POLITECNICO DI TORINO

Master of Science in Automotive Engineering

Master Thesis

Study and definition of a Digital Supply Chain in Automotive Industry

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Contents

Abstract

The increasing globalization of markets and the need for companies to respond to the progressively personalized demand of consumers has created the need by companies for better integration management capable of involving all those phases that compose the life cycle of a product. This thesis aims to analyse a traditional automotive supply chain and to integrate technologies 4.0 to solve its main criticalities. The first chapter gives an overview of the concepts of Supply Chain Management and the Automotive Industry. Then, through literature mapping, the Automotive Supply Chain is defined, and its main processes are explained: receiving and processing an order, procurement, management of logistics flows within the Original Equipment Manufacturer (OEM), assembly, and distribution. For each phase, a dedicated material and information flow chart have been provided. Often, the firms tend to focus on material flow improvement neglecting information management. After an appraisal of the mappings, the main criticalities have been found. It turned out that most of the problems are related to a non-appropriate informative system and consequent lower visibility through the partners involved in the Supply Chain processes. Then, the Five Whys method has been used to find out the root causes of the criticalities described above. In the third chapter, countermeasures are proposed to the matters discussed in the previous chapters exploiting and suggesting the integration of Industry 4.0 technologies. The last chapter provides the benefits that this master thesis work can provide to the traditional Supply Chain, its limits, and some considerations and suggestions for future research.

Acknowledgements

If I am here to write this chapter, it means that I have truly reached the end of a long, tortuous and difficult journey started 5 years ago and surely made lighter by the people I have met during this journey.

I begin by thanking Prof. Cagliano for the support she has given me during this thesis work.

A special thanks go to my family that since day 1 has guaranteed me full support and guided me towards a university choice certainly not easy given the events of the past, but that today turns out to have been the best also in the perspective of a near future.

As in every journey that is worth to be remembered, it is not important the chosen destination but the people with whom you decided to undertake this adventure. In chronological order, I would like to thank the "Pem Pem" group that took in a young, ingenious and unconfident Simone and raised him to become the man he is today. I will never forget the strength you gave me to stay in Turin and without which I would most likely have retired immediately at the first hurdles. A special mention goes to Saverio and Coach who in these years have been and will be like brothers and have always been great listeners, supporters, companions, and I can state that without their advice both academically and in terms of personal decisions I would not have been able to finish the path in a precise time. Is 3 really the perfect number?

Talking about travels, I must mention the "Five guys" and that unforgettable trip to Prague looking for fun. One of the most beautiful trips with the right people at the right time.

As already said, in a trip it is not important the destination but the company with which you decide to do it. Well, does anyone know Turku? I admit that even I didn't know where it was, but a small city in Finland was able to give me great emotions and perhaps the most beautiful year so far. A huge thank you goes to the people I met during my Erasmus and in particular to the "3B" that seen from the outside might seem just an acronym but in these two characters are enclosed a number of adventures that is impossible to describe to those who have not experienced them. Impossible not to mention my buddy Gian, friend, companion, and partner in the craziest adventures

including eating disgusting quark because of Mitchell and without whom perhaps my Erasmus would not have been the same. Again, number 3 shows up again.

Finally, the last stop is the SanPaolo Campus. Here I met the group "Ci siam fatti!" which made the short stay certainly enjoyable. A special mention goes to "little" Alessandro, Bennet's partner, who despite his tender age turned out to be a big friend, listener, and advisor. Muflon, the first person I met on campus and with whom I immediately bonded, also deserves a mention. So, it really is true that 3 is the perfect number.

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Last but not least, to Angelica who has been a pleasant discovery at the most inappropriate time but who has been able to put order in a messy head and to keep me calm when everything seemed to go wrong.

To all these people a huge thank you and even if a new adventure is waiting for me, I will always carry you with me and please remember... never eat a soup alone!

List of Figures

1 Supply Chain and Industry 4.0 notions

The aim of this chapter is to explain the concept of Supply Chain and its main features. The, an overview of the Industry 4.0 are presented.

1.1 Supply Chain definition and main features

A Supply chain is defined as the entire process of making and selling commercial goods, including every stage from the supply of materials and the manufacture of the goods through to their distribution and sale (Grimshaw, 2020). Referring to the Supply-chain operations reference (SCOR) model there are five components of traditional Supply Chain Management systems. It is a reference model developed and endorsed by the Supply-Chain Council and it can be used to map, benchmark, and improve supply chain. The main processes are Plan, Source, Make, Deliver and Return as shown below [1]:

- Plan: describe the activities associated with developing plants to operate the Supply Chain. These include determining requirements, gathering information about available resources, balancing requirements, and resources to determine planned capabilities and gaps in demand or resources, and identifying actions to correct these gaps.
- Source: describe the activities associated with the supplier's choice to provide the goods and services needed to create the product. These include supplier relationship management, purchase orders, scheduling deliveries, receiving orders, validating orders, storing goods, and accepting suppliers' invoices.
- Make: describe the activities associated with the conversion of materials or the creation of content for services. These include assembly, chemical processing, maintenance, repair, recycling, refurbishment, manufacturing, and other types of material conversion processes.
- Deliver: describe the activities associated with coordinating customer orders, scheduling deliveries, dispatch load, invoicing customers and receiving payments.
- Return: describe the activities associated with the reverse flow of goods. These include identifying items that need to be returned, deciding on the proper

method of disposition, scheduling the return, and shipping and receiving returned goods.

In Figure 1.1 is possible to see the scheme of the SCOR model just described.

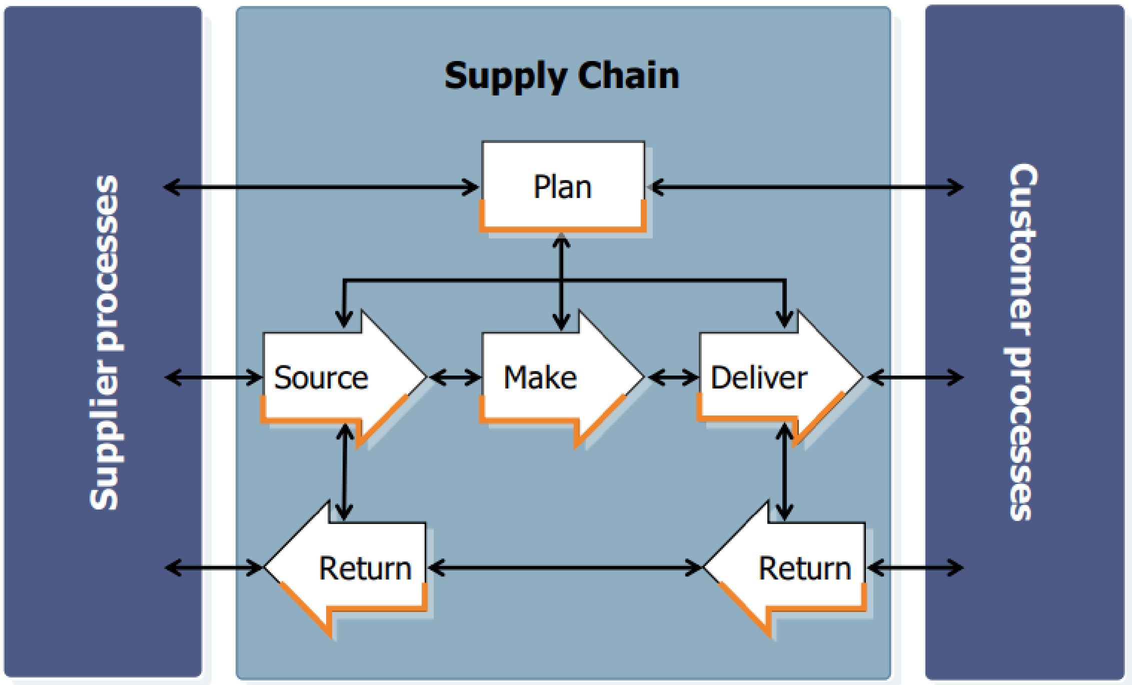

Figure 1.1 SCOR model scheme (Association for supply chain management, 2022)

Based on the processes it is possible to identify six main players in the Supply Chain (Chopra and Meindl, 2015) as shown in Figure 1.2 :

- final customers.
- retailers.
- wholesalers.
- distributors.
- manufacturers.
- components and raw materials suppliers.
- transporters and logistics service providers.

Figure 1.2 Generic Supply Chain players (Corporate Finance Institute, 2015)

Some components, such as wholesalers and distributors, may not be present, in case the manufacturer distributes the finished product straight to retailers, who may be small-scale or large-scale. On the other hand, if a wholesaler is present, he is responsible for purchasing big quantities from the manufacturer and then distributing the product to other retailers. When it comes to transportation between supply chain players, logistics service providers, also known as Logistics Service Providers (LSP), are frequently entrusted with the task. If the LSP, in addition to transport, is also responsible for integrated activities, such as the receipt, storage and preparation of orders, it is known as Third Party Logistics (3PL), or Fourth Party Logistics (4PL).

1.2 Evolution of the Supply Chain

In Figure 1.3 it is possible to see the evolution of Supply Chain Management (SCM) during the years. The main difference is that yesterday's Supply Chain were focused on the availability, movement, and cost of physical assets while modern ones are about data management, services, and products. The SCM affects product and service quality, delivery, costs, and customer experience [2].

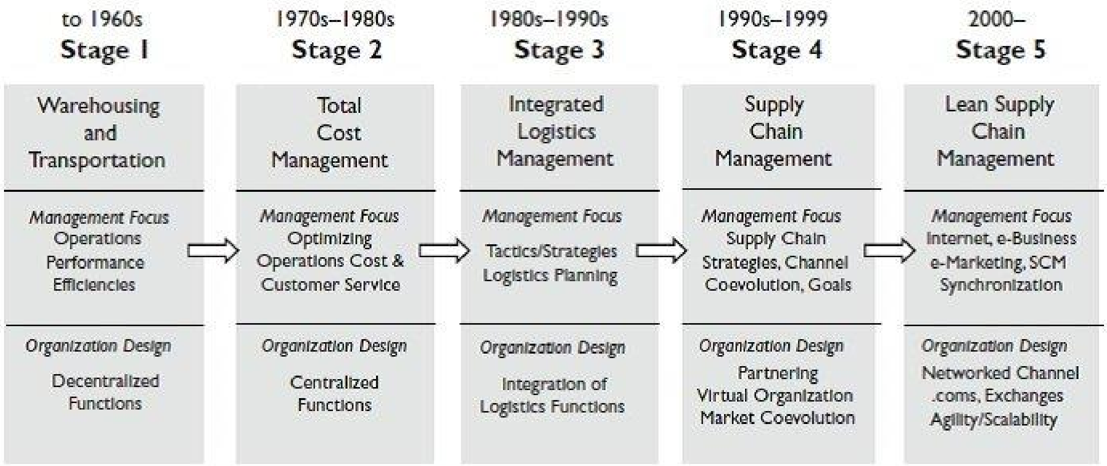

Figure 1.3 Evolution of Supply Chain Management (Daud et al. 2011)

Nowadays it is possible to take advantage of massive amounts of data generated by the chain processes. Effective SCM system can bring benefits such as cost, waste, and time reduction in the production cycle.

1.3 Technologies of Industry 4.0

Until now it has been stated that the integration of new technologies is required to digitalize the traditional Supply Chain. In the next sections, an overview of the main Industry 4.0 technologies will be provided.

1.3.1 Internet of Things (IoT)

The Internet of Things (IoT) describes the network of physical objects, "things", that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet [3].

A complete IoT system is composed four distinct components (McClelland, 2016):

1. Sensors/Devices are used for collecting data from their environment (e.g., camera, GPS, accelerometer etc.)
2. Connectivity: once collected the data are sent to a cloud. The connection between the sensors and the cloud is made by means of satellite, Wi-Fi, Bluetooth, low-power wide-area networks (LPWAN) or connecting directly to the internet via ethernet.
3. Data Processing: the data sent to the cloud are then needed to perform an analysis.

4. User Interface: the information processed are then shown to the user by means of an interface (e.g., email, text, notification, phone app, web browser etc.).

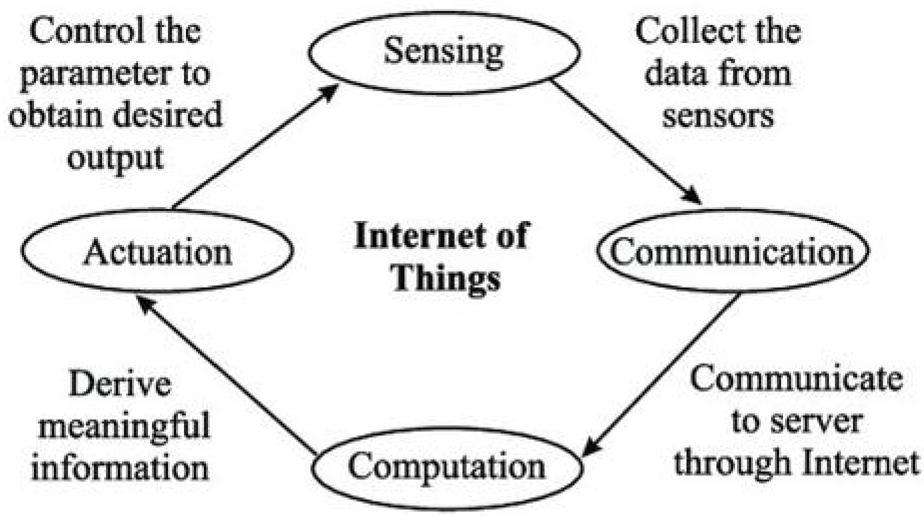

Figure 1.4 Operating Principle of IoT (McClelland,2016).

In Figure 1.4 are shown the main operating principles of IoT technology.

Tan (2021) identifies the following solutions applicable to the warehouse management systems:

- Radio Frequency Identification (RFID) tags where digital data encoded in the tags are captured by a reader via radio waves. The architecture is simply composed by three components: RFID tag or smart label, an RFID reader, and an antenna. The tags contain an integrated circuit and an antenna that are used to transmit data to the reader. Then, the reader converts the radio waves to a more usable form of data. The information collected are sent to a host system and can be visualized and analysed by the user. An overview is shown in Figure 1.5.

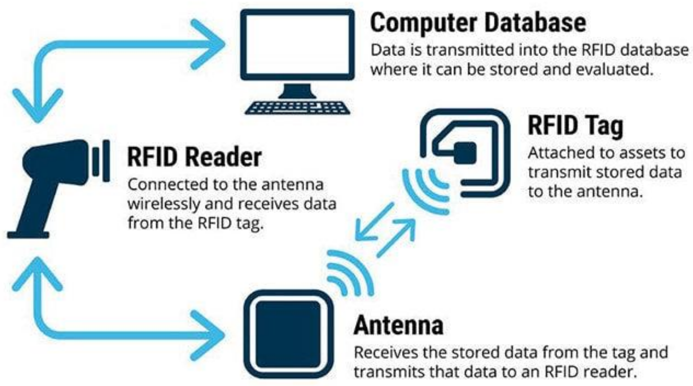

Figure 1.5 RFID technology operating principle (Keenan, 2021)

- <u>Smart shelves</u> can be used to automatically track inventory. Through sensors such as weight sensors it is possible to track the amount of inventory sitting on the shelves giving a real time update about the stock. The technology used is the same of RFID. In Figure 1.6 it is possible to see an example of this technology.

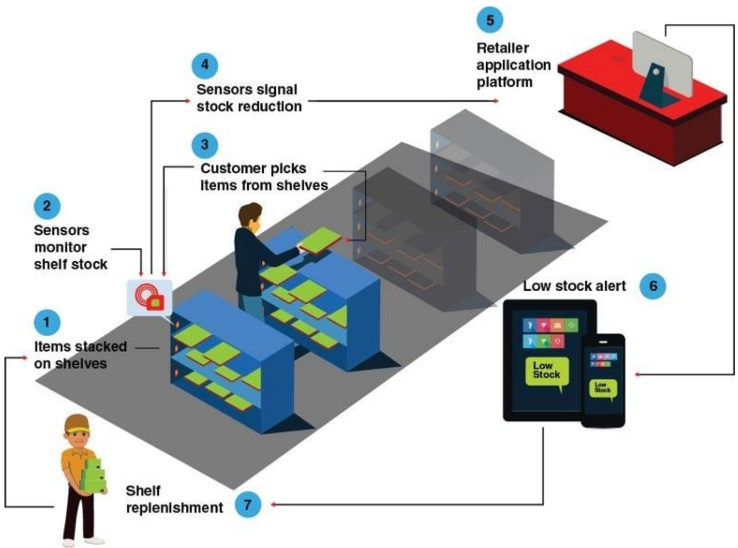

Figure 1.6 Smart shelves concept (Point of Sale, 2016)

- <u>Automated robotic loader</u> can efficiently load and stack boxes and containers. Through appropriate sensors can adjust and position the product that is carrying to the production area considered as destination as shown in Figure 1.7.

Figure 1.7 Example of automated robotic loader (Robotic Technician Training,2017).

IoT implementation allows to perform an intelligent labelling of objects, better object tracking, and more efficient inventory management. and control of objects, environmental supervision, and object tracking.

1.3.2 Blockchain

The Blockchain is based on a Peer To Peer (P2P) architecture, based on the exchange of data not between fixed servers and clients but between nodes in the network. It can be considered as a distributed database, or rather a set of data linked together sequentially and chronologically, stored once and not modifiable, permanently tracked within a register visible to all (Ahram et al., 2017). A distributed database is not stored on a single server, typical of traditional storage system, but in all the nodes that make up the P2P network, in this case the code of the Blockchain, which contains the information necessary to identify each transaction, is stored in as many copies as there are nodes in the network. Regarding the structure of the Blockchain, the chain is made up of blocks, and each of them contains a set of transactions (encoded) occurred in each time interval labelled by a timestamp and the digital signature of the parties involved. Every block of code is verified in a controlled way by one or more subjects of the network. Once the block is validated, it becomes part of the chain and cannot be modified anymore. It is encoded by means of a hash function: the hash is a code generated starting from an encoded and non-invertible transaction. The only way to modify a transaction is to create a new one that replaces the previous one. Technically, the previous one is not replaced as the last transaction made is considered while still maintaining the history, thus providing great transparency (Christidis & DevetsikIoTis, 2016). So, the Ledger contains all the transactions made in the network. The anonymity of the transactions is guaranteed during the sharing phase with the network since each node must authenticate with its own key. The power of this technology lies in the extreme security guaranteed by the fact that any operation is tracked on the system after validation and cannot be modified in any way afterwards. Figure 1.8 shows the blockchain structure.

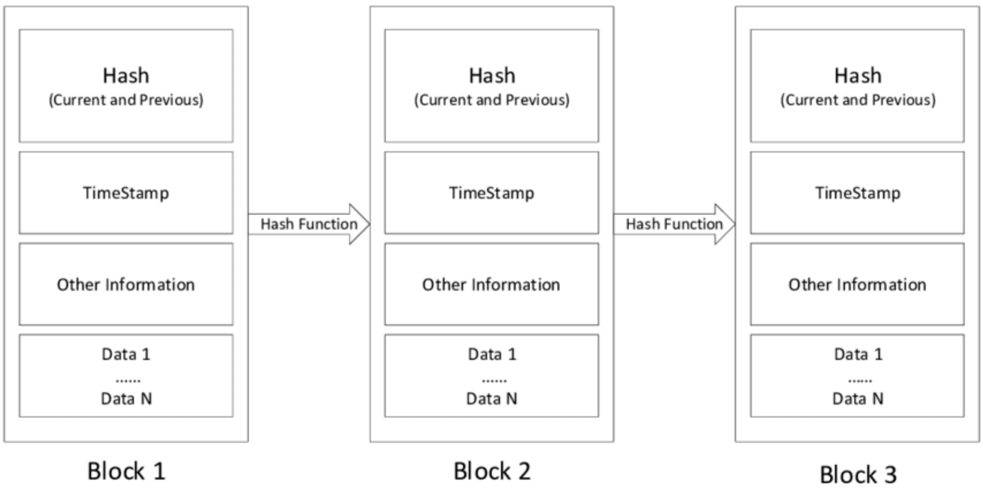

Figure 1.8 Blockchain structure (Joshi et al., 2018)

According to Xu et al. (2021) the blockchain can applied to the industrial control system to realize the traceability of raw materials. It allows more accurate record of information source, logistics information and transaction status of raw materials leading to a better reliability of supply chain.

1.3.3 Advanced Automation

Automation is the use of control systems, such as computers or robots, and information technologies for handling different processes and machineries in an industry to replace a human being [4]. The basic idea of automation was to increase productivity and to reduce the cost associated with human operators. Today, the focus of automation has shifted to increasing quality and flexibility in the manufacturing process.

There are three types of automation [5]:

1. Fixed or hard automation: it performs fixed and repetitive operations to achieve high production rates. Once decided the operation it is hard to change or vary the product design. An example of this technology is shown in Figure 1.9.

Figure 1.9 Example of fixed automation: conveyors (Engineering Review, 2017)

2. Programmable Automation: used for a specific class of product, assembling or processing operations. It can be changed with the modification of control program in the automated equipment. It is an intermediate solution between fixed and flexible automation. In Figure 1.10 is shown a practical example of this kind of automation system.

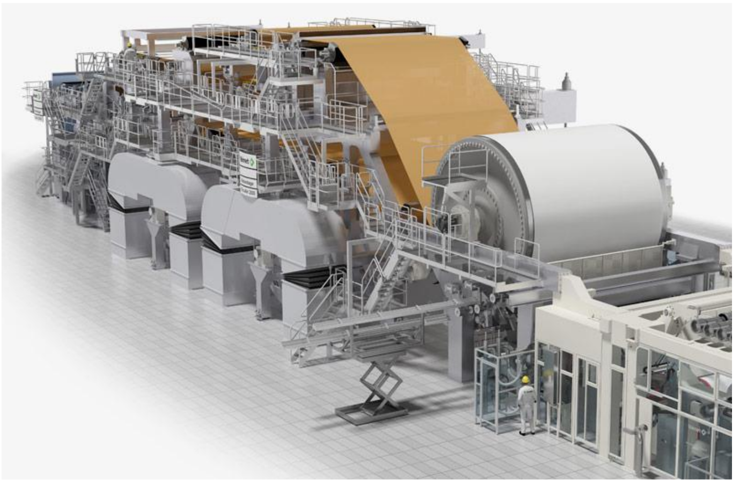

Figure 1.10 Example of programmable automation: paper mills (sael.it [6])

3. Flexible Automation: it offers a great flexibility for making changes in the product design. These changes can be performed quickly through the commands given in the form of codes by the human operators. An example of flexible automation is the CNC machine as shown in Figure 1.11.

Figure 1.11 Example of flexible automation: CNC machines (techmec.it [7])

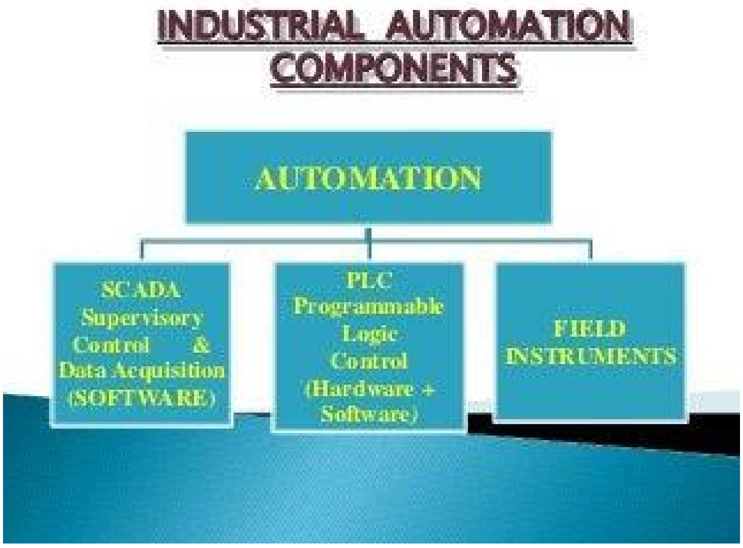

Figure 1.12 Main components of industrial automation (slideshare.net [8])

In the Figure 1.12 are shown the main components of industrial automation. Their main functions are:

- SCADA: is a system of software and hardware elements that allows industrial organizations to control industrial processes locally or at remote locations, interact with devices and elaborate data.
- PLC: deliver automatic control functions based on input from sensors.
- Field instruments: mainly composed by sensors and actuators that have the task to transfer data of machines and processes for monitoring and analysis.

The main advantages of automation in industry 4.0 are [9]:

- Cost efficiency: Reduces labour costs, automating portions of processes that do not require human judgment.
- Standardisation and automatic redesign of procedures: making them constant and accurate, being able to operate 24/7.
- Scalability and flexibility: Human operators need training for new tasks while robots and devices are easily reconfigurable and programmable in a tight time frame
- Time reduction: Reduced information processing times. The platforms with which automation works have a large capacity for the storage and management of data derived from processes.
- More safety: The production line can assign machines and/or robots to hazardous tasks that pose a high risk to staff.

The industries that most have benefitted from automation are automotive, electronics manufacturing, medical, welding, food service and law enforcement. (Matthews, 2018).

1.3.4 Cloud Computing

Cloud computing is the delivery of different services through the Internet. These resources include tools and applications like data storage, servers, databases, networking, and software (Frankenfield, 2020). Through cloud services users can store files and applications on remote servers and then access all the data via Internet. The main benefit is that the user doesn't have to be in a specific place to gain the access and remote working is permitted. Cloud computing can be both public and private. In the former case, cloud providers share their services over the internet for a fee. In the second case the service is provided to a certain number of people.

According to Frankenfield (2020) there are three types of services:

- Software-as-a-service (SaaS) provides software to users. The users subscribe to an application rather than purchasing it once and installing it. Users can log into and use a SaaS application from any compatible device over the Internet. This type of system can be found in Microsoft Office's 365.

- Infrastructure-as-a-service (IaaS) cloud service provider manages the infrastructure such as the actual servers, network, virtualization, and data storage. The user manages the operating system, apps, and middleware while the provider takes care of any hardware, networking, hard drives, data storage, and servers; and has the responsibility of taking care of outages, repairs, and hardware issues. Popular examples of the IaaS system include IBM Cloud and Microsoft Azure.
- Platform-as-a-service (PaaS) the hardware and an application-software platform are provided and managed by an outside cloud service provider, but the user handles the apps running on top of the platform and the data the app relies on. Primarily for developers and programmers, PaaS gives users a shared cloud platform for application development and without having to build and maintain the infrastructure usually associated with the process. This model includes platforms like Salesforce.com and Heroku.

In Figure 1.13 are shown the main features of the three types of services just described.

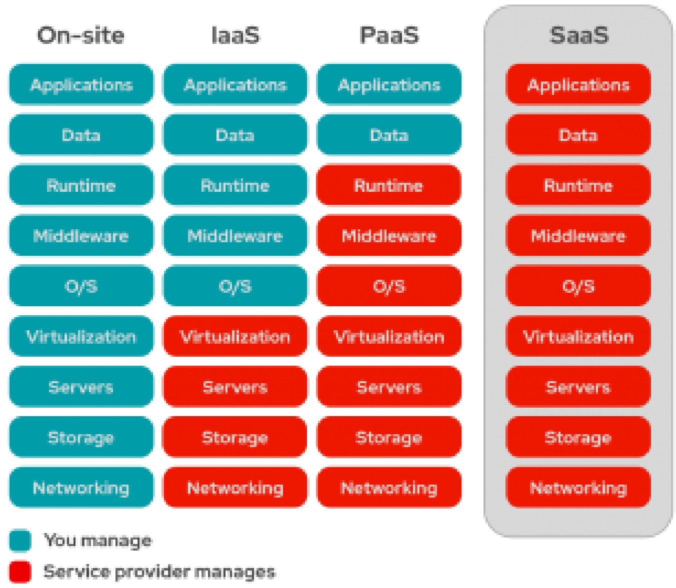

Figure 1.13 Differences between cloud computing services (redhat.com [10])

The implementation of cloud computing in the Supply Chain can benefit in exchange of real-time data and improvement of product availability, plan and control material flows by accessing up to date information.

1.3.5 Virtual Reality (VR) and Augmented Reality (AR)

Virtual reality (VR) refers to a computer-generated simulation in which a person can interact within an artificial three-dimensional environment using electronic devices, such as special goggles with a screen or gloves fitted with sensors (Mitchell, 2020). Nowadays VR device are used in many fields such as medicine, education, entertainment, architecture, and industry.

There are three categories of simulations used today: (Heizenrader, 2019)

- Non-immersive: allows the user to stay aware of and keep control of their physical environment.
- Semi-immersive: gives to the user the perception of being in a different reality when the focus on the digital image, but also allows users to remain connected to their physical surroundings.
- Fully immersive: gives to the user the most realistic simulation experience.

The main concepts are:

- Smartphone based
- Standalone: doesn’t require a PC or a smartphone to deliver a VR experience. The self-contained headsets include built-in processors, GPU, sensors, battery, memory, displays etc.
- Windows platform based VR
- Own platform (e.g., Oculus, HTC)

The application of VR in the manufacturing industry enables the designers to simulate their design prototype or model. This helps them to rectify errors at the primary stage and reduce production time and cost. Furthermore, with the rising of new technologies is possible to prepare an interactive 3D model of the factory. This allows to improve the following processes:

- Factory planning: design and test the best set up of manufacturing lines.
- Internal mobility heatmaps: show how the personnel and machines can move among the facility.
- Upgrade simulation: design and test in case of need to add more manufacturing lines or tracking the internal logistics.

- Evacuation training: train the personnel to evacuate the site as fast as possible.

On the other hand, Augmented reality (AR) is an enhanced version of the real physical world that is achieved using digital visual elements, sound, or other sensory stimuli delivered via technology (Hayes, 2020). The main difference with VR is that it uses the existing real-world environment and puts virtual information on top of it to enhance the experience and the operations can be performed using only AR smart glasses, without any additional input devices while VR immerses the users into a completely different environment and input devices are needed.

According to Joshi (2019) the integration of AR can improve warehouse management in the following ways:

- Warehouse planning: can help in optimizing the use of warehouse space through a digital and interactive layout.
- Inventory management: warehouse managers and staff can manage stocks all hands-free and in a more accurate way.
- Order picking: help the staff to locate and extract products in a more smooth and rapid way.

1.3.6 Big Data and Industrial Analytics

In the modern era it is asked to the companies to deal with a large volume of data and datasets coming from multiple sources. It is not sufficient to just collect the data, but it is important to analyse and use them for better decision making.

Big data analytics refers to collecting, processing, cleaning, and analysing large amount of information as shown in Figure 1.14.

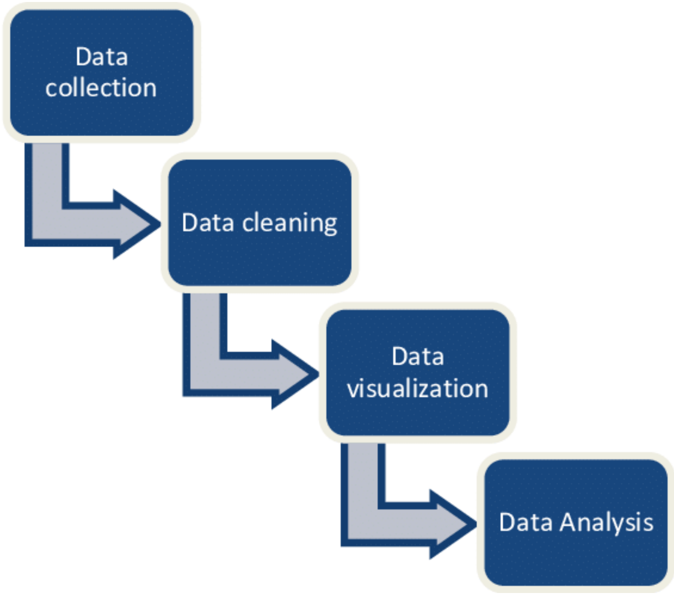

Figure 1.14 Big Data Analytics steps (Almaslamani et al., 2020)

The main steps are now briefly explained:

1. Collect Data: with today's technology, organizations can gather both structured and unstructured data from a variety of sources ranging from cloud storage to mobile applications to in-store IoT sensors and beyond.
2. Process Data: once the data are collected and stored, they have to be organized in a proper way to perform the analysis. There are two types of processing: batch processing where large data blocks are involved and stream processing where small batches of data are treated separately.
3. Clean Data: all data must be formatted correctly, and any duplicate must be eliminated
4. Analyse Data: once all the previous steps are completed the data can be analysed. Some of the most popular methods are data mining where patterns and relationships are identified, predictive analytics where future predictions are made based on historical data and deep learning which imitates human learning patterns.

According to Silva et al., (2021) this technology helps in Real-time delivery tracking, customized production and service, optimized pricing, forecasting, demand management.

1.3.7 Additive Manufacturing

Additive manufacturing is the process of creating an object by building it one layer at a time [11]. To create an object through additive manufacturing it is required to create a geometry using a Computer Aided Design (CAD) software. There are 7 additive manufacturing processes [12]:

1. Binder Jetting: uses a 3D printing style head moving on x, y and z axes to deposit alternating layers of powdered material and a liquid binder as an adhesive.
2. Directed Energy Deposition: a laser, electric arc or an electron beam gun mounted on an arm moves horizontally melting wire, filament feedstock or powder to build up material as a bed moves vertically. It can be used for ceramics, metals, and polymers.
3. Material extrusion: the material is drawn through a nozzle, heated, and then deposited in a continuous stream. This nozzle moves along horizontally, and the platform moves up, down, and vertically and the layers are created.
4. Power bed fusion: a layer of powder is applied to the platform. A thermal energy source like an electron beam or laser fuses the powder before a second layer is applied with a roller or blade. This layering process is then repeated.
5. Sheet lamination: is a process that binds layers using ultrasonic welding or an adhesive.
6. Vat Polymerisation: it uses a vat of liquid resin photopolymer to create an object layer by layer. Mirrors are used to direct ultraviolet light which cures the successive layers of resin through photopolymerization.
7. Wire Arc Additive Manufacturing: uses arc welding power sources and manipulators to build 3D shapes through arc deposition.

According to Delic et al. (2020) the adoption of additive manufacturing reduce material inputs for leaner manufacturing, improve process flexibility reacting faster to demand, producing spare parts as demanded by customers, rather than holding expensive warehouses of stock that have uncertain demand.

1.3.8 Human Machine Interface

A Human-Machine Interface (HMI) is a user interface or dashboard that connects a person to a machine, system, or device [13]. In industry the HMI is connected to SCADA (Supervisory Control and Data Acquisition) systems which control and monitor the industrial processes as shown in Usually tablets, smartphones and computers are the most popular output of this technology. Traditionally, HMIs communicate with Programmable Logic Controllers (PLCs) and input/output sensors to get and display information for users to view. HMI screens can be used for a single function, like monitoring and tracking, or for performing more sophisticated operations, like switching machines off or increasing production speed, depending on how they are implemented.

It is typical used to:

- Visually display data.
- Track production time, trends, and tags.
- Oversee KPIs.
- Monitor machine inputs and outputs.

A better visualization of key parameters can reduce cost and waste and ultimately improve processes and profitability.

Figure 1.15 SCADA software interface for smartphone e tablet (automationworld.com [14])

1.4 Digital Supply Chain

The main difference between the traditional and digital Supply Chain is that in the former one the items tend to travel linearly with each step dependent on the previous one, while the latter one provides significantly more visibility into workings of the chain, supplier performance and customer needs. Digital supply chains are more customer-centric and aim to meet today's three pillars of excellence in demand fulfilment: speed, personalization, and choice (Jenkins, 2020). Through the implementation of advanced technologies it is possible to enhance the cooperation between the parties in the supply chain processes. In Figure 1.16 a better look on the concept just explained is provided.

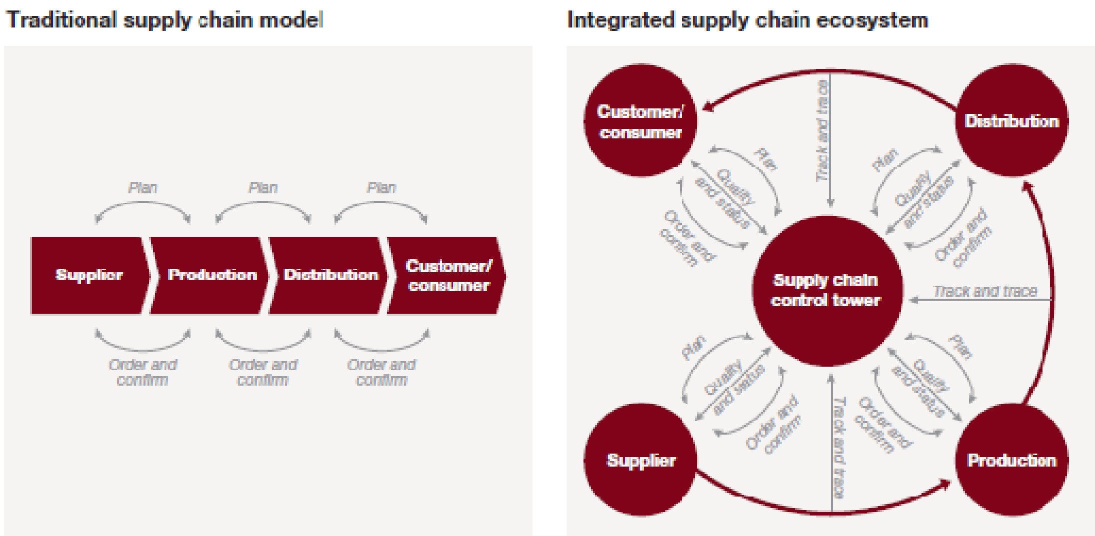

Figure 1.16 Comparison between traditional and integrated supply chain model (PWC, 2016).

Normally, the marketing department analyses customer demand and tries to predict sales for the coming period. Based on that information, manufacturing department orders raw materials, components, and parts needed to fulfil the predicted sales. Then, distributors account for upcoming changes in the amount of product coming down the pipeline, and customers are told when to expect shipment. If everything goes smoothly the gap between demand and supply at every point in the system is small (PWC,2016).

The main issue is that forecasting is not so easy and the data it depends on can be inconsistent or incomplete. Often it happens that the various partners involved in the supply chain operate independently leading to a lack of transparency and a consequent confusion of the all the players' needs. Digitalization and integration of Industry 4.0

technologies allow to have full visibility into the needs and challenges of the others. Some of the benefits are greater transparency and accuracy, data-backed decision, improved warehouse management and greater agility to sudden changes.

To make digitalization come true it is needed not only to renew hardware and software components inside the facility but also to provide appropriate training to personnel to better exploit the benefits coming from the new technologies. In other words, a transformation of entire organization is required. In the following sub-chapter, the Technologies 4.0 are presented.

2 Mapping of Automotive Supply Chain

A preliminary know-how phase has been performed to cover and deepen the missing knowledge of Industry 4.0. In a vehicle, it is possible to find thousands of different components and for this reason, it has been chosen to focus just on one part composing the vehicle rather than the entire assembly of the final car. It has been decided, then to analyse the supply chain of tire manufacturers. Unfortunately, the technical documents found in the official websites of the most important tire manufacturers (e.g., Continental, Pirelli, Bridgestone, and Hankook) were not sufficient to perform a critical appraisal of the current material and information flow processes.

This issue led to a change of plans, and it has been decided to use as reference a generic Automotive Supply Chain defined through the literature by a previous colleague's thesis work (Cucchietti,2019). In the following paragraphs are analysed the relevant phases of four processes: order acquisition and procurement, inbound logistics, assembly, and distribution.

2.1 Receiving and processing an order

The cross-sectional process of executing an order, from its reception to the delivery of the finished product is called the Order To Delivery Process (Holweg & Jones, 2001). The process of execution of an order begins upon its receipt from the final customer, which has specific characteristics as each customer changes. Low-segment, high-demand vehicle models are examined in this study. They are produced based on forecasts made by the sales network. If the time it takes to fulfil an order exceeds the amount of time the client is willing to wait, it is essential to predict the demand by creating stocks and reducing the risk of unsold inventory through appropriate forecasting analysis. The forecast is fundamental in the phase of planning is in terms of the configuration of the productive system as far as supplies. Since it is not possible to place an order directly from the manufacturer's sales site, but only to receive an estimate based on the customized configuration, the database of sales orders is constantly updated upon receipt of new orders from so-called dealers and more recently of orders received via the Internet on dealer sales portals.

If the customer, who comes to a sales point, opts for a custom-made order rather than choosing among the cars in stock, the seller sends the order to the manufacturer through an IT procedure. The order is not immediately uploaded to the order database, the Order Bank, but is automatically subjected to a check that verifies the compatibility between the order specifications and the configuration allowed for that type of car (Suthikarnnarunai, 2008). Today, this phase has been replaced by digital configurators, which allow customization within the constraints imposed by the software, programmed directly by the manufacturer, which specifies only the options that can be selected.

Subsequently, the material required for the specific order is calculated; this information will be used for the supplying process.

Now it is possible to insert the order in the Order Bank, which still does not represent the plan of production, but only a point of departure from which constructing it, with that part of orders based on the forecast. Starting from the orders collected in the Order Bank, the production plan is created. Based on a study by Aoki and Staeblein (2015), it is possible to define the planning process as the sequence of four main steps.

1. The first phase concerns the forecast of demand together with its allocation within the sales network. Monthly sales volumes are reviewed based on the forecast of each model in the catalogue with an annual horizon. The forecasts are integrated with the orders received from the network of retailers: each retailer annually plans a certain number of orders based on its own forecasts, which is then evaluated centrally considering the sales history for that retailer and the area in which it is located.
2. The second phase is developed starting from the orders present in the Order Bank, drawing up the so-called Master Production Planning or Master Production Schedule (MPP/MPS), a production plan updated monthly with a

time horizon usually equal to three months. It contains the production planning divided by production plant and the short and medium-term scheduling of production sequences.

3. The third phase involves the planning of material requirements, elaborated in the Material Requirements Planning (MRP) starting from the MPP. In this phase, it is also necessary to use the expected demand and not only the orders received because the complexity of the Supply Chain implies considerable adaptation time, and suppliers need to know in advance quantities and types of supplies needed for the next four months (Gobetto, 2014).
4. The fourth phase concerns the weekly schedule, this is frozen and becomes the object of the sequencing activity of the cars in production. This function transversal to the production and purchasing department provides for the determination of the exact production sequence, which is based on the principles of JIS and provides for the synchronization of incoming flows from suppliers, which must strictly comply with this sequence.

2.2 Procurement

The production plan defined for each production plant, which considers the capacity constraints of plants and suppliers, allows the elaboration of the MRP Its role is to calculate the material requirements for each time slot to satisfy production targets. Since the orders received do not cover the entire time frame of the MRP, it is necessary to communicate to suppliers the long-term requirements, aggregating the expected demand into product families in the so-called Aggregated Production Planning which reduces the uncertainty of the forecast (Gobetto, 2014). The material requirements are generated when the forecast plan is created, considering the bill of materials that characterize each product. The suppliers, in turn, through the MRP tool, will request to the lower-level suppliers the needed components of the sub-assembly production.

It can be noticed how the distortion of the final demand is easily generated in the passage from one party to another. In fact, as one moves up in the Supply Chain, the requirements generated by the MRP of each party are influenced by forecasts that can distort the final demand, generating the so-called Bullwhip Effect (Beamon, 1998).

The weekly requirement is directly linked to the daily schedule generated from the order database: starting from the MPP, the weekly programming is defined, and through scheduling software, the sequence that must be respected in all the production phases is generated. Boysen et al (2014) emphasize the importance of complying with the timelines and sequences established by the daily production schedule. Shutdowns caused by missing components essential to vehicle assembly cause substantial damage due to assembly-line stoppages.

In Figure 2.1, Figure 2.2 and Figure 2.3 are shown the flow charts of material and information flow charts of order and acquisition phases.

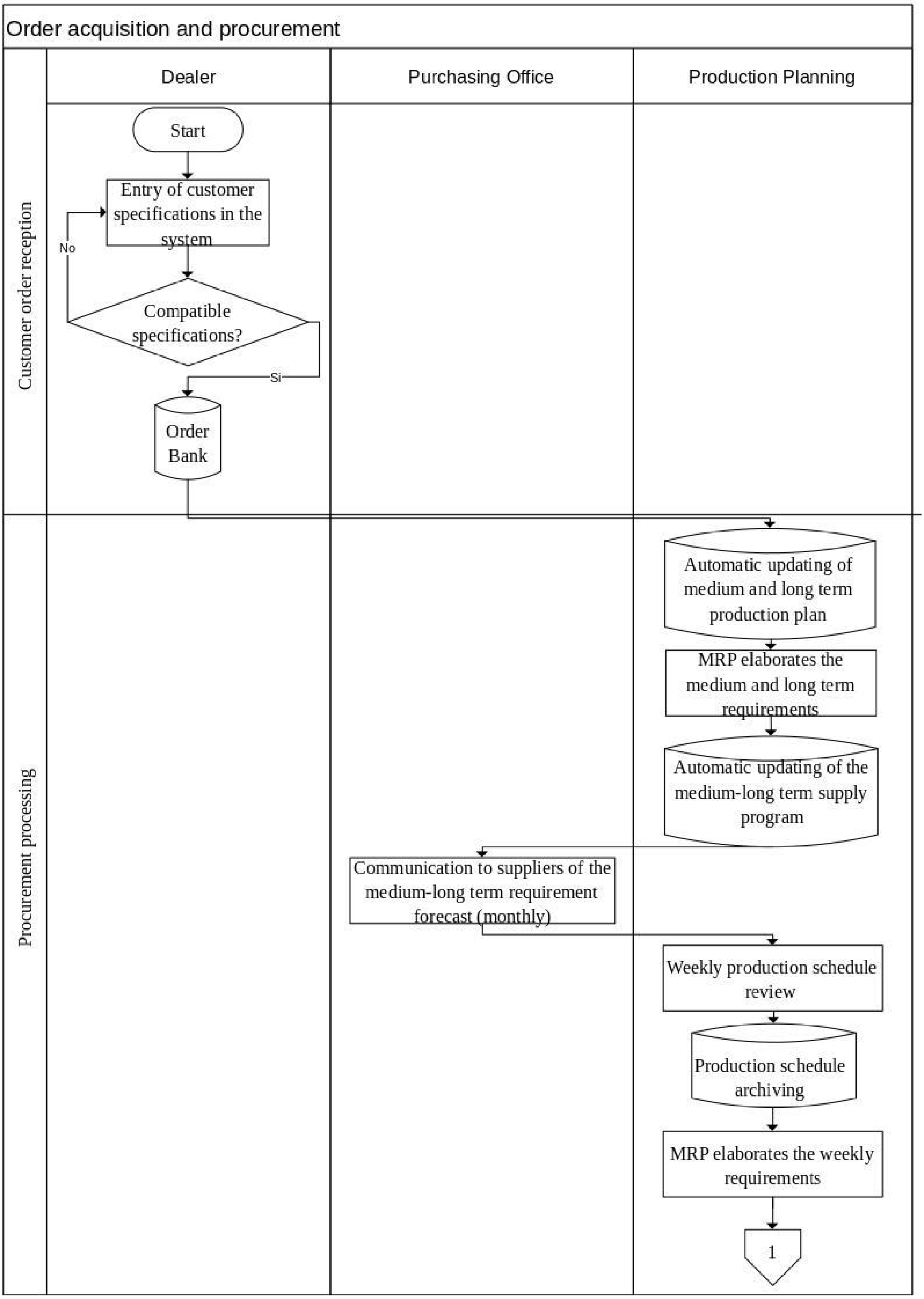

Figure 2.1 Order acquisition and procurement flow (Part 1)

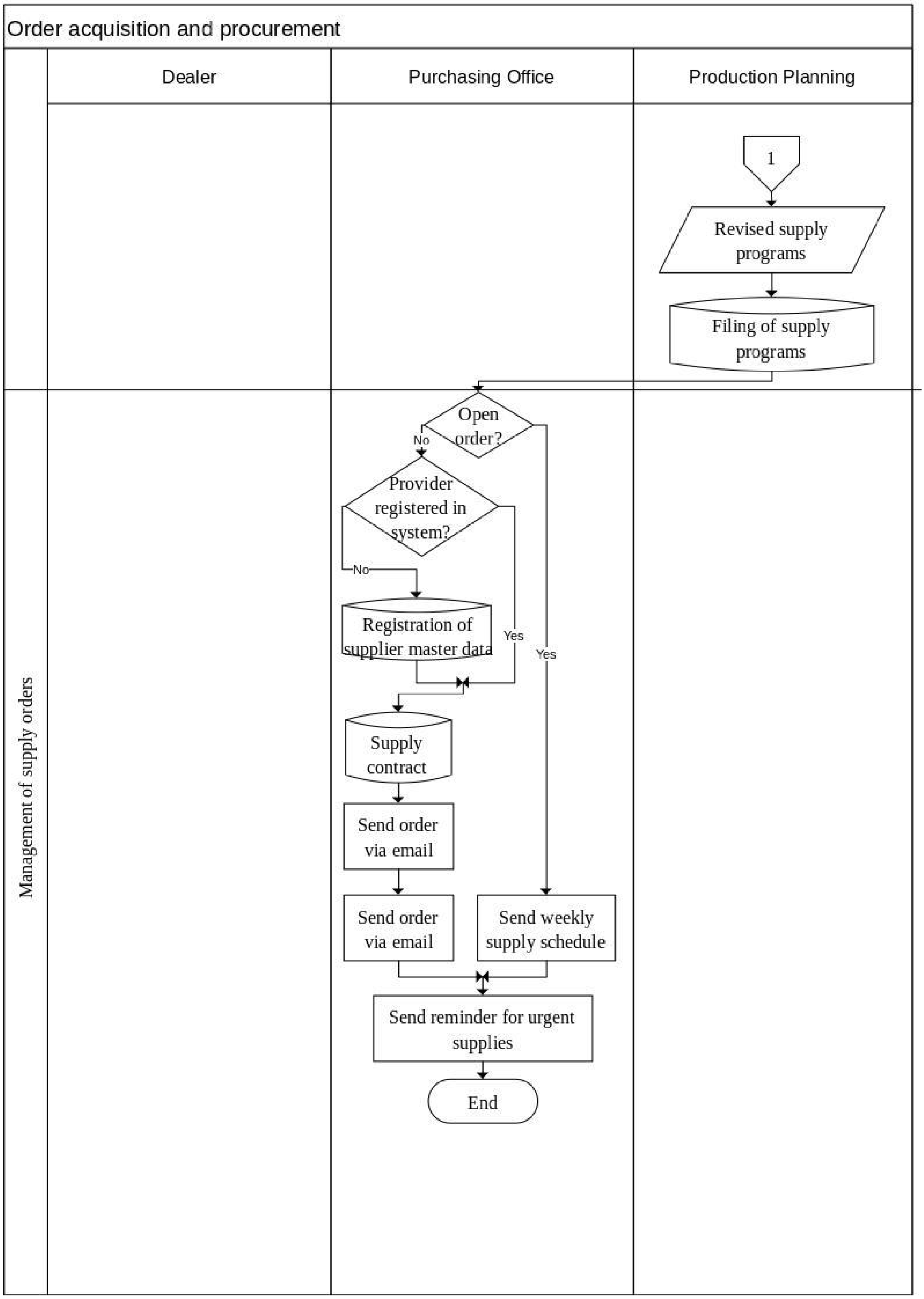

Figure 2.2 Order acquisition and procurement flow chart (Part 2)

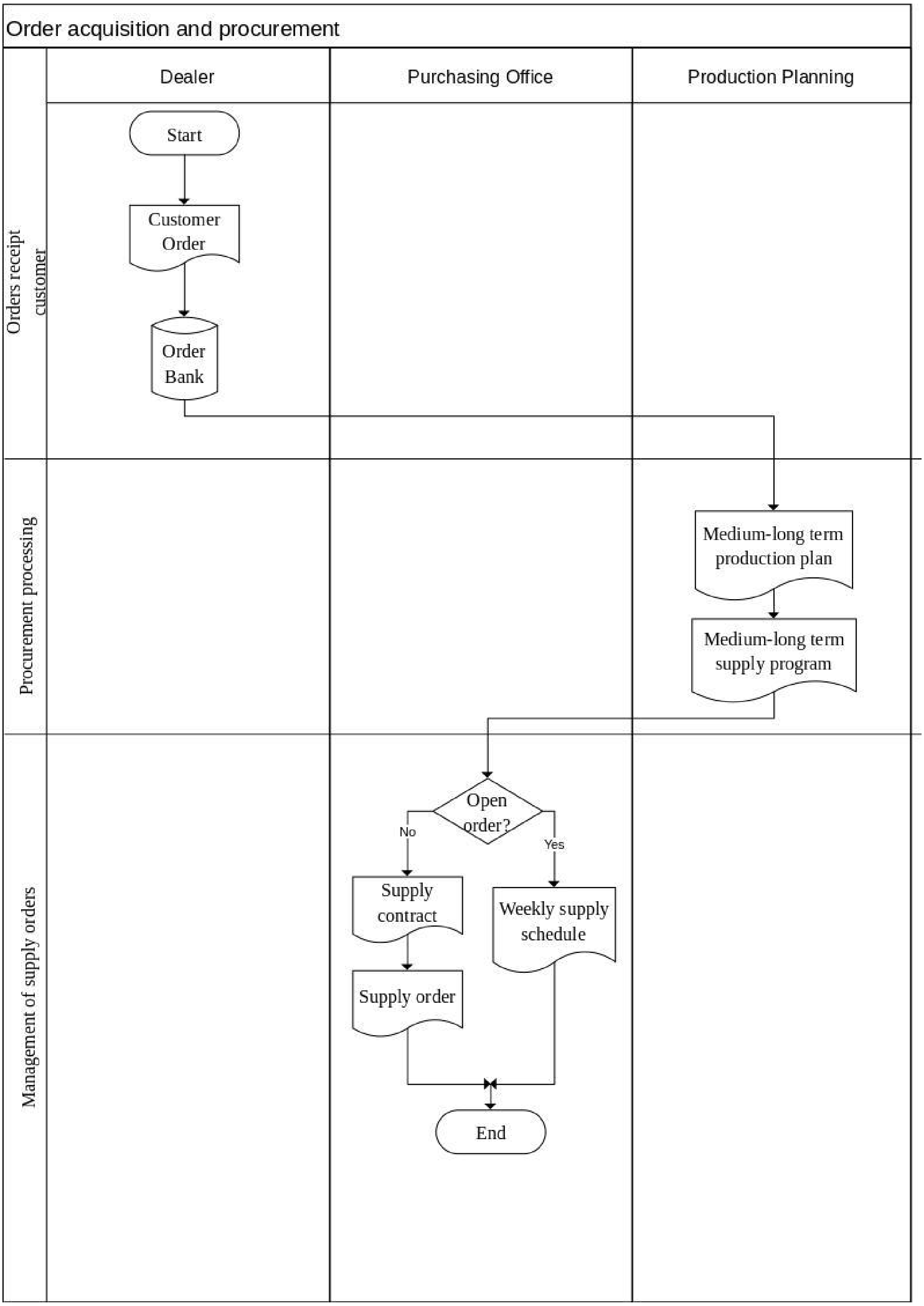

Figure 2.3 Order acquisition and procurement information flow chart

2.3 Management of logistics flows within the OEM

There are two types of orders in terms of production scheduling and material requirements: closed and open orders. Closed orders are ones that are not continuous, or at least not to a fixed term, in which are specified the date of delivery, the supplied, the quantity, the price, and other conditions of delivery. This type of order is typical of equipment and tools purchases. Instead, open orders are typical of consumables and components, whose demand is closely linked to the production plan. Quantities and delivery dates are based on what is calculated by the MRP and the weekly production plan. For this last type of order, medium-long term supply contracts are made, and the price is decided initially and valid for the entire term of the agreement. Thanks to MRP systems, quantities, and delivery dates are calculated and communicated automatically (Gobetto, 2014).

Boysen et al. (2014) distinguish two types of orders by the assembler to the first-tier supplier: Push orders and Pull orders. The former concerns parts whose requirements are closely related to the demand of the vehicles in the production schedule, and depend directly on the schedule for the frozen time interval, which is usually one week. These are, for example, seats, engines, wheels, transmissions, steering wheels, etc. On the other hand, Pull orders are based on consumption and not on production orders (Hua & Johnson, 2007). For example, a pull order can include brackets, bolts, and screws. It can be misleading thinking that Push orders generate inventory since they follow the JIT logic too. The only difference between the two types of order is the principle they are linked to. In both cases, the communication takes place electronically through the automatic transfer of the demand generated by the OEM's MRP to the supplier's planning software, thus dealing with open orders, and so related to the produced quantities.

Push supplying is programmed based on the scheduled production sequence. To reduce the size of the lots and the storage space the frequency of delivery is increased. In this way there is more control on lots, being smaller, and more flexibility due to the coordination between supplies and production. Therefore, an efficient unloading system is required that provides for the scheduled allocation of a dedicated area to the incoming truck.

Once the transport document is signed, the material is taken from the vehicle, checked in terms of quantity and quality, and according to the type of delivery, stored or not in stock. If anomalies are found with respect to the expected quality or quantity specified on the transport document, the supplier is notified of the non-conformity, with a possible request for compensation. Once the transport document is signed, the material is taken from the vehicle, checked in terms of quantity and quality, and according to the type of delivery, stored or not in stock. If anomalies are found with respect to the expected quality or quantity specified on the transport document, the supplier is notified of the non-conformity, with a possible request for compensation. Open orders receive an invoice at the end of the month that includes all orders placed throughout the month, whereas closed orders receive an invoice that can be added to the transport document. If the material is JIT or JIS, the most common method is to install a conveyor belt specific to the component to be carried near the unloading dock, which transports the item to the appropriate assembly station (Boysen et al., 2014).

The so-called Supermarket is extensively employed by automobile manufacturers. It involves setting up a storage facility at the line's edge for consumables and components installed from nearby workstations (Battini et al., 2013).

The flow of materials in a Supermarket system, described in Figure 2.4 as follows:

1. Storage incoming supplies in the central warehouse.
2. Supply of the Supermarket by means of trailing motorized trolleys or trolleys to forks and temporary stocking of the material in the shelves of the Supermarket.
3. Receipt of picking list generated by station call.
4. Preparation of material based on the picking list.
5. Loading of the material onto the trolley that cyclically serves the assembly stations related to that Supermarket. The material is placed in the wagons pulled by the trolley, as required by the sequence specified in the picking list.
6. Delivery of the material at the stations of assembly.

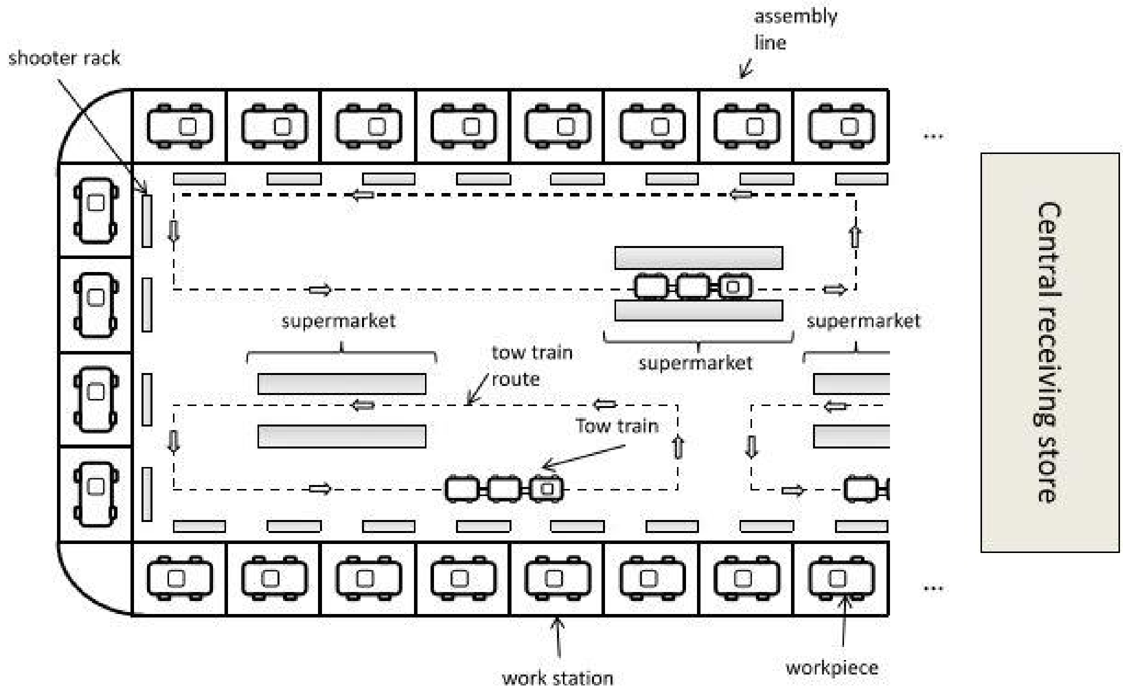

Figure 2.4 Supermarket scheme (Battini et al., 2013)

The kitting operation consists of preparing parts in specific containers to facilitate installation and handling of the final component; these parts are sent to the station via motorized carts or conveyor belts (Hua & Johnson, 2010). The main drawback of this operation is the introduction of additional activity for the preparation of kits. The use of specific containers for each kit is also an effective way to lead the operator to the correct installation because by having all the parts necessary for installation in one container there is less chance of installation errors.

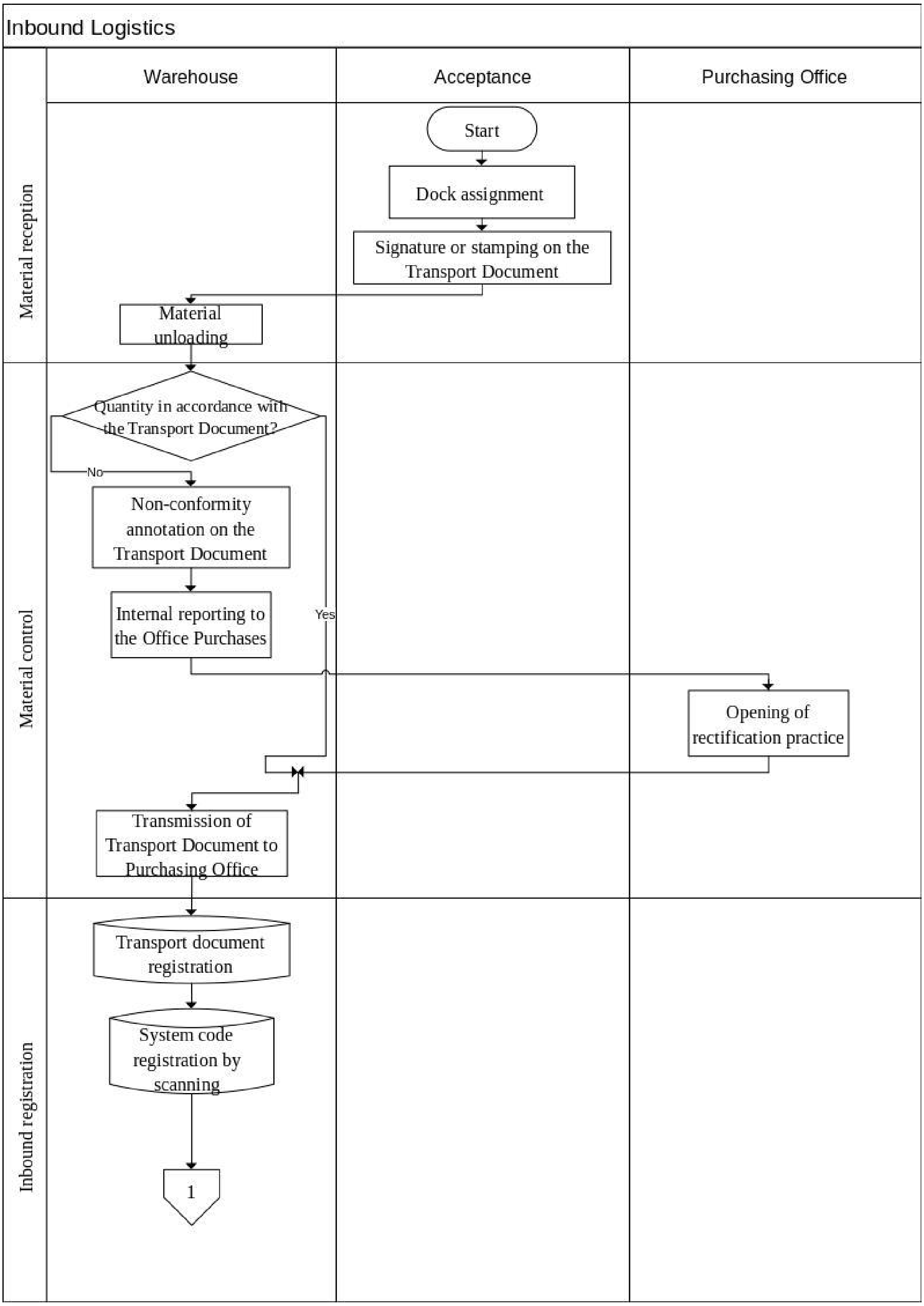

Figure 2.5 Inbound Logistics flow chart (Part 1)

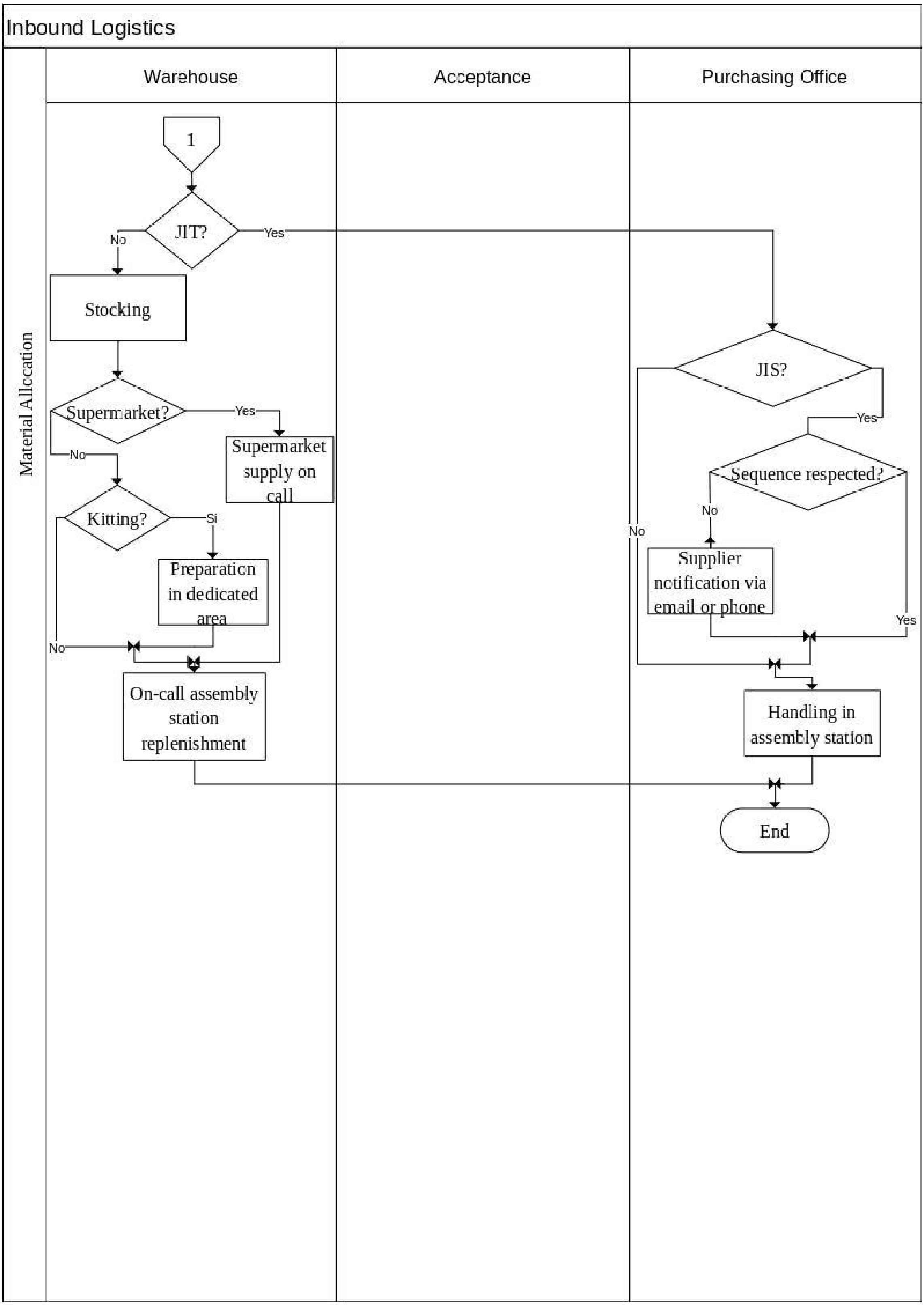

Figure 2.6 Inbound Logistics flow chart (Part 2)

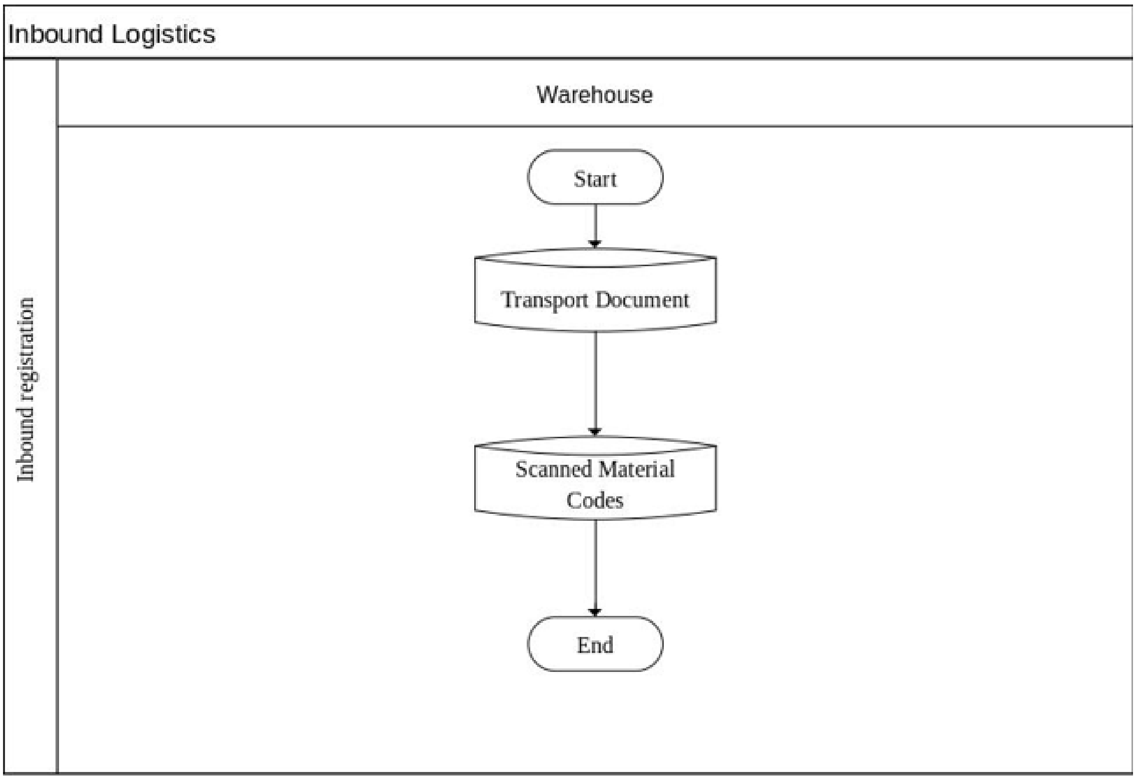

Figure 2.7 inbound Logistics information flow chart

2.4 Assembly

Starting from the daily production sequence, the activities that compose the assembly process are generated. The assembly processes are:

- Molding of the metal parts that compose the body of the car. The molding is done in batches, reducing as much as possible the time to change the molds, since these machines are used to produce different models of cars. Routine maintenance and monitoring of operating parameters are essential to avoid interrupting a continuous flow of processing.
- The metal parts making up the body are welded to the frame. This department is highly automated and almost all the fixing and welding operations are carried out by robots.
- Assembly of moving parts to the body (Body in White).
- Washing and anti-corrosion treatment.
- Installation of wiring harnesses and dashboard received from first-tier supplier.
- Steering controls such as steering wheel and attached linkages, tank.
- Powertrain.

- Cooling system, engine oil tanks, and other powertrain support components.
- Bumpers, lighting system, and wheels.
- Seats and interior trim.
- Door’s installation.
- Steering calibration, ECU parameters control.

Once the vehicle can move it is tested on a test bench to calibrate the steering system and the verification of engine performance under load through the Engine Control Unit (ECU). In case all tests are successful, the car is moved to the motor pool, from which it will be picked up to reach the dealer or distribution center (Gobetto 2014).

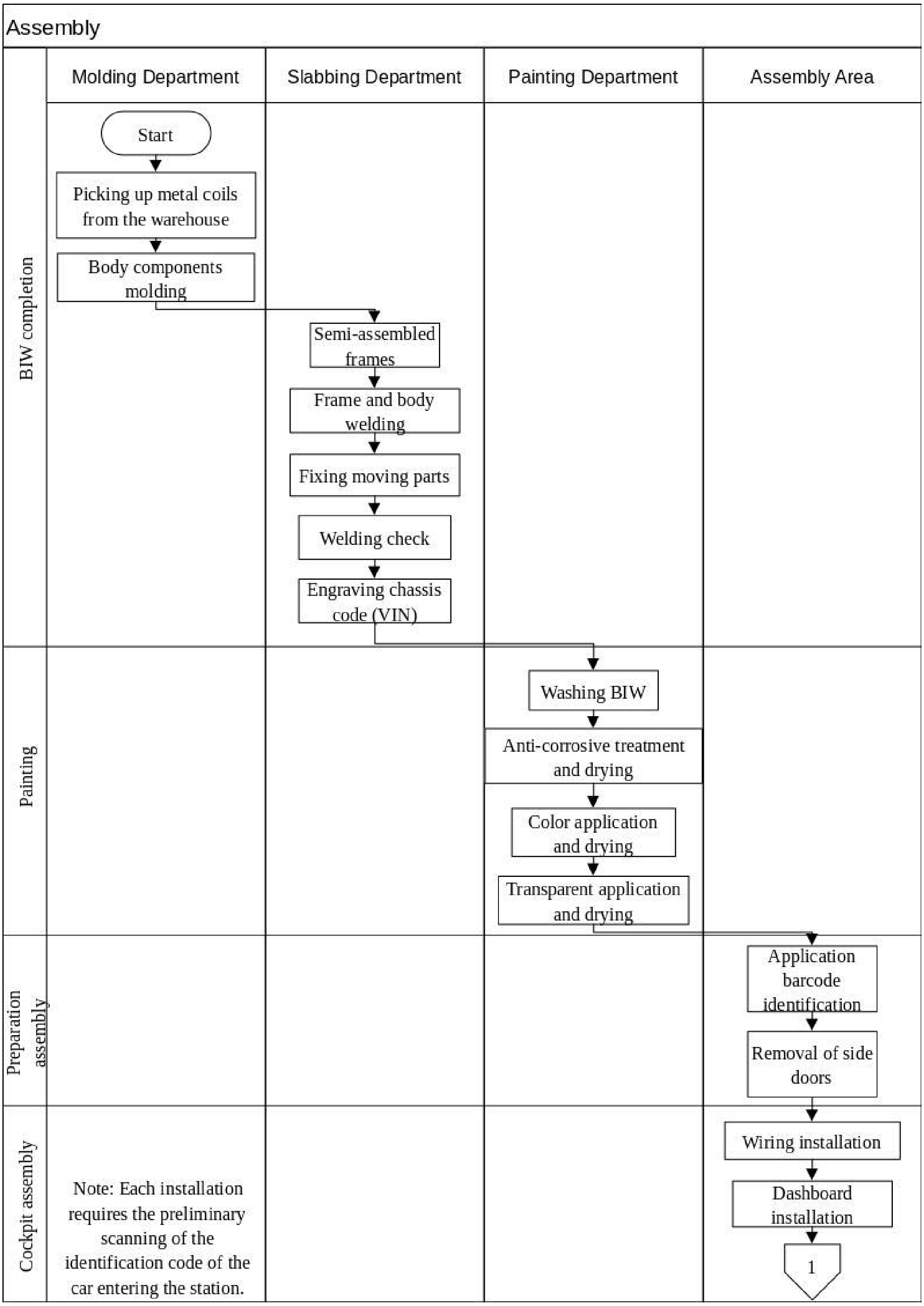

Figure 2.8 Assembly flow chart (Part 1)

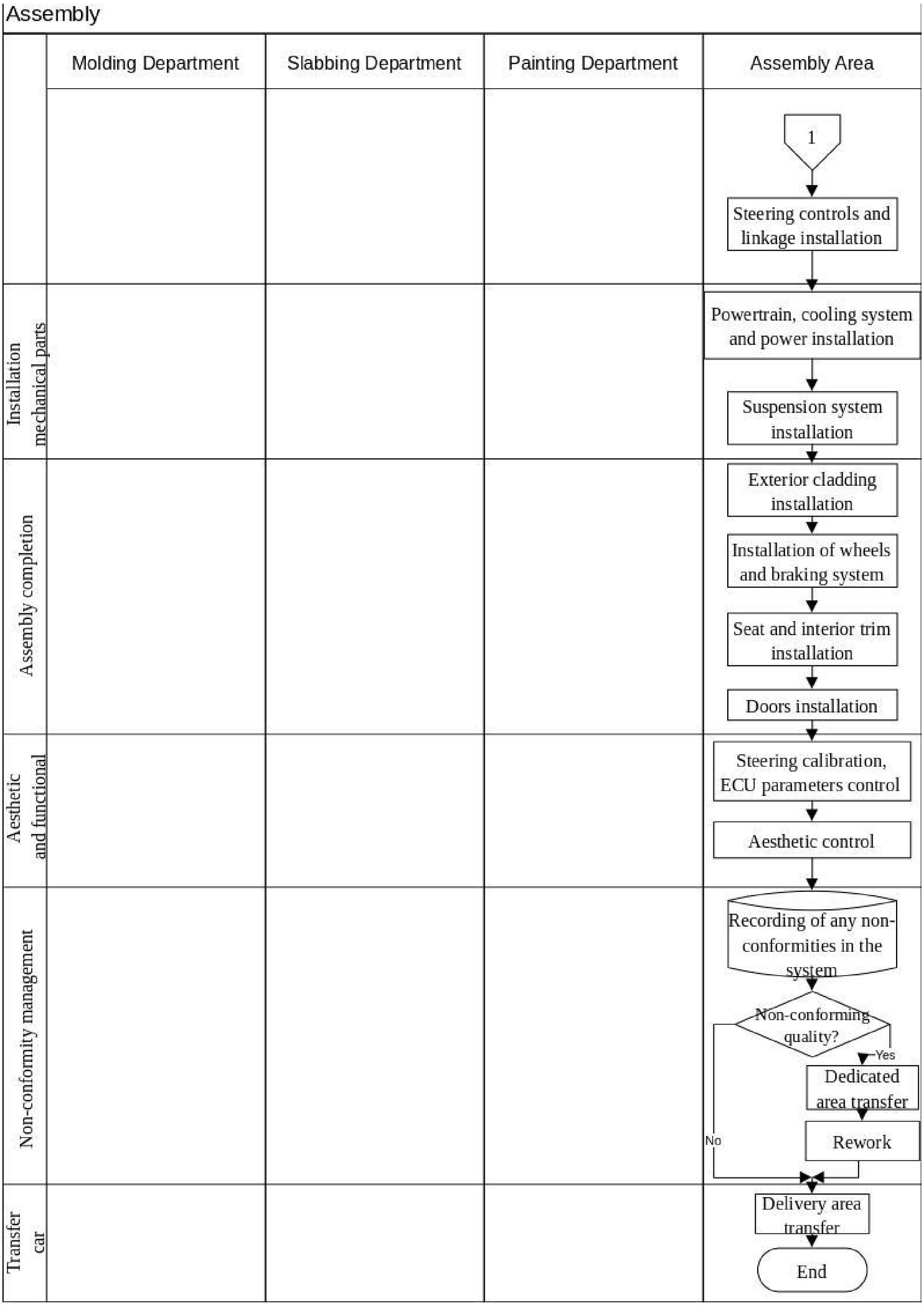

Figure 2.9 Assembly flow chart (Part 2)

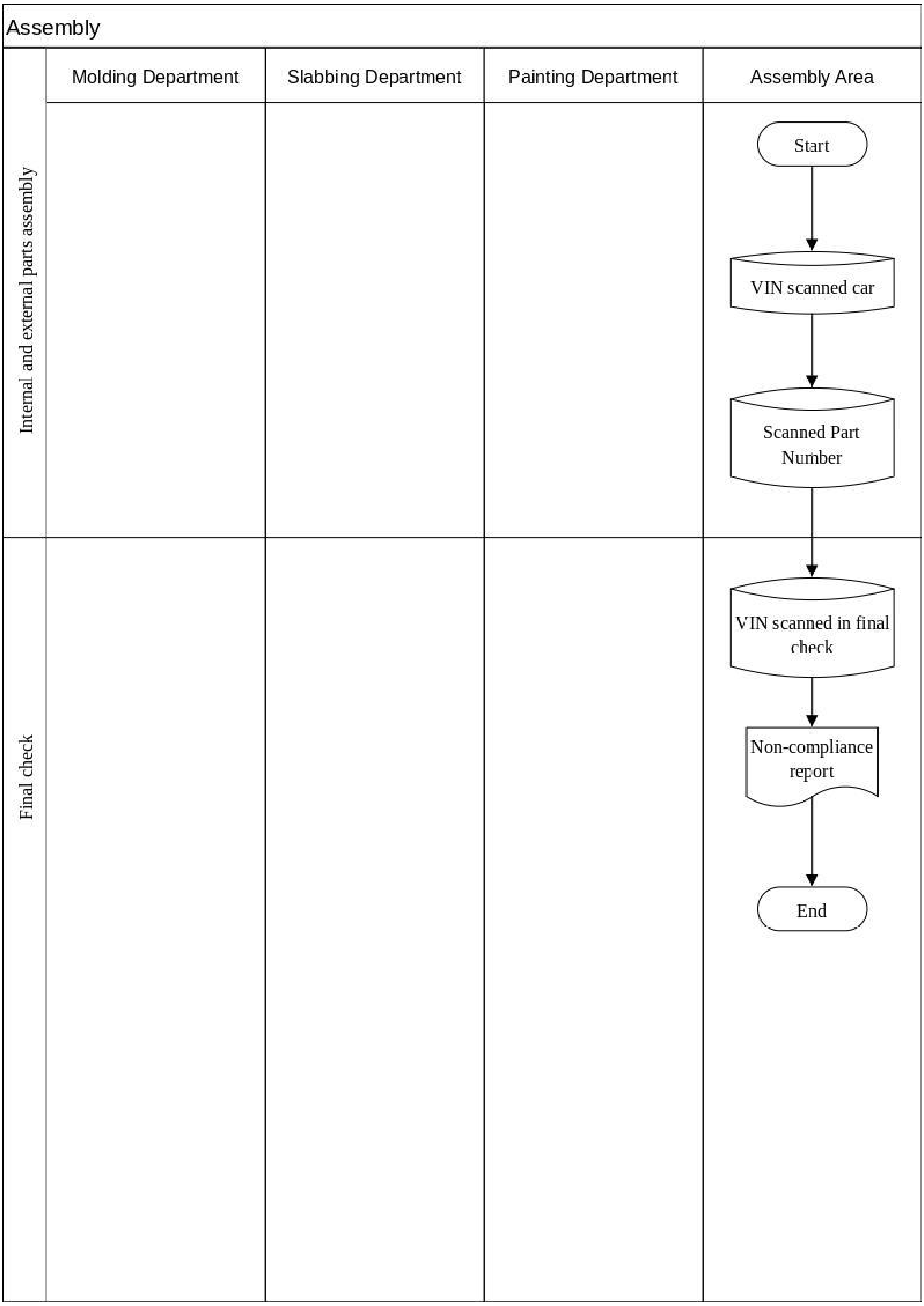

Figure 2.10 Assembly information flow chart

2.5 Distribution

The distribution process deals with the delivery of the cars to the dealers respecting the deadlines imposed during the ordering phase. According to Gebhard and others (2015) there are four parties involved in this process:

- OEM, which is responsible for preparing the cars for pickup at its assembly plants.
- Logistics Service Provider (LSP), who is entrusted with the management of the cars in the consolidation and transportation activities at the sales network.
- Dealers: they are the final link with the customer.

The OEM prepares a trimestral delivery schedule, subdivided into weekly schedules, updated from week to week, which allows the LSP to organize itself based on a medium-term forecast. The LSPs' scheduling takes place on average three days before taking charge of the cars (Holweg & Mieczyk, 2002). After leaving the assembly line, the cars are arranged in a parking lot. According to the delivery order, the cars are collected from the parking area and placed in the loading zone where they will find the assigned transport vehicle. Once the transport document has been issued by the OEM, the LSP picks up the cars and transports them to consolidation centers with car transporters, and then organizes the transport on trains or ships, towards its territorial warehouses called Regional Distribution Centers. Here the registration of incoming cars on internal registers takes place (Gebhard et al., 2015) and after car inspection and washing, they are delivered to the dealers (Brandwein et al., 2013). The main issue is that at the consolidation centers and regional warehouses there is no communication to the OEM of the cars' status and there is no tracking system that allows them to be traced from the assembly plant to the point of sale. Once the cars have been delivered, the dealer signs the transport document, checks the integrity of the cars and notifies the OEM of any non-conformities. The invoice, either immediate or deferred, is issued by the OEM at a price including transport costs, which are then charged to.

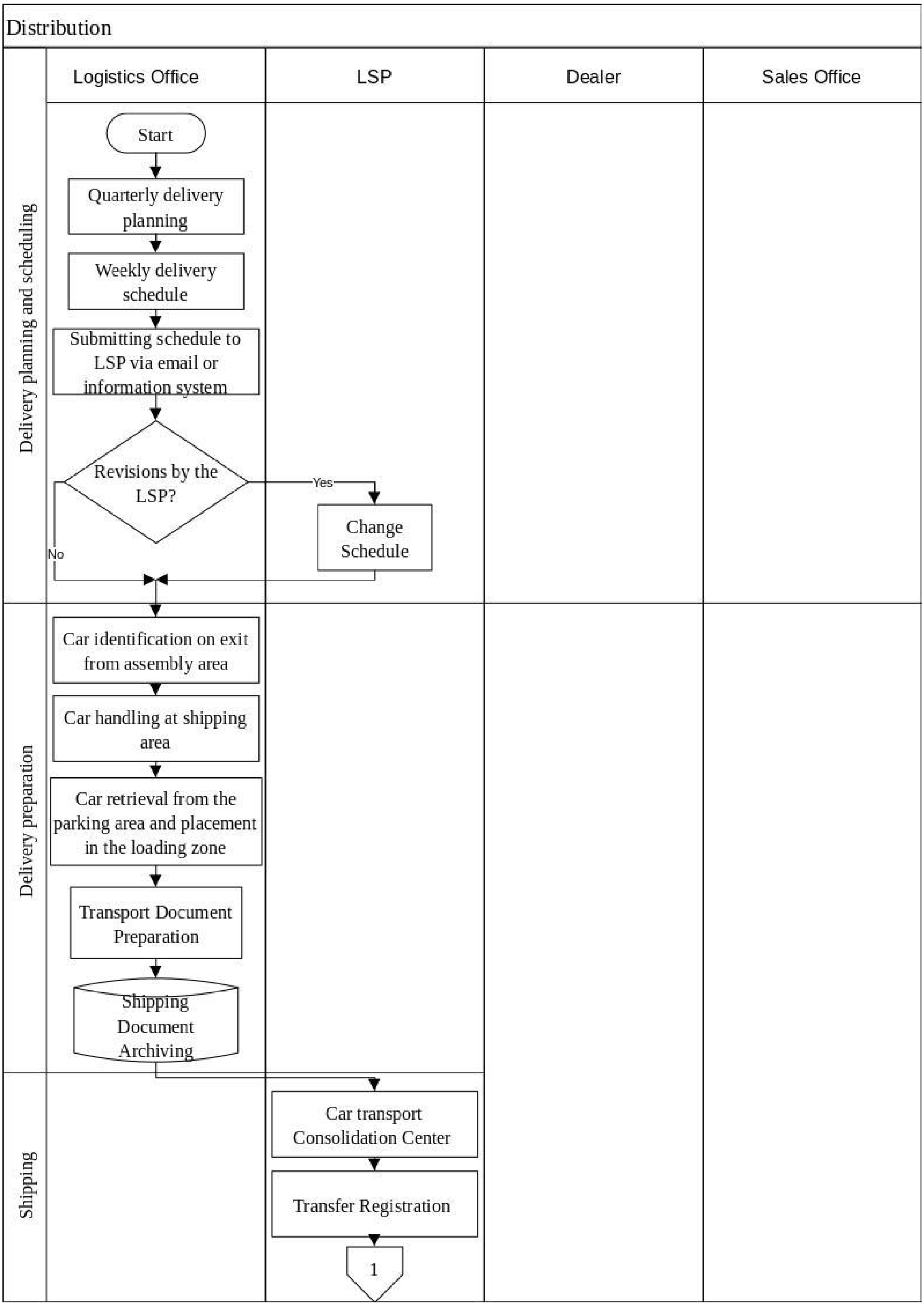

Figure 2.11 Distribution flow chart (Part 1)

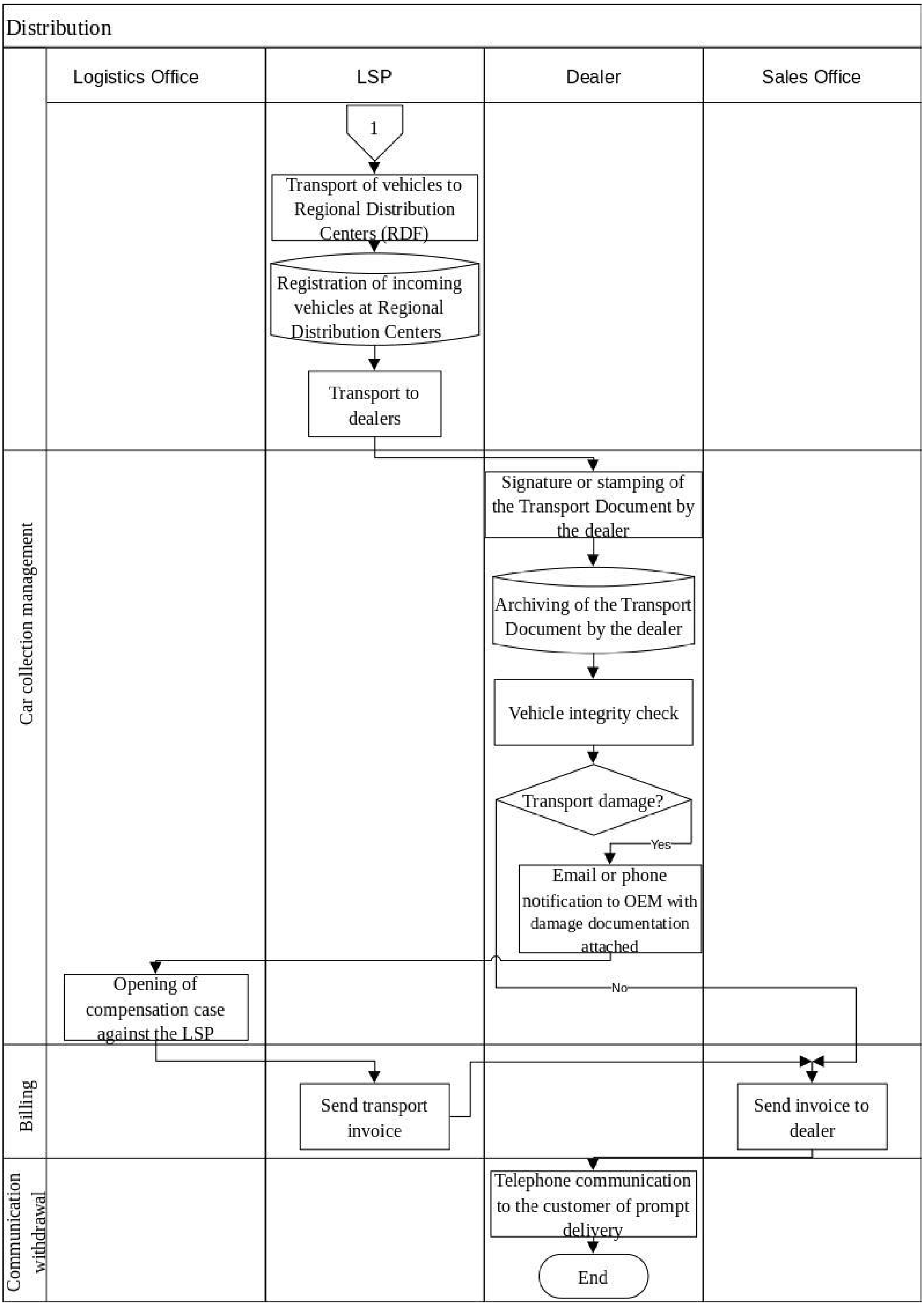

Figure 2.12 Distribution flow chart (Part 2)

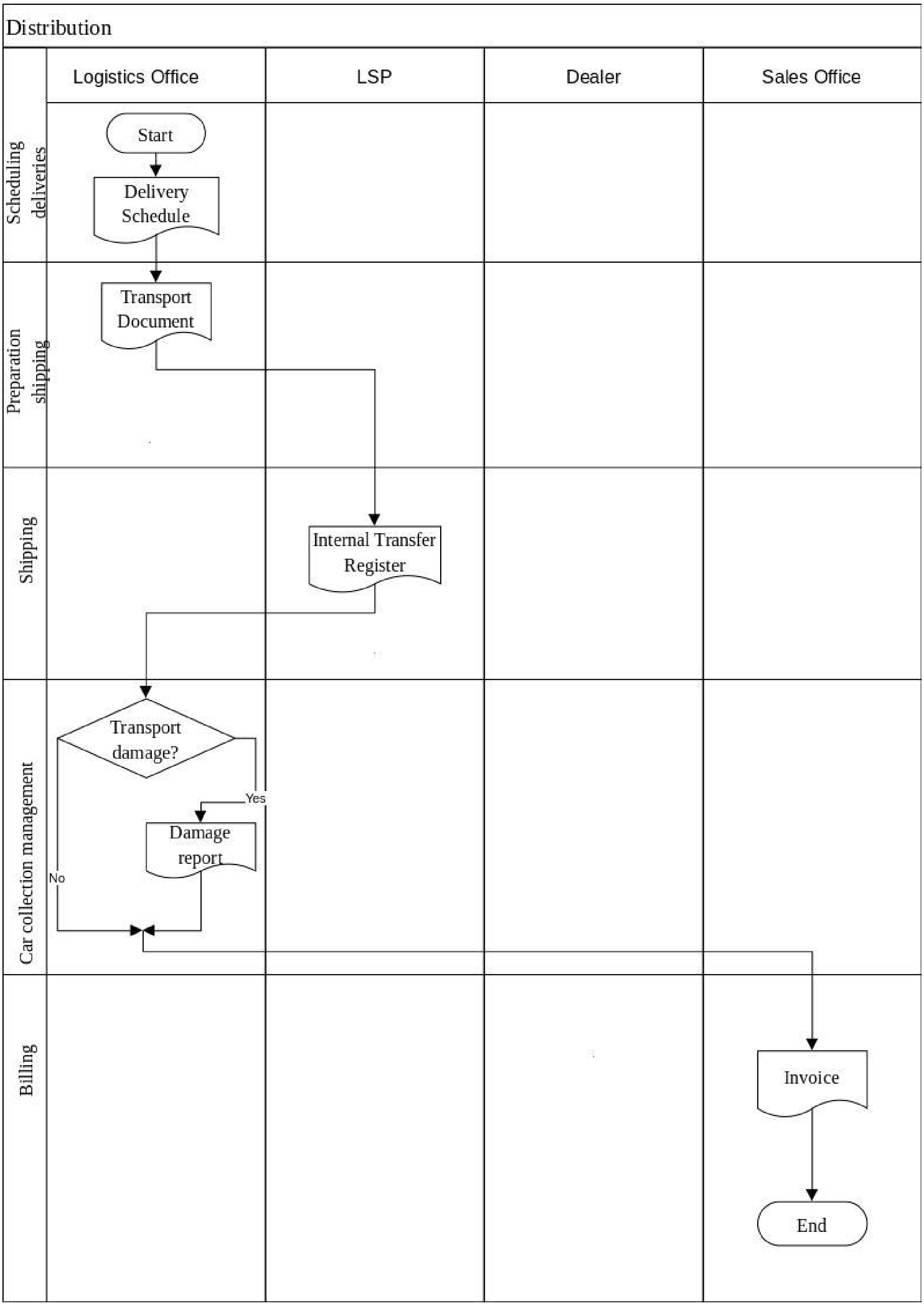

Figure 2.13 Assembly information flow chart

2.6 Criticalities of traditional supply chain

The next step of this study is to define the criticalities of the traditional supply chain described until now. To better understand them it has been decided to analyze each phase of the supply chain separately. In the following sub-sections each criticality has been associated to a specific activity in the supply chain. Once, the criticalities are found, the 5 Whys approach is used to find the route cause. The method is remarkably simple: when a problem occurs, you drill down to its root cause by asking "Why?" approximately five times. Then, when a countermeasure becomes apparent, you follow it through to prevent the issue from recurring. [15]

Procurement

In the procurement phase three main criticalities have been found: Bullwhip Effect, the information system of different companies not integrated, and the management of urgencies and reminders does not have a dedicated communication channel.

The Bullwhip Effect is a supply chain phenomenon describing how small fluctuations in demand at the retail level can cause progressively larger fluctuations in demand at the wholesale, distributor, manufacturer, and raw material supplier levels. [16]. This problem is due to the fact that upstream in the supply chain there is still little visibility of final demand. Forecasts are based on sellers. Very often sales do not correctly represent the real demand since they are subject to promotions in case of unsold and consequently represent a reduced profit margin. (Gobetto, 2014). In Figure 2.14 is shown the 5 whys analysis of the demand distortion.

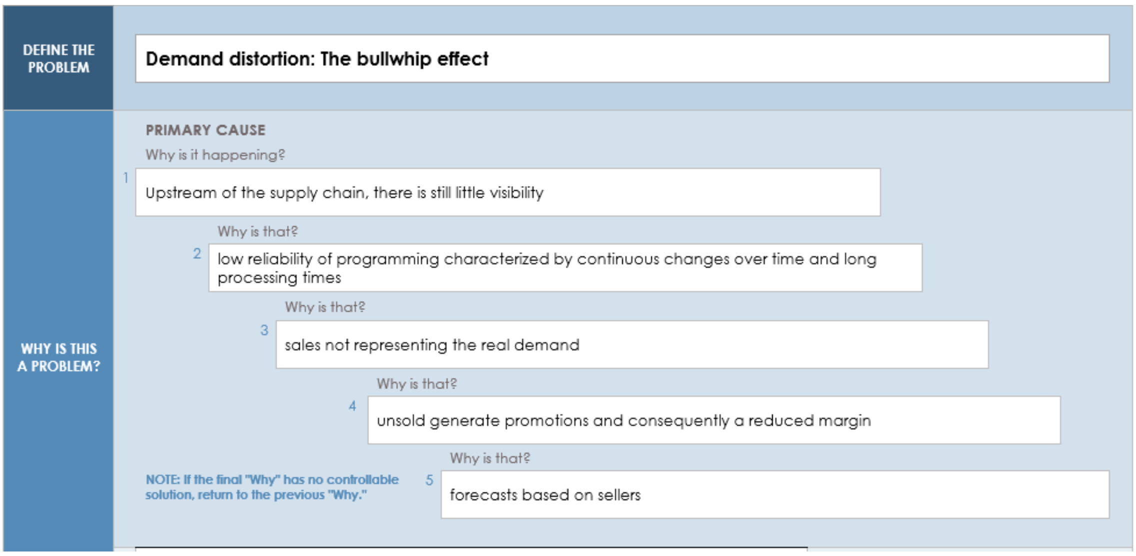

Figure 2.14 5 Whys for Bullwhip Effect

In Figure 2.15 it is possible to notice where the Bullwhip Effect occurs in the information flow.

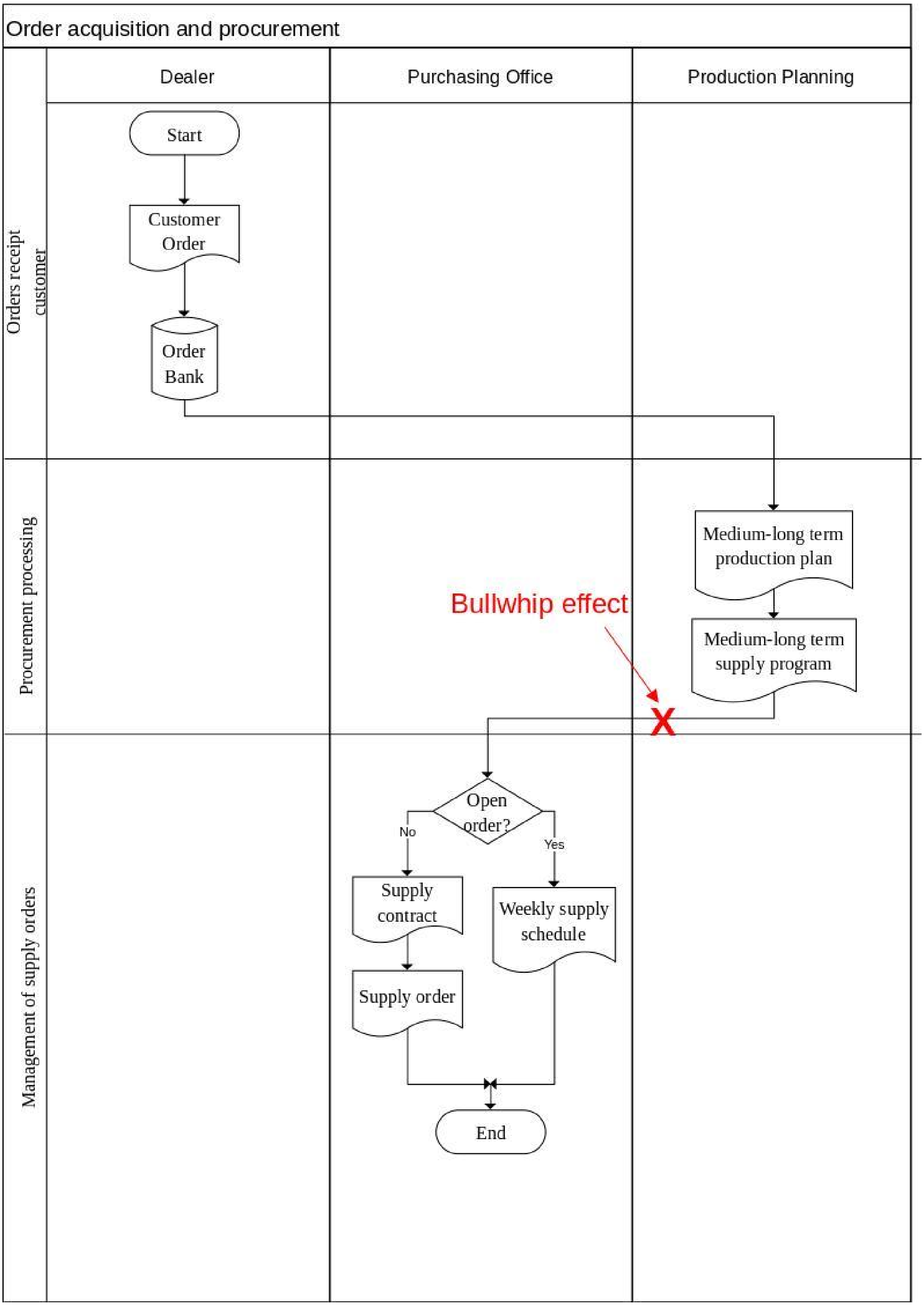

Figure 2.15 Bullwhip Effect in the procurement information flow

In some cases, orders and urgencies are still sent via email, fax, or phone due to a lack of integrated information systems between the different parties (Boysen, N, 2014). This could lead to a loss of track of important communications causing a delay to the entire procurement system. There are multiple reasons that lead to a company not choosing to integrate their systems with the partners starting from the high investments, shortage of integration experts, security issues to end up with more ethical reasons like loss of independence. [17] [18] Among them, the security factor has been chosen as a key reason in this study. In Figure 2.16 are shown the causes linked to this issue.

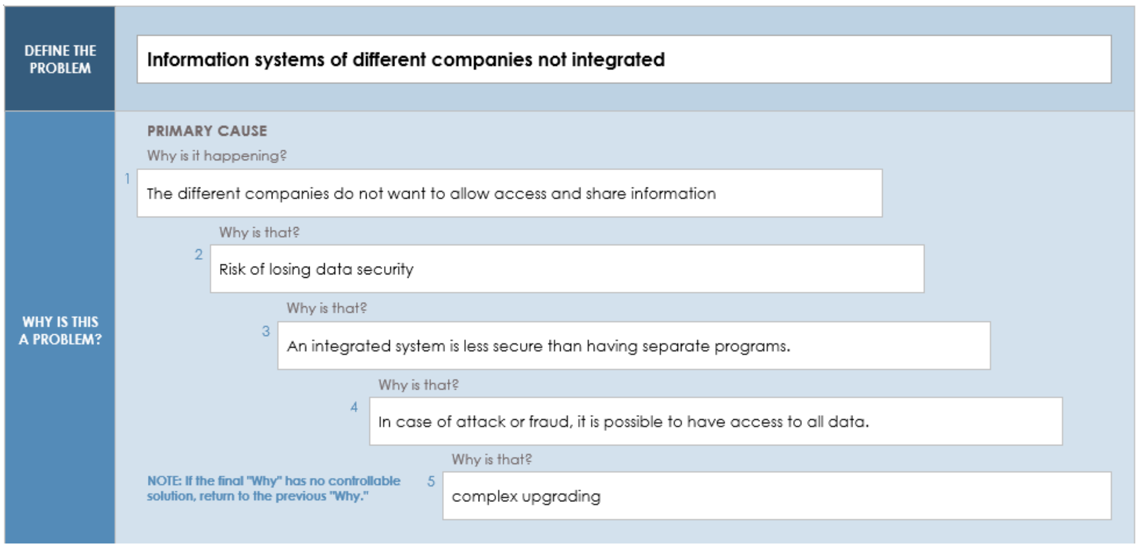

Figure 2.16 5 Whys for not integrated information systems

The same reasoning can be made for the management of urgencies and reminders. It can be considered as a direct consequence of the lack of integration of the informative systems.

In Figure 2.17 it is possible to see where the missing integration of informative systems occurs.

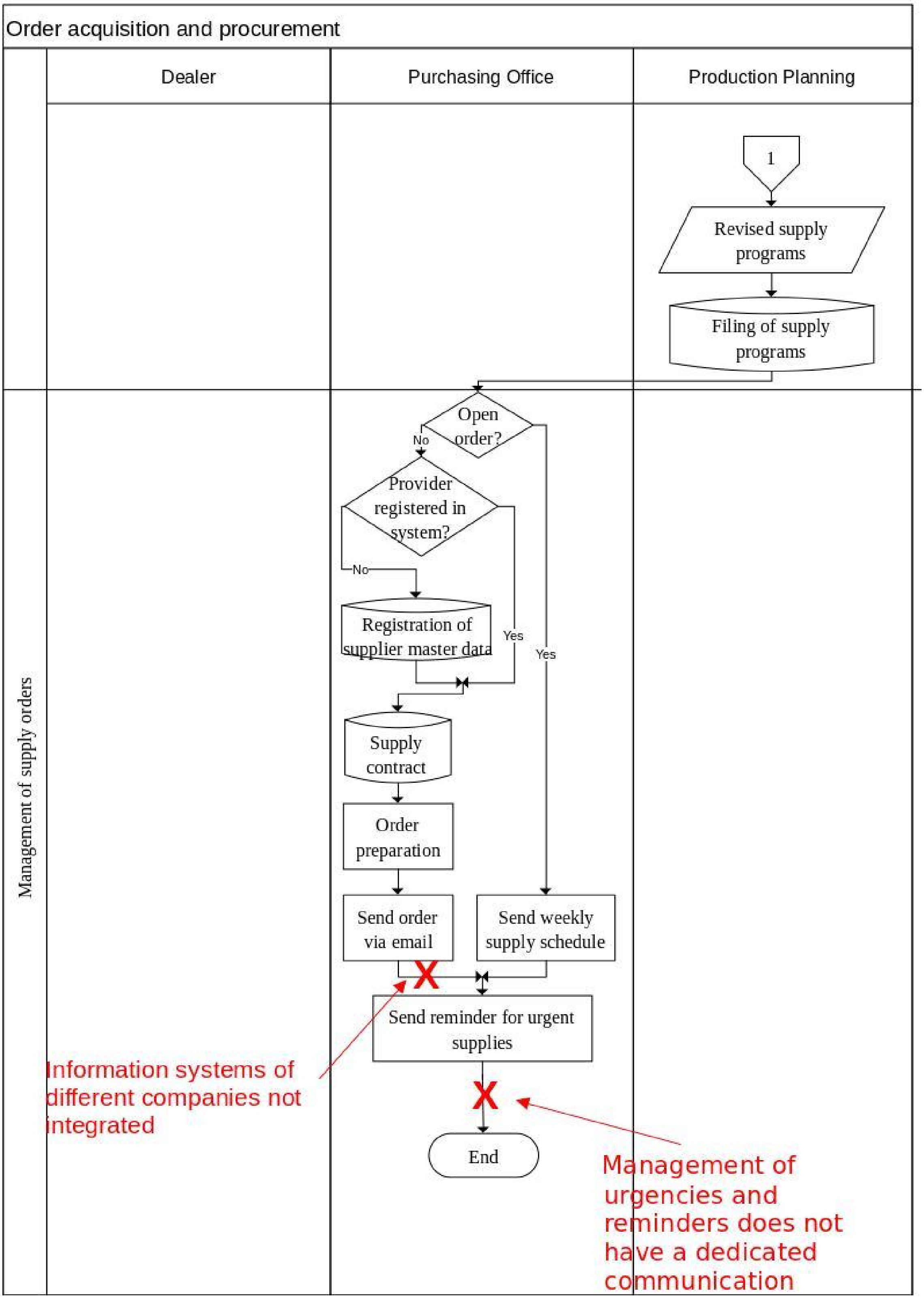

Figure 2.17 Not integrated information system in the procurement activity flow

Management of logistics flows within the OEM

In this phase, two criticalities have been found: e-mail communication of requirements and lack of traceability of incoming materials.

The first one is somehow linked to the lack of integrated systems issue discussed in the previous paragraph. This time to have a better overview the cost factor is considered as shown in the Figure 2.18 . Even though the benefits of system integration are quite evident a business owner can be discouraged by the high initial investment the process requires. [4]

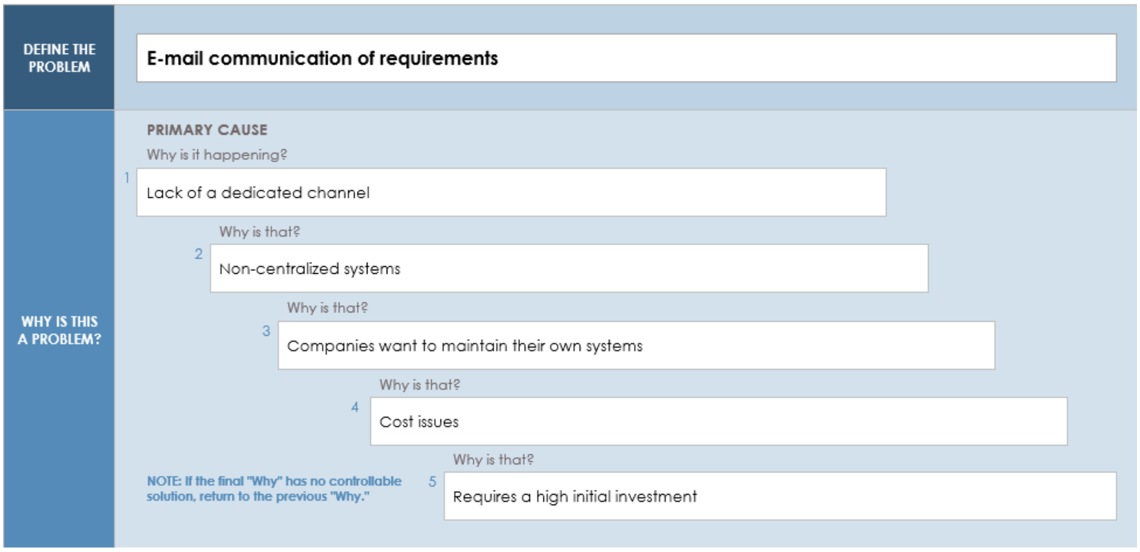

Figure 2.18 5 Whys e-mail communication of requirements

In Figure 2.19 It is possible to see where the e-mail communication holds.

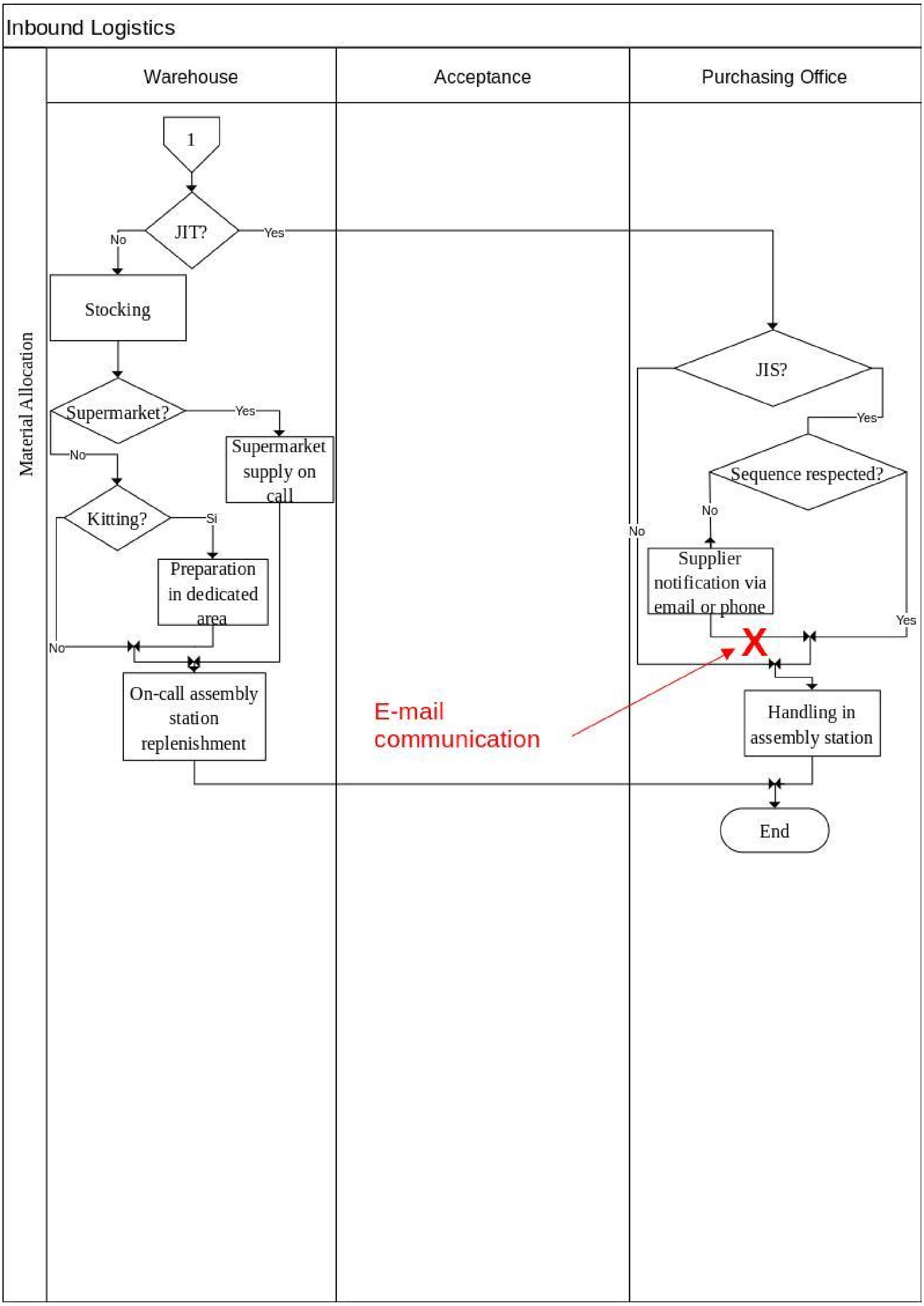

Figure 2.19 E-mail communication in inbound logistics material flow

Referring to Boysen et al. (2014) the traceability of the incoming material could represent a criticality. The information is recorded in company databases and not in shared systems. This doesn't allow to have good visibility between the different parties composing a supply chain. Moreover, the identification and recording processes are done manually in some industries leading human error and slow processes. In Figure 2.20 are shown the causes of the issue described.

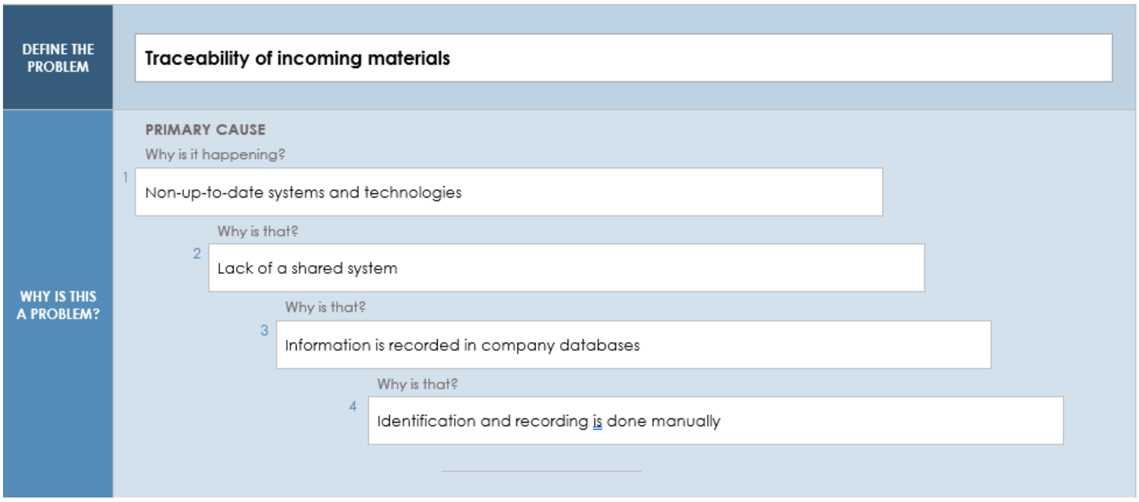

Figure 2.20 5 Whys Traceability of incoming materials

In Figure 2.21 it is shown that the traceability of incoming materials issue occurs when the material is received from the supplier and has to be stored in the warehouse.

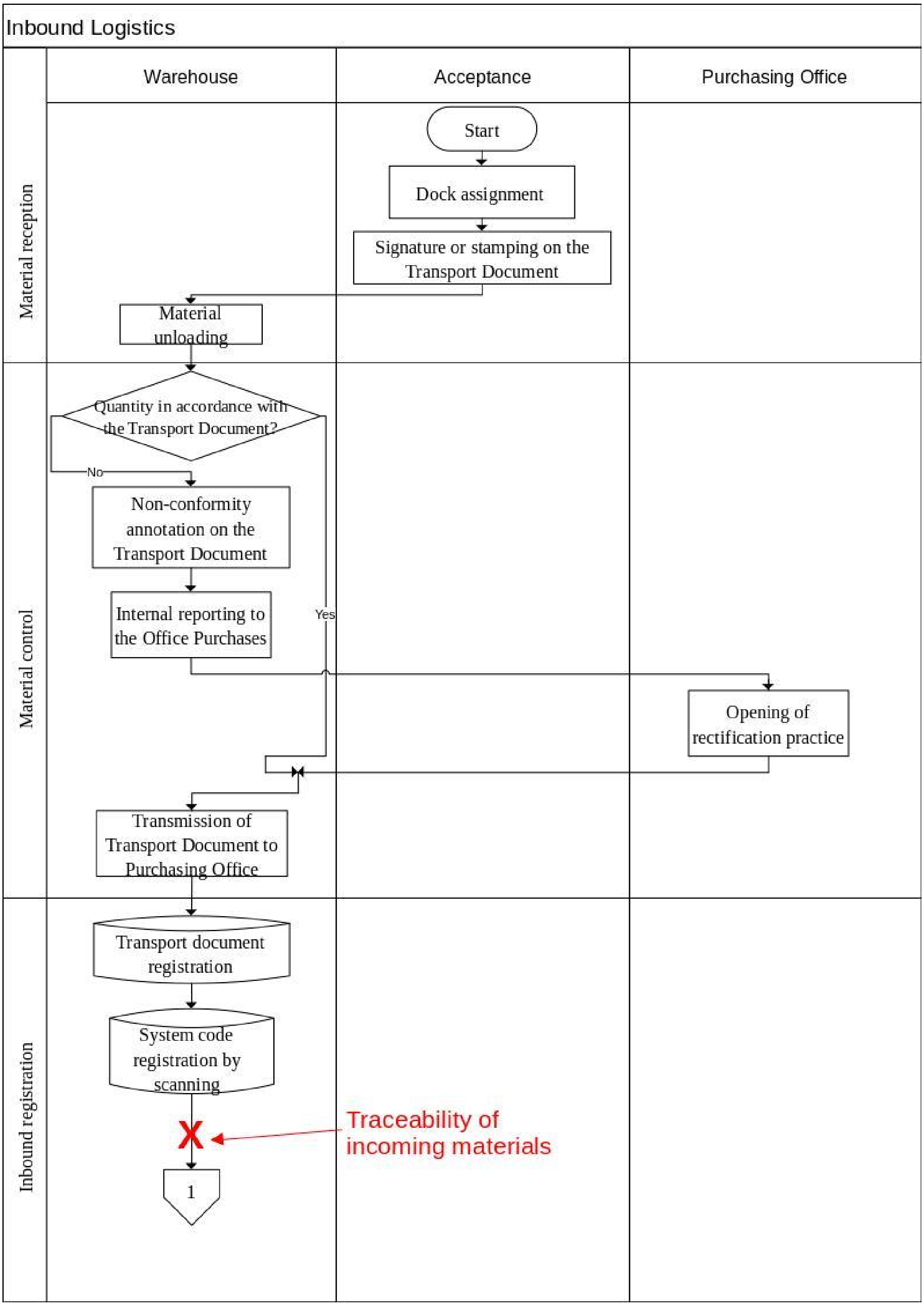

Figure 2.21 Traceability of incoming materials in Inbound logistics flow

Assembly

The assembly phase is long and complex because it involves many different processes ranging from the chassis building to the engine mounting. Three main criticalities have been highlighted: machinery failure prediction in molding process, not complete automation in some picking processes, and issues related to vehicle identification entering the assembly lines.

The former deals with the fact that the machinery can inform of a failure once it has already occurred (Rodriguez,2010). A preventive prediction of a failure can avoid long stops and more critical damages that can involve larger repairing costs. In Figure 2.22 are shown its route causes.

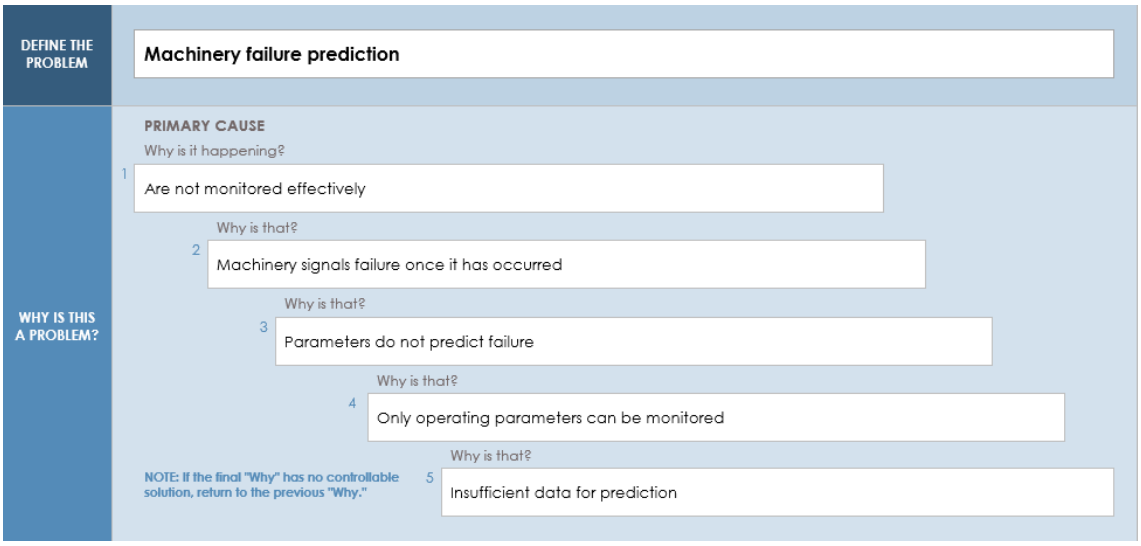

Figure 2.22 5 Whys machinery failure prediction

The machinery failure is more critical in the first assembly process which involves the molding of metal parts composing the body of the vehicle as shown in Figure 2.24.

The picking operations of metal coils from the warehouse are not fully automated (Boysen et al., 2014). The robot exploitation for heavy load materials handling can ease and fasten the picking and transportation to the production area. In Figure 2.23 are shown the root causes.

Each installation requires the preliminary scanning of the identification code of the car entering the station (Dias et al. 2019). As explained in the previous paragraphs this operation is not really optimized.

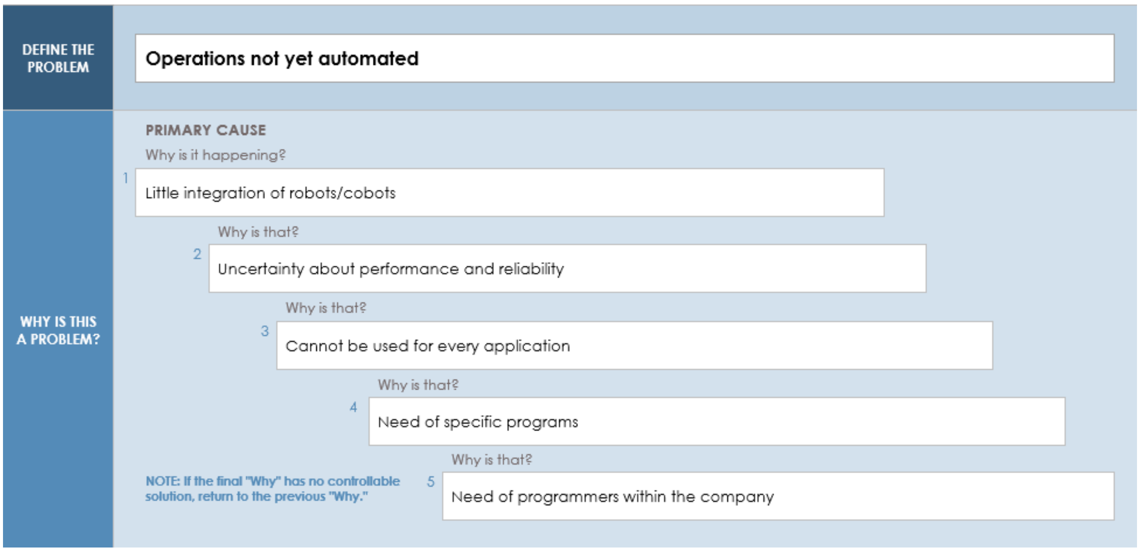

Figure 2.23 5 Whys operations not yet automated

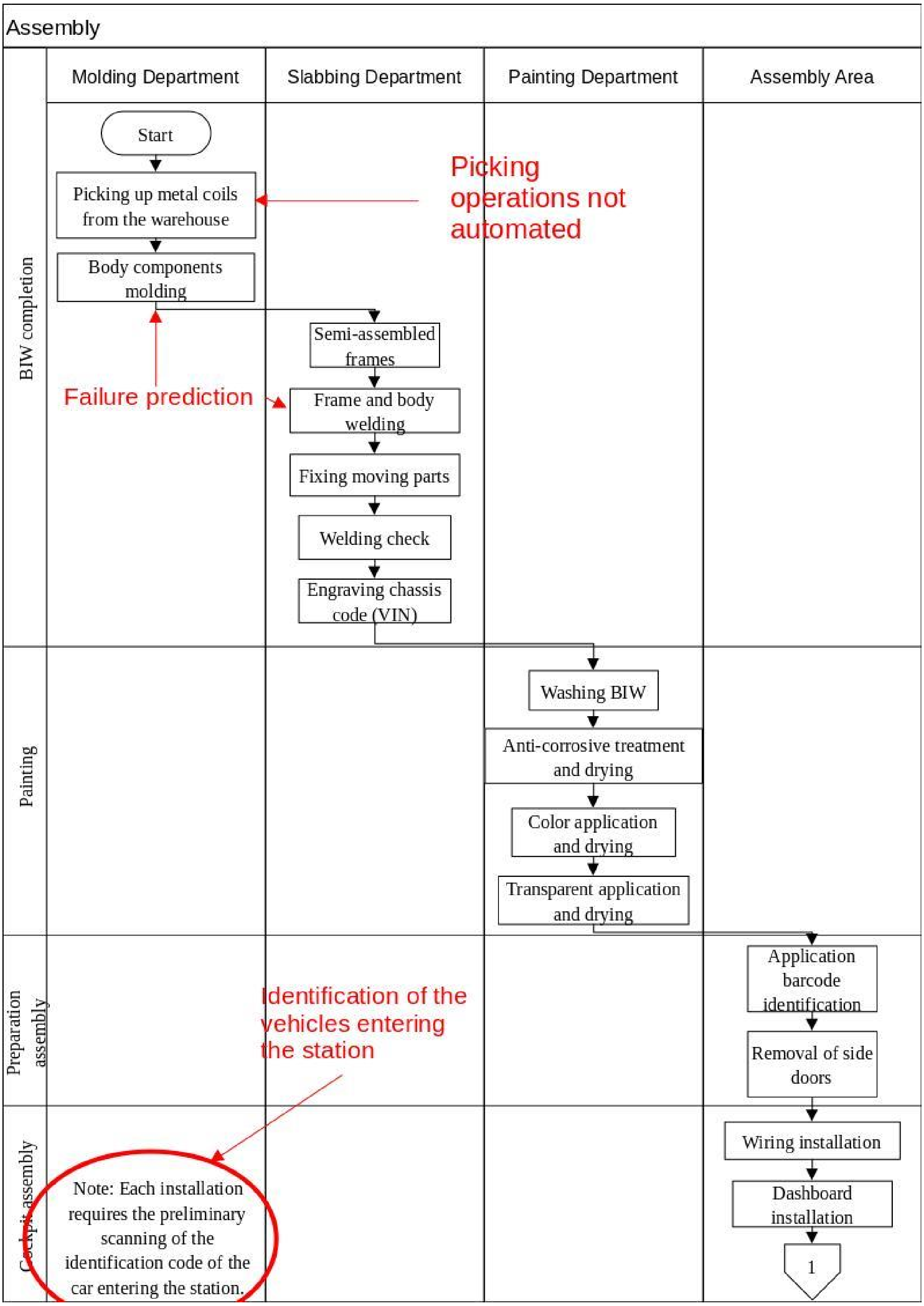

Figure 2.24 Assembly line criticalities

Distribution

The distribution phase is where the greatest number of criticalities have been found. They can be resumed with insufficient space in delivery areas (Holweg & Mieczyk, 2002) and no communication of the vehicle status at the consolidation centers and regional depots as shown in Figure 2.27 and Figure 2.28.

The insufficient space in delivery areas is a consequence of a non-optimized preparation of the vehicles exiting the assembly line and a non-smooth communication between the OEM and Logistics Service Provider (LSP). The identification of the vehicles coming from the assembly line is still done manually by operators (Gobetto, 2014). Moreover, it creates organizational issues for the LSP who doesn't know in advance the availability of the cars he has to deliver to the dealer. The combination of these two factors generates confusion even inside the intermediate parking areas where the vehicles are placed while waiting to be picked up by the delivery service (Holweg & Mieczyk, 2002). In Figure 2.25 are explained better the root causes discussed until now.

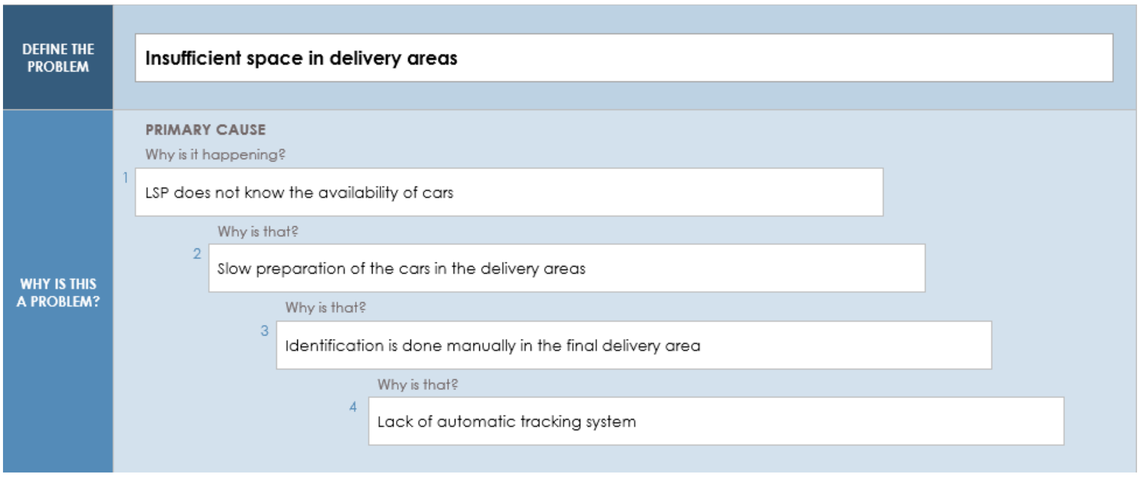

Figure 2.25 5 Whys insufficient space in delivery areas

The lack of communication of the vehicle status at the consolidation centers and regional depots causes a shortage of traceability in the delivery process (Gebhard et al., 2015). Once the vehicle is picked up from the OEM there is no information of the tracking until the car is delivered to the dealer. In Figure 2.26 are shown the root causes.

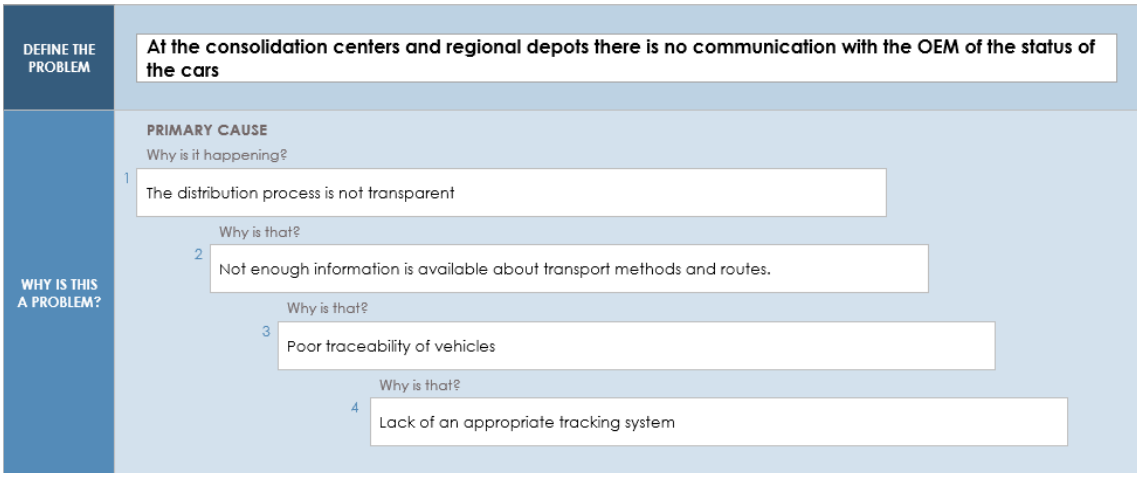

Figure 2.26 5 Whys no tracking at the consolidation centres

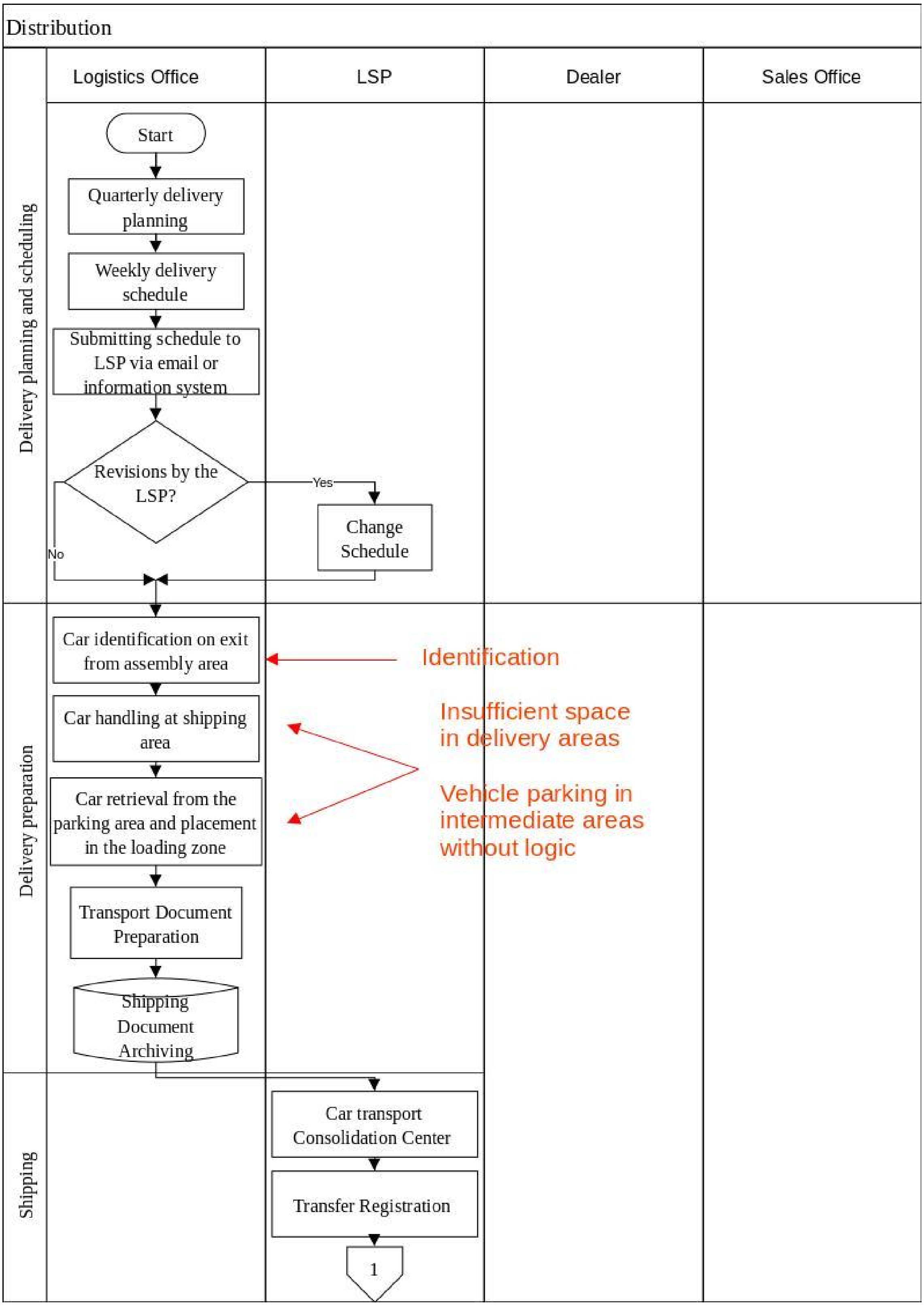

Figure 2.27 Criticalities in Distribution

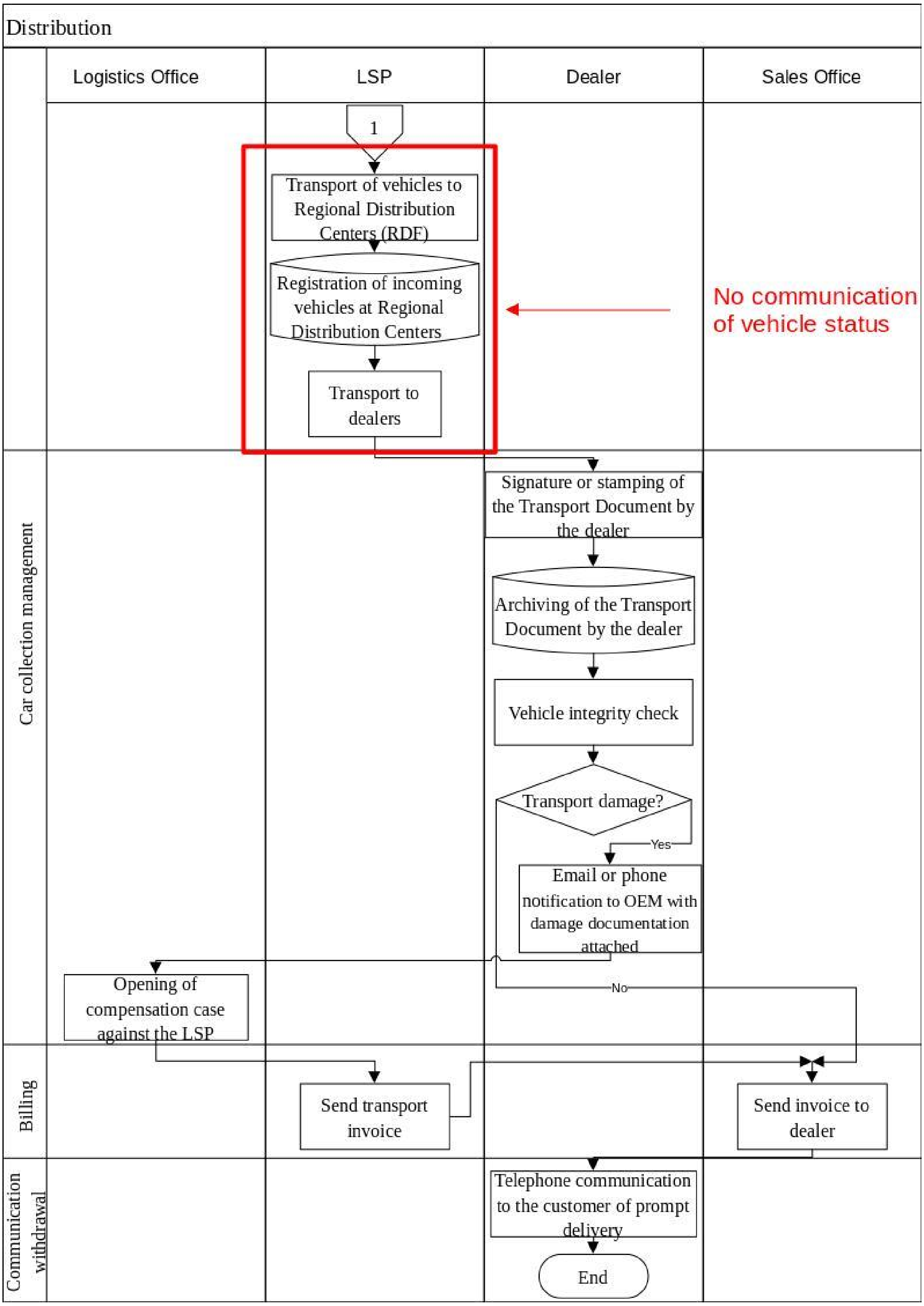

Figure 2.28 Criticalities in Distribution

3 Identification and development of Technologies 4.0

In this chapter the implementation of technologies of Industry 4.0 are proposed to solve the criticalities identified in Chapter 2. Combining the knowledge of the available technologies described in the first chapter and the root causes analysis through the five whys method the solutions in Table 3.1 have been found.

Criticality	Department	Technology integration
Bullwhip Effect	Procurement	Cloud Computing + Blockchain (for sensitive data protection)
Information systems of different companies not integrated	Procurement	Cloud Computing
E-mail communication of requirements	Management of inbound logistics	Cloud Computing
Traceability of incoming materials	Management of inbound logistics	RFID tags
Machinery failure prediction	Assembly	Predictive Maintenance with Machine Learning
Operations not yet automated	Assembly	Automated cranes
No communication with the OEM of the status of the cars at the consolidation centers and regional depots	Distribution	GPS and GSM
Traceability of vehicles in the parking lot	Distribution	RFID or GPS + GSM tracking systems

Table 3.1 Proposed solutions to the traditional Supply Chain criticalities

3.1 Cloud computing

Cloud computing is an IT service model where computing services, both hardware and software, are delivered on-demand to customers over a self-service fashion, independent of device and location (Marston et al., 2011). This technology is suitable for solving issues related to Bullwhip Effect and integration of informative systems between the parties involved in the Supply Chain. A quick overview of the main types of cloud computing services is provided to illustrate the choice proposed:

- Infrastructure as a Service (IaaS) where businesses can benefit of hardware, servers, storage space etc. equipment. The cloud providers offer from physical or virtual machines to raw storage, firewalls, load balancers and networks (Mell & Grance, 2011). A remarkable example of this service is Amazon Cloud Services.
- Platform as a Service (PaaS) where a computing environment is provided and it typically includes operating system, data base and programming language execution environment (Sujay, 2011). Users can rent visualized servers for running existing applications or developing new ones without the cost and complexity of buying and managing the related hardware and software. A remarkable example is Windows Azure.
- Software as a Service (SaaS) where the cloud providers install and operate application software in the cloud and users access the software various client devices through either a thin client interface, such as a web browser or a program interface (Garg & Buyya, 2012). The main benefit of this service is that the users don't have to manage the cloud infrastructure and platform on which is running. Salesforce CRM is a good service provider.

As McPherson (2010) states, SaaS is a very attractive and low-cost solution for companies that don't want to revolutionize their infrastructures.

Cloud solutions play a pivotal solution for more accurate statistical demand forecasting and order planning allowing better coordination and visibility between the Supply Chain network partners (retailers, suppliers, and distributors) (Schramm et al., 2010). This benefit can reduce the Bullwhip Effect that was highlighted in the previous chapter. As shown in Figure 3.1, when a customer generates demand, dealers can send data in the public cloud sharing it immediately to the upstream players of the chain.

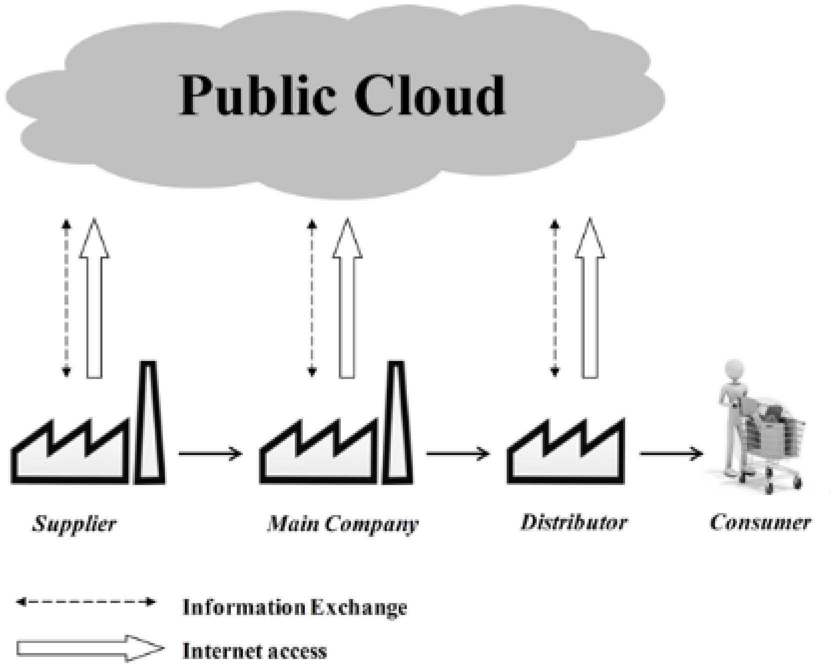

Figure 3.1 Integration of Supply Chain Processes (Toka et al. 2013)

Sourcing and procurement process especially the acquisition, receipt, and inspection of incoming materials with procurement processes and selection of the appropriate suppliers can be improved using this technology (Schrödl & Turowski, 2011). Automotive manufacturers have to deal with many suppliers and cloud-based platforms can operate as a database about different suppliers and creates a shared communication channels for real time data updates, requirement and urgencies management.

Inventory, warehouse, and transportation managed can be enhanced because such solution offers a better tracking of the material flows and increases the effectiveness of Radio Frequency Identification (RFID) system adoption that will be explained in the next chapter.

A drawback that can rise with cloud computing is that highly sensitive insights (e.g., customer personal information) can be shared when exchanging demand data vertically in the supply chain. Blockchain technology can be adopted to secure sensitive information. All the entries codified on the digital ledger are cryptographically protected, making the data virtually impossible to breach. Additionally, customer records do not change hands per se. Instead, every participant is given key access to the data stored on the ledger. Opting for such architecture means that customers can retain access to their private data and only choose to grant access to it (Keil, 2022).

3.2 Radio Frequency Identification (RFID)

Problems regarding the traceability of materials in the warehouse and assembly lines have been pointed out in the previous chapters. The manual identification and tracking systems have higher occurrence of human error in recording the logistics operation of the transport items. These errors have negative effect on the production and logistics cycle time. Jamaludin and others (2018) propose Radio Frequency Identification (RFID) and barcode technology as solution for efficient logistic management by automating the information identification, verification, and documentation process in almost real-time.

In the literature review a case study has been found. An automated tracking system for metal-based trolley using RFID system have been designed and validated at an automotive manufacturing plant in Alor Gajah, Melaka (Jamaludin and others, 2018). The system consists of an interrogator, transponder, and a host computer as shown in Figure 3.2 .A radio wave signal is transmitted by the interrogator to detect tags within the interrogating field. The powered tag then responds with unique information to the tag to the interrogator (Fan, 2010).

Figure 3.2 RFID system components (Javad, 2012)

The automated tracking system consist both of hardware and software components. The hardware components include a Dell Vostro 3400 Laptop (as host computer), eco UHF-RFID reader, reader antenna and Xerafy Mercury Metal Skin UHF tag while the software allows the management of data flow, data collection, data storage and data presentation.

The system architecture is composed of three tiers, and it allows to monitor the activities of the kitting trolleys:

1. Data collection: it is responsible to deliver command of captured RFID tag information and reply command of RFID response.

2. Storage tier: store any received information and response to any query on specific information.
3. Data management tier: model identification of the kitting trolley locations and providing reports on Returnable Transport Items (RTI).

On Figure 3.3 is shown the architecture of RFID tracking system.

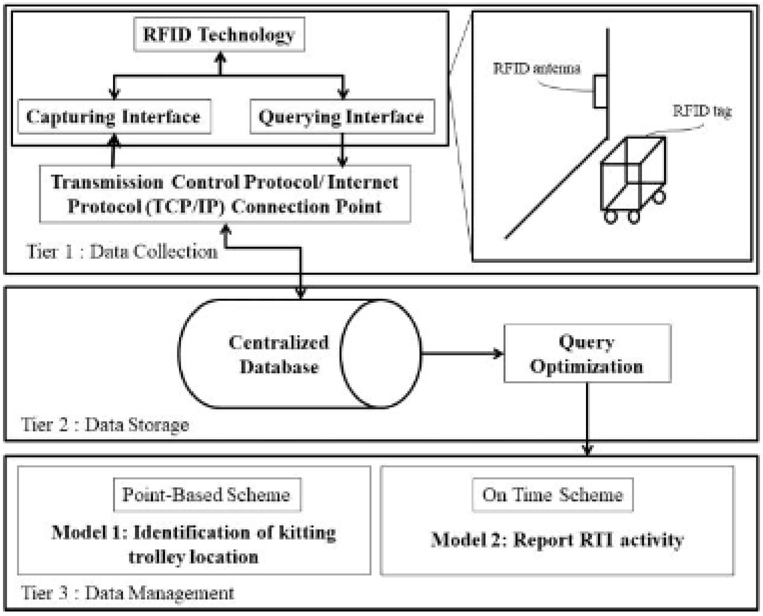

Figure 3.3 System architecture of RFID-based RTI tracking system (Jamaludin et al. 2018)

As result of the study conducted on the cited paper it shown that the speed of handing the items is increased by 9,4% and the data handling efficiency is improved by 91,5%.

RFID tracking system combined with cloud services it's an important tool for increasing the tracking capabilities and efficiencies in the warehouse management, assembly line and final product in the parking lot identification.

3.3 Predictive Maintenance with Machine Learning

The traditional supply chain doesn't include a machinery predictive maintenance. Periodic maintenance could not be sufficient to avoid sudden failures with consequent long stops in the production. According to Susto et al. (2015) there are three categories of maintenance procedures:

- Run-to-Failure (R2F) or Corrective maintenance happens only when an equipment stops working. This is the simplest maintenance strategy.

- Preventive Maintenance (PvM) is a scheduled maintenance performed periodically with a planned schedule in time.
- Predictive Maintenance (PdM) uses predictive tools to determine when maintenance actions are necessary. It is based on continuous monitoring of a machine or a process integrity.

Predictive maintenance allows an early detection of the failures and reduces costs due to periodic checks performed in case of Preventive Maintenance. Thanks machine learning a predictive analysis can be performed based on historical data and integrity factors such as wear, temperature, pressure etc. According to Wuest et al. (2016) Machine Learning approaches have the ability to handle high dimensional and multivariate data, and to extract hidden relationships within data in complex and dynamic environments. It is then required to design a proper model of machine learning and the main steps are shown in Figure 3.4.

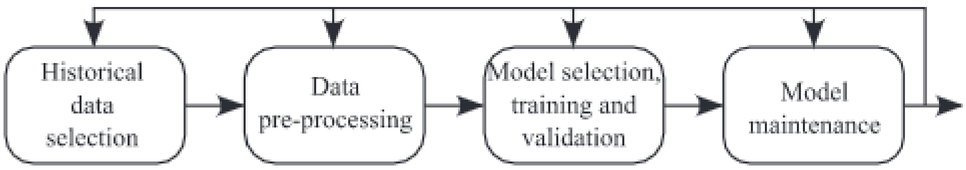

Figure 3.4 The main steps for the design of a machine learning model (Jardine et al. 2006)

Referring to Jardine et al. (2006) the main steps are:

- The historical data selection step determines how data is collected and stored to select important data for ML model creation.
- The data pre-processing stage cleans and changes data so that the ML model can process it efficiently. Data normalization, data cleaning, and data reduction are all part of this process
- The model selection, model training, and model validation process involves choosing an appropriate machine learning model, training the model (i.e., model development), and model validation (i.e., a procedure that evaluates whether the model can represent the underlying system).
- The model maintenance stage aims to keep the model running smoothly throughout time. This is because industrial applications can change over time, causing the model's performance to decrease.

Artificial Neural Network (ANN) is a common solution adopted in industrial applications. ANNs are intelligent computational techniques inspired by the biological neurons (Biswal and Sabareesh, 2015). ANN is composed of several processing units (nodes or neurons) connected by communication. The strength of this technology comes from the interactions between the processing units of the network. This solution fits perfectly with large number of data coming from machine parameters and it is capable to maintain long term performances without degradation respecting the requirements described above.

3.4 Automated cranes

An innovative solution for picking up heavy metal coils is provided by KoneCranes [19] as shown in Figure 3.5. Compared to traditional cranes smart features are present:

- Sway Control: it limits load swing by controlling bridge and trolley acceleration and deceleration.
- Target positioning: in predictable and repetitive work cycles will bring the load from a home position to a defined target position in a single push of a button.
- Snag prevention: it is possible to continuously monitors rope angle and automatically stops crane movement if a hook, sling, or load accidentally gets caught on something.
- Hook centering: if the hook is off-centre by even a small amount when the load starts to lift, this feature will detect the resulting side pull and automatically move the trolley and bridge, positioning the hook directly over the load.

These features help the crane operator handle the crane by automating repetitive tasks or adjusting for misalignment and irregular movements. When managing a load, Smart Features improve precision and accuracy and can lessen the risk of collision with personnel or equipment. Furthermore, smooth functioning reduces wear and tear on the crane's steel structure and components.

Moreover, with remote monitoring it is possible to collect data through sensors such as s running time, motor starts, work cycles and emergency stops, providing visibility to crane usage. In this way it is possible to predict failures and safety risk events.

Figure 3.5 Automated crane (Konecranes.com)

3.5 GPS and GSM

Criticalities in the distribution phase are caused by lack of traceability in the parking lot. Hlaing and others (2019) propose a vehicle tracking system based on a combination of Global Positioning System (GPS) and Global System for Mobile Communication (GSM). The system includes a GPS device and a GSM modem with SIM card used to implement the same communication technique as in regular cell phone [20]. It can be easily installed or fitted in the vehicle. Then it is possible to track the car using the mobile phone and dialling the phone number of the SIM attached to the GSM modem and a SMS will be send to the user with the information relative to the vehicle location. An example is shown in Figure 3.7. In Figure 3.6 is shown the block diagram of the described technology. Since the GPS module gives as output lot of data an Arduino UNO is required to filter the useful information and they are displayed on the LCD. The message projected to the LCD will be then send to the user mobile device.

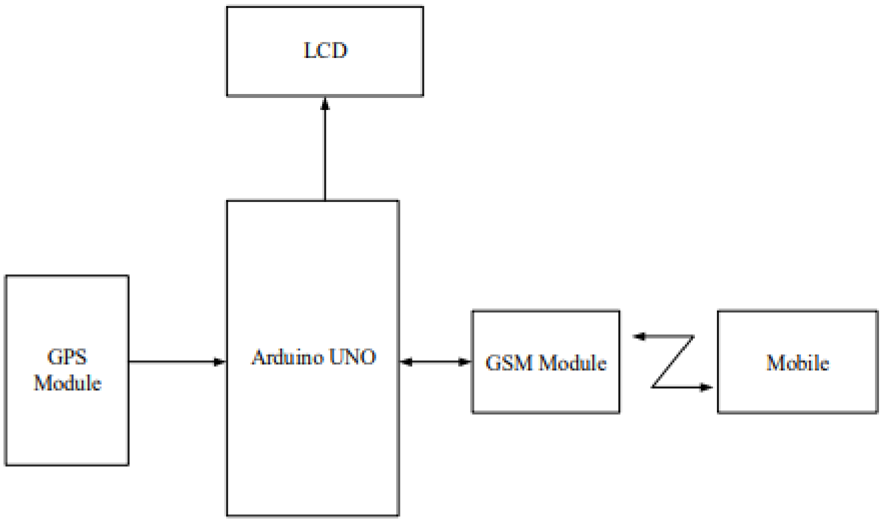

Figure 3.6 Block Diagram of GPS and GSM Based Vehicle Tracking System

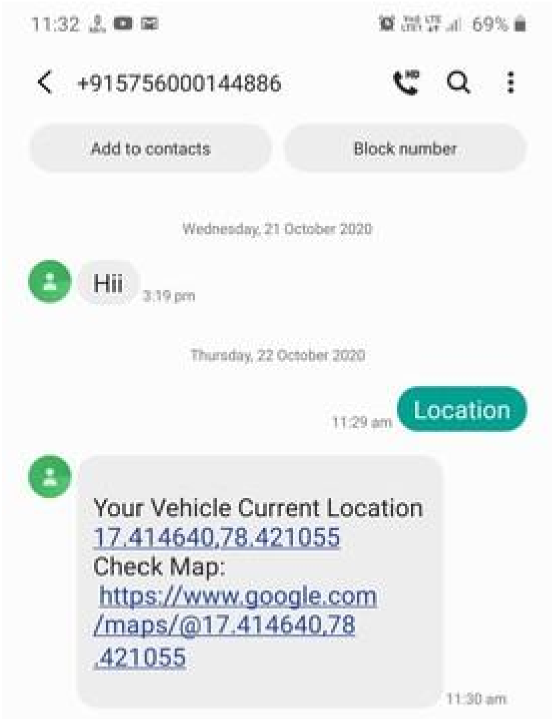

Figure 3.7 Example of SMS Message (how2electronics.com [21])

4 Conclusions

This thesis provides an overview of new technologies and their potential in improving an automotive supply chain. To better understand the characteristics of these technologies a literature review has been performed. Through the technical documentation (Cucchietti, 2017), the mapping of a traditional supply chain has been defined, highlighting its criticalities. From the present study it emerges that a large number of the criticalities are linked to low visibility and insufficient exchange of information between the actors involved in the various processes. Cloud computing represents an effective, cheap, and fast solution to solve these issues. Through this technology it is possible to make visible the information and relative updates in real time making the demand forecast more accurate and creating a unique communication channel between the various partners reducing the risk of loss of important notifications such as reminders and emergencies.

Typical IoT technologies, such as RFID tags, allow instead a better traceability of material flows inside and outside warehouses and assembly stations. Big Data and Machine Learning, on the other hand, make the so-called "predictive maintenance" possible, capable of forecasting machinery failures based on historical data and operating parameters, reducing the risk of sudden stops in production, and reducing the costs of periodic maintenance, which is sometimes can be unprofitable.

Automation makes the pick-up and transportation materials easier. Finally, with Blockchain it is possible to protect sensitive data and make their access more secure.

4.1 Benefits of the thesis work

During the research process, the lack of specific documentation of some implementations of Industry 4.0 technologies within an Automotive Supply Chain became apparent. While the use and benefits of solutions such as IoT are quite clear, the other proposed options are derived from practical applications that are not unique to the industry being analysed but can be theoretically adopted for this study. Thus, this thesis aims to be a starting point for future research by illustrating the benefits that digitization can bring.

4.2 Limitations of the thesis work

The lack of sufficient documentation of a specific OEM, has directed the work of this thesis towards an analysis of a generic traditional Supply Chain, although it is known that many manufacturers have already begun to adopt new technologies independently. Moreover, the lack of technical validation by experts represents a limitation on the actual applicability of the proposed solutions. So, this study can be considered exclusively theoretical. In addition, the amount of investment required at economic and infrastructural level for the implementation of the proposals made has not been considered.

4.3 Ideas for future research

Nowadays, technology is making progresses very quickly. It will certainly be possible to find more effective solutions than those proposed in the coming years. However, this work can be considered as a theoretical proposal that lacks a practical implementation that could be carried out in the near future to verify qualitatively and quantitatively the achievable improvements. To do this, a validation process is necessary at the end of which a comparison can be made between the Traditional and Digital Supply Chain to better understand the benefits that the digitalization can bring in the Supply Chain processes.

References

Ahram, T., Sargolzaei, A., Sargolzaei, S., Daniels, J., Amaba, B. (2017), "Blockain Technology Innovations", Technology & Engineering Management Conference (TEMSCON).

Almaslamani, Farah & Abuhussein, Raneem & Saleet, H. & Abuhilal, Laith & Santarisi, Nader. (2020). Using Big Data Analytics to Design an Intelligent Market Basket-Case Study at Sameh Mall.

Aoki, K., Staeblein, T. (2015), "Planning and scheduling in the automotive industry: A comparison of industrial practice at German and Japanese makers", International Journal of Production Economics, Vol. 162, pp. 258-272.

Battini, D., Boysen, N., Emde, S. (2013), "Just-in-Time supermarkets for part supply in the automobile industry", Journal of Management Control, Vol. 24, No. 2, pp. 209–217.

Beamon, B. M., (1998), "Supply Chain Design and Analysis: Models and Methods", International Journal of Production Economics, Vol. 55, No. 3, pp. 281-294.

Biswal S. and Sabareesh G. R., "Design and development of a wind turbine test rig for condition monitoring studies," 2015 International Conference on Industrial Instrumentation and Control (ICIC), 2015, pp. 891-896.

Boysen, N., Emde, S., Hoeck, M., Kauderer, M. (2014), "Part Logistics in the Automotive Industry: Decision Problems, Literature Review and Research Agenda", European Journal of Operational Research, Vol. 242, No. 1, pp. 107-120.

Brandwein, D, Scholz-Reiter, B., Ruthenbeck, C., Werthmann, D. (2013), "Standardized Information Exchange in Automotive Distribution Processes", IFAC Proceedings Volumes, Vol. 46, No. 9, 2013, pp. 670-675.

Christidis, K., Devetsikiotis, M. (2016), “Blockchains and Smart Contracts for the Internet of Things”, IEEE Access, Vol. 4, pp. 2292-2303.

Cucchietti G. (2017), “Digital Supply Chain nel settore Automotive: studio di possibili applicazioni”, Torino.

Daud A. and Zailani S., “Lean supply chain practices and performance in the context of malaysia,” Supply Chain Management–Pathways for Research and Practice, p. 1, 2011.

Dias P., Silva F.J.G., Campilho R.D.S.G., Ferreira L.P., Santos T., Analysis and Improvement of an Assembly Line in the Automotive Industry, Procedia Manufacturing, Volume 38, 2019, Pages 1444-1452, Pages 381-392.

Engineering Review (2017), “Importance of conveyors in automation system”.

Fan X., “Progress on RFID technology application in logistics industry,” in 2010 International Conference of Logistics Engineering and Management, 2010, pp. 2375–2381. Management, 2010, pp. 2375–2381.

Frankenfield J. (2020), “Cloud Computing”.

Garg, S., & Buyya, R. (2012). Green cloud computing and environmental sustainability. In Murugesan, S., & Gangadharan, G. (Eds.), Har-nessing Green IT: Principles and Practices (pp. 315–340).

Gebhard, M., Hartmann, E., Herrmann, S., Rogers, H. (2015), “Co-creating value in the Automotive Supply Chain: an RFID Application for Processing Finished Vehicles”, Production Planning & Control, Vol. 26, No. 12, pp. 981-993.

Gobetto, M. (2014), Operations Management in Automotive Industries, Springer, Berlin, Germany.

Grimshaw J. (2020), “What is supply chain? A definitive guide.”

Hayes A. (2020), Augmented Reality, Investopedia.

Heizenrader. (2019, September 11). The 3 Types of Virtual Reality.
Hlaing, Ni & Naing, Ma & Naing, San. (2019). GPS and GSM Based Vehicle Tracking System. International Journal of Trend in Scientific Research and Development. Volume-3. 271-275.

Holweg, M., Miemczyk, J. (2004), "Building Cars to Customer Order – What Does It Mean for Inbound Logistics Operations?", Journal of business logistics, Vol. 25, No. 2, pp. 171-197.

Holweg, M., Pil, F. K. (2001), "Successful Build-to-Order Strategies Start with the Customer", Sloan Management Review, Vol. 43, No. 1, pp.74-83.

Hua, S. Y., Johnson, D. J. (2007), "Research Issues on Factors Influencing the Choice of Kitting versus Line Stocking", International Journal of Production Research, Vol. 48, No. 3, pp. 779-800.

Jamaludin, Z., Huong, C.Y., Abdullah, L., Nordin, M.H., Abdullah, M.F., Haron, R., & Jalal, K.B. (2018). Automated Tracking System Using RFID for Sustainable Management of Material Handling in an Automobile Parts Manufacturer. Journal of Telecommunication, Electronic and Computer Engineering, 10, 35-40.

Javad Majrouhi Sardroud, Influence of RFID technology on automated management of construction materials and components, Scientia Iranica, Volume 19, Issue 3, 2012.

Jenkins A. (2020), "Digital Supply Chain explained"

Joshi, Archana & Han, Meng & Wang, Yan. (2018). A survey on security and privacy issues of blockchain technology. Mathematical Foundations of Computing. 1. 121-147.

Joshi, N. (2019). 3 ways AR for warehouse management | Augmented Reality

Keenan, M. (2021) “What Is RFID Technology and How Can I Use It?”

Keil, J. (2022). How Can Cloud Computing and Blockchain Reduce the Bullwhip Effect in Supply Chain? | Infopulse

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing - The business perspective. Decision Support Systems Journal, 51(1), 176–189.

Matthews K. (2018), “6 Industries that have been improved by robotic automation”.

McClelland C. (2016), “IoT Explained - How Does an IoT System Actually Work?”

McPherson, A. (2010). How private equity firms can use software as a service to improve portfolio company management.

Mell, P., & Grance, T. (2011). The NIST definition of cloud computing. National Institution of Standards and Technology

Mia Delic, Daniel R. Eyers (2020), The effect of additive manufacturing adoption on supply chain flexibility and performance: An empirical analysis from the automotive industry, International Journal of Production Economics.

Mitchell, C. (2020). “Virtual Reality”, Investopedia.

PWC (2016) “Industry 4.0: How digitalization makes the supply chain efficient, agile, and customer focused”.

Rodriguez A., Bourne D., M. Mason, Rossano G. F. and Wang J., (2010) "Failure detection in assembly: Force signature analysis," 2010 IEEE International Conference on Automation Science and Engineering, 2010, pp. 210-215.

Schramm, T., Wright, J., Seng, D., & Jones, D. (2010). Six questions every supply chain executive should ask about cloud computing.

Schrödl, H., & Turowski, K. (2011). SCOR in the cloud – Potential of cloud computing for the optimization of supply chain management systems.

Silva N, Barros J, Santos MY, Costa C, Cortez P, Carvalho MS, Gonçalves JNC. (2021), Advancing Logistics 4.0 with the Implementation of a Big Data Warehouse: A Demonstration Case for the Automotive Industry. Electronics.

Sujay, R. (2011). Hybrid cloud: A new era. International Journal of Computer Science and Technology, 2(2), 323–326.

Susto G. A., Schirru A., Pampuri S., McLoone S. and Beghi A., "Machine Learning for Predictive Maintenance: A Multiple Classifier Approach," in IEEE Transactions on Industrial Informatics, vol. 11, no. 3, pp. 812-820, June 2015.

Suthikarnnarunai, N. (2008), "Automotive Supply Chain and Logistics Management", International Multi Conference of Engineers and Computer Scientists, 19-21 March 2008, Hong Kong.

Tan, Z. (2021). Internet of Things Technology and Its Practice in Smart Warehouse Management.

Thorsten Wuest, Daniel Weimer, Christopher Irgens & Klaus-Dieter Thoben (2016) Machine learning in manufacturing: advantages, challenges, and applications, Production & Manufacturing Research, 4:1, 23-45.

Toka, Agorasti & Aivazidou, Eirini & Arvanitopoulos-Darginis, Konstantinos & Antoniou, Antonios. (2013). Cloud Computing in Supply Chain Management: An Overview.

Xu J., Yang Z., Fang H. (2021) Raw Material Traceability of Industrial Control System Based on Blockchain.

Visited Websites

[1] https://scor.ascm.org/processes/introduction

[2] https://www.ibm.com/topics/supply-chain-management

[3] https://www.oracle.com/it/internet-of-things/what-is-iot/

[4] https://www.surecontrols.com/what-is-industrial-automation/

[5]https://www.electricaltechnology.org/2015/09/what-is-industrialautomation.html

[6] https://www.sael.it/en/paper-automation/

[7] https://www.techmec.it/fresatrice-cnc/

[8] https://www.slideshare.net/Aakashkumar276/industrial-automation-plcscada

[9] https://nexusintegra.io/automation-in-industry-4-0/

[10] https://www.redhat.com/it/topics/cloud-computing/what-is-iaas

[11]https://mitsloan.mit.edu/ideas-made-to-matter/additive-manufacturing-explained

[12]https://www.twi-global.com/technical-knowledge/faqs/what-is-additive-manufacturing

[13]https://www.inductiveautomation.com/resources/article/what-is-hmi#:~:text=A%20Human%2DMachine%20Interface%20(HMI,context%20of%20an%20industrial%20process.

[14] https://www.automationworld.com/

[15]https://www.mindtools.com/pages/article/newTMC_5W.htm

[16]https://searcherp.techtarget.com/definition/bullwhipeffect#:~:text=The%20bullwhip%20effect%20is%20a,involved%20in%20cracking%20a%20whip.

[17] https://www.youredi.com/blog/10-reasons-why-integration-projects-fail

[18] https://techvera.com/pros-and-cons-of-system-integration-for-smbs/

[19]https://www.konecranes.com/sites/default/files/download/5_step_guide_for_selecting_the_right_cranes_for_steel_warehousing_metric_0.pdf

[20] https://www.electronicsforu.com/electronics-projects/hardware-diy/gsm-gps-based-vehicle-tracking-system

[21] https://how2electronics.com/gps-gsm-based-vehicle-tracking-system-using-arduino/