of the processes of the supply chain (supply, production and distribution) is explained below, as well as the participation of the components presented in the architecture diagram.

Supply process

The supply process starts with the need to purchase from suppliers. The operator must create the supplier if it is not already registered in the MFS database. Then, the raw material quantities are verified in order to know the order query. The operator must request the quantity consulted by the MFS logistics module, that means if the quantity consulted for both products is equal to 0, no purchase order is placed. The supplier receives the purchase order and delivers the requested quantities. The process ends when the order enters the CP Factory and the ASRS64 warehouses are filled with the raw material received. The supply process is shown in Fig 11.

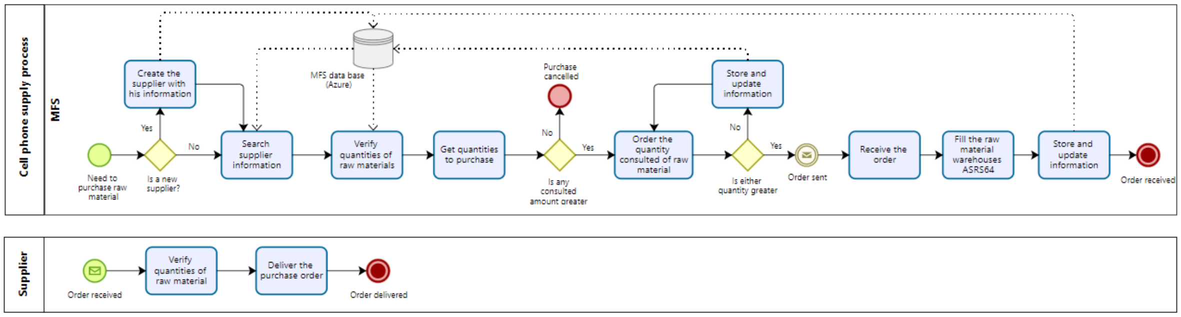


Fig 11. TO-BE diagram of the cell phone supply process [Own author]

Production process

The production process starts with the verification of the quantity of finished goods in order to determine if it is necessary to produce. Next, it is validated if there are enough raw materials. If there is sufficient stock, the MFS logistics module sends a message with the quantities of each cell phone to be produced. The operator receives this information and refreshes the ASRS32 raw material warehouses. The process continues with the transfer of raw material from the ASRS64 warehouses to the ASRS32 warehouses if it is required. The production order is created in MES 4, and the production process is performed in CIROS. Finally, the produced cell phones are stored in the ASRS32 warehouses. They must be moved to the ASRS64 finished good warehouses. The production process ends when all production batches have been produced. The production process is shown in Fig 12.

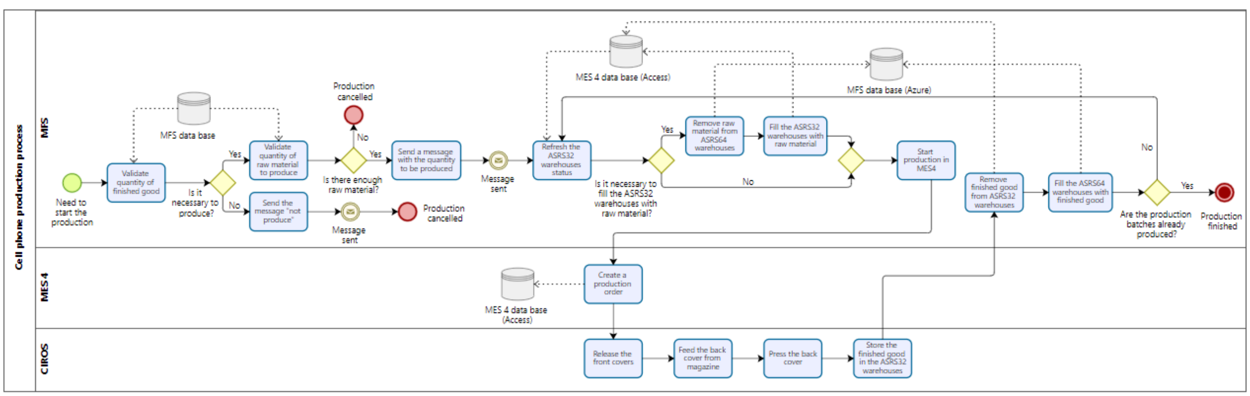


Fig 12. TO-BE diagram of the cell phone production process [Own author]

Distribution process

The distribution process is mainly based on the sales process that is carried out to deliver finished goods to customers. The process starts when the customer wants to purchase a cell phone. The customer must generate a sales order with his personal information and the quantities of each cell phone to be purchased. If any of the requested quantities is greater than 0, the sales order is generated, otherwise the customer must enter new quantities. It must be verified that there is enough product to be able to deliver the requested quantities of product once the sales order is saved in the MFS database. An order can be delivered complete if there is enough stock of both cell phones; incomplete if there is only enough stock of one cell phone and undelivered if there is not enough stock of any cell phone. The customer receives a message in order to know the status of his order. Finally, the customer receives the quantities ordered if there is enough stock to fill the order placed. The distribution process is shown in Fig 13.

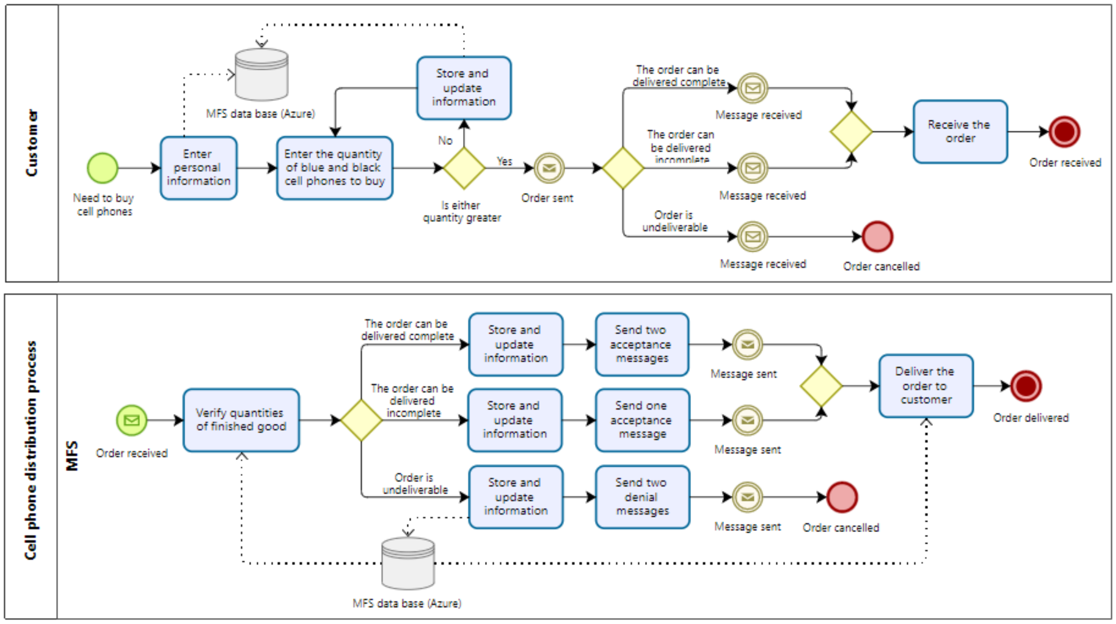
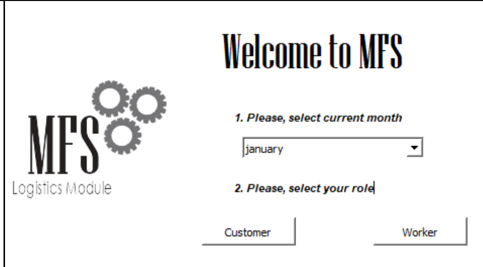
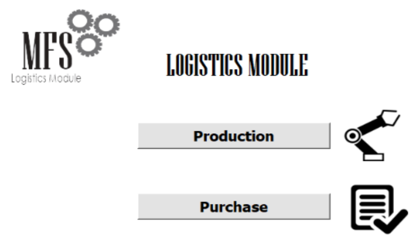
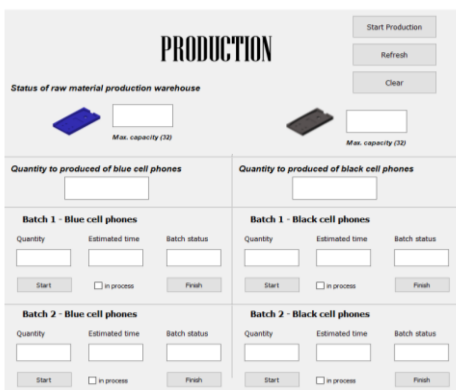
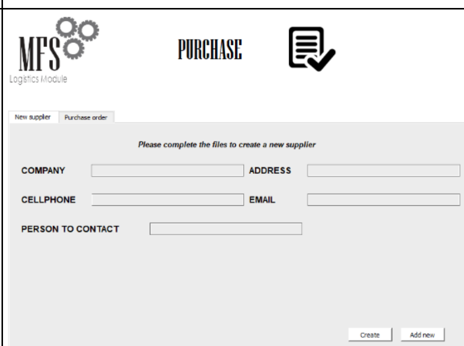


Fig 13. TO-BE diagram of the cell phone distribution process [Own author]

5.3. Integration of manufacturing and logistics modules

The MFS logistics module has seven windows that allow the user to interact with the different processes. Table IX presents the name of each window, its image, the description of each one and the classes and subs of the code found in each window. Additionally, the user's manual MFS logistics module can be found in Appendix VII.

Window name	Image	Description	Subs of the code
Main window		The logistics module starts with the main window. The user must select the current month and the type of role he/she wants to adopt depending on the process he/she wants to execute	Class Mainprin - Def mes - Def ventana - Def ventana1
Sales window		The sales window is opened when the user selects the customer role in the main window. The user can place orders. In addition, each customer's record and order information is stored in the Azure database once the sales order has been generated. Finally, the customer can know if the requested quantity of each cell phone can be delivered depending on the amount of stock in the finished goods logistic warehouses	Class Sales - Def primersub - Def comprobarPTazul - Def comprobarPTnegro - Def totalventa - Def datoscliente - Def llenartablasalesorder

Worker window		The worker window is opened when the user selects the worker role in the main window. The worker window is a transition window, where the user will find the two activities that must be performed: production control and generation of orders to suppliers	Class App
Production validation window		The production validation window is opened when the user selects the production option in the worker window. The production validation window is an informative and transition window. This window provides information on the quantity of cell phones that must be produced to meet the next month's demand. In addition, this window validates if there is enough raw material available to carry out the production	Class producc - Def produccion - Def comprobarPTproducir - Def abrir
Production window		The production window is opened when the user presses the "go to production" button in the production validation window. The production window allows the user to visualize the information of each production batch: quantity, estimated time and status. Additionally, the information related to the quantity of raw material in the production warehouses and the total quantity to be produced for each cell phone can be found in this window	Class produ - Def activar - Def startazul - Def startnegro - Def finishazul - Def finishnegro - Def refresh
Supplier creation window		The supplier creation window is opened when the user selects the purchase option in the worker window. The supplier creation window allows the user to create new suppliers. The user must fill in all the fields with the supplier's information. Finally, the user can create as many suppliers as desired	Class pur - Def_init

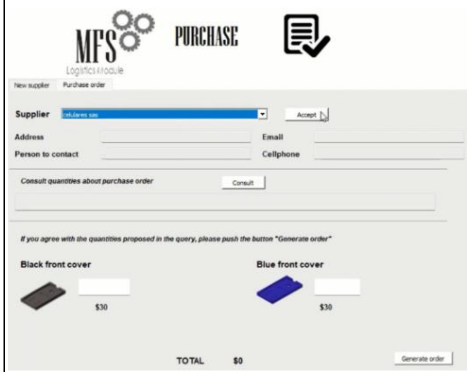
Purchase order window		The purchase order window is opened when the user selects the purchase option in the worker window. The purchase order window allows the user to select the supplier from whom the purchase order is to be placed. Additionally, the user must consult the quantity of raw material to be ordered. Finally, the purchase order is generated with the information provided	Class pur - Def ordenpro - Def sugerencia - Def gurdarinfopro - Der traerdatos

TABLE IX. MFS WINDOWS DESCRIPTION

Additionally, Table X presents the dashboards developed with their image and description of each one. Furthermore, the detailed presentation of each dashboard with the description of each KPI and variable used can be found in Appendix VIII.

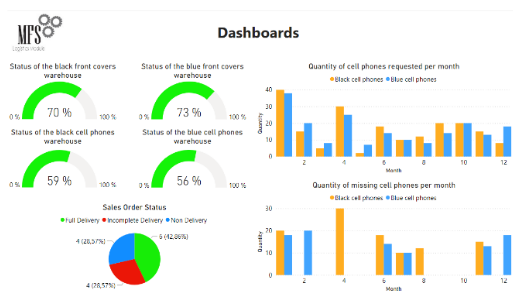
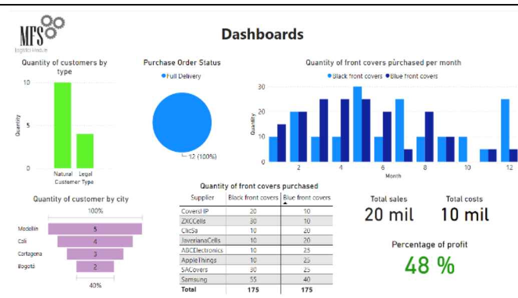
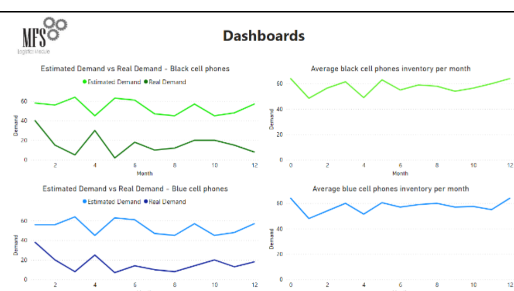
Dashboard	Image	Description
First dashboard		The first dashboard shows information related to the occupancy percentage of each warehouse (production or logistics). Additionally, the percentage of the status of each sales order can be viewed on the dashboard. Finally, the bar chart shows information related to the number of sold and missing cell phones per month
Second dashboard		The second dashboard shows information related to customers and suppliers. Additionally, the proportion of the status of each purchase order is displayed on the dashboard. Also, the bar chart shows information related to the number of cell phones ordered from suppliers per month. Finally, the profits KPI is presented in this dashboard
Third dashboard		The third dashboard shows information related to demands. The graphs show a comparison between estimated and real demands for each cell phone in the month. Also, the dashboard presents information related to the behavior of the inventory of each finished good per month

TABLE X. DASHBOARDS DESCRIPTION

5.4. Validation of horizontal integration

5.4.1. Software testing

The check of the functional requirements is presented in Table XI.

FUNCTIONAL REQUIREMENTS	Has the requirement been met?	
Functional adequacy - Process requirements	**Yes**	**No**
Allow the simulation of cell phone sales to customers.	X	
Store information of a sales or purchase order generated.	X	
Store information of a sales or purchase order generated with empty fields.		X
Store customer and supplier information.	X	
Inform the customer about the status of the order.	X	
Know the status of the logistic warehouses (ASRS64) of raw material and finished goods.	X	
Redirect to other applications such as Ciros, MES 4 and Power BI.		X
Allow the simulation of purchase of raw material from suppliers.	X	
Notify the operator when each batch finishes the production process.		X
Allow the creation of suppliers.	X	
Generate quantities to request to the supplier in the purchase order.	X	
The supply process includes the following steps: selection of the supplier, request of the quantity required and generation of the order.	X	
Update the production warehouses (ASRS32) of raw material and finished product when a transaction is made.	X	
Update the logistic warehouses (ASRS64) of raw material and finished product when a transaction is performed.	X	
Communicate the MFS logistics module database with the MES 4 database.	X	
Store information to create dashboards.	X	
Visualize dashboards from the MFS logistics module.	X	
Know the status of the production warehouses (ASRS32) of raw material and finished goods.	X	
Allow the modification of estimated demand values from an interface.		X
Facilitate the search of purchase and sale orders made.		X
Generate details of each production batch to the operator.	X	
Assign each sales or purchase order a unique identifier.	X	
Display the sales or purchase orders generated in an interface.		X
The sales process includes the following steps: entering customer information, requesting the quantity required by the user, validating the status of the order and delivering finished goods.	X	
Functional adequacy - Graphical interface requirements		
Amount fields accept only numeric values.	X	
Address fields accept alphabetic, numeric, and special characters.	X	
The supplier field is populated with a drop-down list of the created suppliers.	X	
The name fields accept only alphabetic characters.		X
The city field is populated with a drop-down list.	X	
The date field presents the current day, month, and year.		X
Functional adequacy - External interface requirements		
The MFS logistics module works without the need to install additional software, except for MES 4.	X	
The MFS logistics module can be used on Windows and Mac Os operating systems.	X	

TABLE XI. CHECK OF THE FUNCTIONAL REQUIREMENTS

Some requirements were not performed or not fully met because they were not strictly necessary for the basic functioning of the MFS logistics module. The functional requirements that were not performed or not fully met do not affect the main objective of the MFS logistics module as they are part of the aesthetics and ease of use. For example, the information provided for the generation of purchase orders and sales orders is stored in the Azure database, however all fields must be filled in order to save the data. Furthermore, the MFS logistics module does not notify the operator when a production batch is finished, however, the operator knows the estimated time per batch. Likewise, the logistics module does not redirect to other programs, but the operator can enter each of them independently and visualize the information exchange. Additionally, the demands can be modified but this change must be made directly in the database. The storage of sales and purchase orders is performed; however, the database must be accessed in order to locate a specific order. Finally, the name field can include numeric characters and for the date field only the current month is selected.

The check of the non-functional requirements is presented in Table XII.

NON-FUNCTIONAL REQUIREMENTS		Has the requirement been met?	
Product requirements		**Yes**	**No**
Efficiency	Each action performed with the MFS logistics module must not take more than 5 seconds to be executed	X	
	The database information must be updated for all users in less than 2 seconds when any transaction is performed.	X	
Reliability	Database can only be modified by the administrator.	X	
Usability	The user is able to operate the MFS logistics module after reading the manual.	X	
	The MFS logistics module has a user manual with all the necessary information to know and use it.	X	
	Have a help system in case the MFS logistics module fails.	X	
	The graphical interfaces are organized in such a way that the information in each one is easily understood by the user.	X	
	Provide messages or informative elements to the user during the process.	X	
	The MFS logistics module has a visually pleasing design for the user (color, font, font size, images).	X	
	The MFS logistics module can be used in different languages.		X
	The time to start the MFS logistics module is no more than 1 minute.	X	
Portability	The MFS logistics module does not occupy more than 3 GB of disk space.	X	
Security	Control and allow access to the "worker" window only to authorized users.		X
	Users must log in with a username and password to the worker window.		X
	Send alert messages when unexpected events occur in the sales, production, and supply processes.		X
Organizational requirements			
The information stored with the MFS logistics module allows the creation of KPI's to know the status of the CP Factory.		X	
External requirements			
The MFS logistics module does not disclose personal customer information to external entities.		X	

TABLE XII. CHECK OF THE NON-FUNCTIONAL REQUIREMENTS

The non-functional requirements were not met for the same reason as the functional requirements. The use of different languages in order to extend the use of the module to different cultures is an aesthetic feature that does not affect the main use of the software. Additionally, security requirements can be added in order to further complete the module, however, it does not change the main essence.

5.4.2. Qualitative observational study

In addition, the results obtained from the qualitative study are presented in the "results and reports" section of Appendix VI. The participants mentioned some recommendations, suggestions or modifications on the one hand, that could be made to the MFS logistics module in order to improve its functionality and usability. On the other hand, the participants reflected their agreement with respect to the dashboards, speed, and comprehension of the MFS logistics module. Finally, Fig 14 presents the evidence of the tests conducted at Javeriana University with the selected participants.

Fig 14. Evidence of the test conducted at Javeriana University [Own author]

6. Limitations, conclusions and recommendations

The integration of the supply chain processes is key to achieve higher productivity as well as to improve decision making. Therefore, the objective of this research project is to create a logistics extension of a Manufacturing Execution System of the CP Factory of the Javeriana University by developing a logistics module that integrates horizontally with the production module. In this research project it was demonstrated that the integration between processes facilitates the operation of the supply chain because all the factors that compose it are visualized. Likewise, the use of dashboards is a key complement to manage resources and improve decision making.

In addition, the contextualization of the manufacturing system of the CP Factory is an important step to be able to establish the needs required for the construction of the logistics module. It is important to identify the processes and phases where logistics is involved in order to know the parts where the logistics module should interact.

The conceptual design of the logistics module was developed from the established needs where the architecture, parameters, variables, requirements and new processes were established. In this research project it was found as a result that the theoretical can sometimes vary with the practical because there are several factors in reality that can modify what is stipulated theoretically.

Furthermore, it is concluded that the logistics module is a complement to the manufacturing system that meets logistical needs. This facilitates the management of the supply chain. However, there are some limitations to develop the theoretical approach of the module during the implementation. Additionally, there are some restrictions that limit the desired performance of the MFS.

Finally, the tests allow on the hand, to know the performance and usability of the module. Furthermore, it is possible to know how external constraints affect the development of the established requirements. On the other hand, the development of the focus group was necessary in order to determine future recommendations for the MFS logistics module.

This research project had limitations coming from the Javeriana University network. The MES 4 databases are in Microsoft Access, so it was necessary to respect their nomenclature and order in order to generate the integration. Likewise, the CIROS and MES 4 programs need to be connected to the Javeriana University network, since the latter provides the licenses for their use. For this reason, the MFS logistics module must be used on equipment with these licenses. Due to the cyber-attack that occurred at the Javeriana University, the aforementioned programs could not be used in the tests with the focus group participants. This directly affects the study since people could not clearly visualize the exchange of information between both systems. Finally, the Javeriana University network does not allow the generation of executables for security reasons, which is why the MFS logistics module could not be presented as an exe file.

Finally, it is important to continue with the review of other parallel processes that can strengthen the Manufacturing Execution System, such as human resources and finance among others, allowing the student to apply the knowledge acquired in his studies as an industrial engineer in a way closer to reality. Additionally, it is suggested to analyze, evaluate and implement the recommendations mentioned by the focus group participants to improve the functionality and usability of the MFS logistics module. Finally, it is recommended to implement calculations to find optimal inventory policies and forecasting methods in order to get more out of the MFS logistics module.

7. Appendix

Appendix	Tittle	Description
I	MES 4 information	MES 4 manual, characterization of MES 4 and characterization of MES 4 database
II	Variables and parameters	Presentation of the variables and parameters used for the construction of the module and their relationship
III	Case study	Presentation of the case study for the understanding of the factors of this research project
IV	Characterization of the Azure database	Information related to the tables and variables that compose the Azure database

V	White box and black box testing	Elaboration of white box and black box tests that support the validation of the functional requirements
VI	Qualitative observational study	Informed consents, video of the expert's answers, video of the focus group, transcription of participants' answers and results of the categorization obtained
VII	MFS information	User's manual MFS logistics module and video of the use of the MFS logistics module
VIII	Dashboards presentation	Explanation of the KPI's established and the variables used in each one

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