POLITECNICO DI TORINO

Department of Mechanical and Aerospace Engineering

Master of Science Program

in Automotive Engineering – Management of industrial processes

(LM–33)

Thesis of Master of Science

Monitoring and assessment of the supply chain of a manufacturer of automotive components

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July 2021

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Foreword

The objective of this paper is to give to the audience some indications about the subject of Supply Chain Management (the subject related to the definition of all aspect concerning management of value flows inside and out an industrial company) and its real implication in the industrial tissue of a manufacturing company, spinning off in the production of automotive components.

In detail, the aim of this Thesis of Master of Science is to develop an analysis based on a real working experience, to set the path of comprehension on how the Supply Chain is managed, and how the setting of disturbances along the production process development could possibly affect the whole chain, in positive or negative ways.

In the following chapters, a case study based on a personal experience in a prestigious manufacturer of automotive components is reported, describing the impact on normal production rates of an increase in the production volumes, leading to the formulation of different strategies to overcome it without any suffering hints by the Supply Chain, especially related to the warehousing facilities capability to withstand it, through the proposition of re-designed storage solutions and methods.

The situation analysis will follow a description of the disturbance, the proposed solution, and a correlation to its validity according to performance indicators and numerical values.

1. Introduction about the company

1.1 Continental Brakes Italy

1.1.1 History of the company

Continental Brakes Italy S.p.A is an industrial reality placed in the north-western area of the Italian peninsula. The plant is situated in the Ligurian backcountry, being thirty kilometres apart from the town of Savona. The position of the plant allows it to be in a crucial place, in a land between the Ligurian seaports and the North-west regions of the countries, characterized by a developed industrial tissue.

In fact, the close proximity to the *Ports of Genoa* consortium for overseas goods movement (first in Italy for volume of moved goods, business diversification and value creation, with an average by 70 million tons moved and 2.7 million TEU moved in the last decade, in four different ports) and the Turin area for intermodal transportation and connection to Europe, make it possible for the plant to be in a central node of the so-called commercial triangle of Northern Italy (at whose apex Genoa, Turin and Milan are placed).

The presence of two interstate roads and the E 717 motorway make this place a central hub for the connection of Ligurian ports and motorways from the French Riviera to the Po Valley, allowing an exchange of freights that is vital for European commerce, as well as for the automotive industry.

Continental Brakes Italy is a relevant institution in the economical tissue of the department of Savona since the Eighties, period of establishment of the plant by the name of Automotive Products Italia S.r.l. (brand of the former British company Automotive Products), as a result of transferring of an existing plant (dating back to the Sixties) from the Ligurian Riviera to the background territory of Savona.

The plant occupies a total floorspace of 20,000 m^2, of which 16,600 m^2 dedicated to production, while the remaining area is dedicated to logistic business (**Figure 1.1**).

Figure 1.1 Aerial view of Continental Brakes Italy plant (Source: Google Maps)

The staff is composed by 500 employees: around 350 among them are directly employed in the production workshop.

Starting from the latest Nineties, a new organizational strategy was set up, involving *diversification of customers*. The process naturally implied:

- the ***definition of partnerships*** with important players in the global automotive environment.
- The ***enlargement of the plant portfolio*** with new projects/products.
- ***Increments on human-resources*** employment side.

High quality standards, skilled human resources and continuous economical investments brought a constantly growing amount of business to the plant, making Continental Brakes Italy the first supplier plant of some of the most important global OEM at world-wide level.

Continental Brakes Italy plant is now a member company of **CAS** (***C****ontinental* ***A****utomotive* ***S****ystems*) division of *Continental AG* (German group established in Hannover and global supplier of automotive industries, with plants and design offices spread all over the world) since 2010, after the acquisition of the Italian plant by the German international company and the creation of Continental Brakes Italy: it has been an important event for the plant, making possible to it to enter *de facto* the rank of the world's five largest suppliers of automotive components and manufacturers of spare parts for vehicles.

Continental Brakes Italy is part of the Continental branch involved in the manufacturing of braking systems, **Continental HBS** (the acronym stands for ***H****ydraulic* ***B****rakes* ***S****ystems*), manufacturing drum brakes for different automotive customers, placed around the world.

1.1.2 Quality indicators, vision, and mission of the company

The main target for the company is to lead the market by dealing with two main aspects: design process and insourced manufacturing of the products, thanks to techniques consolidated during the years and procedures of **Total Quality Management**, to keep updated to the latest industrial requirements.

Continental Brakes Italy is totally involved into transmitting the best product possible to customer, increasing its value, and allowing to maintain it during time: to make that possible, the company has acquired certification that proves the compatibility of the production processes with quality achievement, as stated by quality standard, such as:

1. UNI EN ISO 9001:2000: being oriented towards the continuous development of drum brakes and parking brakes is a core value for the company, to satisfy every need of customers, so it naturally adapted to apply internal policies for environmental care and safety, by means of an environmental management system operating through specific procedures prescribed by the authorities.
2. UNI EN ISO 14001:2004: direct involvement in the continuous improvement, lean manufacturing and design of modern machineries are the most aspect on which the plant is more concerned about, especially when dealing with the safety of the workers. Lean Manufacturing department is strongly involved into the pursuit of that target, according to the Machinery Directive 2006/42/CE, as well as supported by the UNI EN ISO 12100:2010

The motto of the company is a clear statement of the Continental vision:

"Your mobility. Your freedom. Our signature."

Smart technologies and continuous improvement for today mobility, freight transport and data analysis mark the vision of Continental AG, a business corporate in charge of supplying in an efficient way goods and services for fulfilment of customers' satisfaction, as well as the one of its stakeholders.

Continental AG has the duty of providing the best solution for every single market, performing operations in the most efficient way, according to continuous improvement. Best quality standard is the core element for turning conceptual ideas in business: these considerations turned Continental AG in a reliable value-adding partner to modern industry.

The mission of the German firm is to lead the market to a sustainable world, being the one who drives the change: knowing the essentiality of mobility in human life, Continental AG wants to act as a pioneer of the automotive industry, by challenging problems related to globalization, demographic changes, and urban mobility. The following program sums it up correctly:

- Safety: zero accidents: To protect life and conserve resources
- Information: saving time, increasing comfort: Intelligent mobility through constantly connected driving
- Environment: clean air: Resource-efficient and emission-free driving
- Affordable mobility: individual mobility for all: Enabling more freedom and opportunities

And that is summed up by Elmar Degenhart, Chairman of the Executive Board of Continental:

"*Continental today helps protect millions of road users around the world,*
against accidents and their consequences.
Continental contributes to cleaner air.
Continental is paving the way for safe, efficient and intelligent mobility." [1]

[1] Elmar Degenhart, *Our Mission: The future starts earlier with Continental*. www.continental.com. [Online].

1.2 The product: the drum brake

1.2.1 Overview of braking systems

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system.[2] It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction.

According to their design, different typologies of sliding friction brakes can be depicted (**Figure 1.2**):

1. **Drum brakes**, distinguished in *clasp brake* (with external braking shoes, commonly adopted on railway systems), *band brake* (ancient kind of brakes, adopted in the early stage of auto-traction – steam locomotors – or on old models of bicycles), *expansion brake* (in which shoes are put in contact with the external plate by a hydraulic cylinder).
2. **Disc brakes**, distinguished in *rotating disc brakes* (many can be listed: single disc, floating calliper, floating disc, hybrid systems, multiple discs) and *fixed disc brakes*.

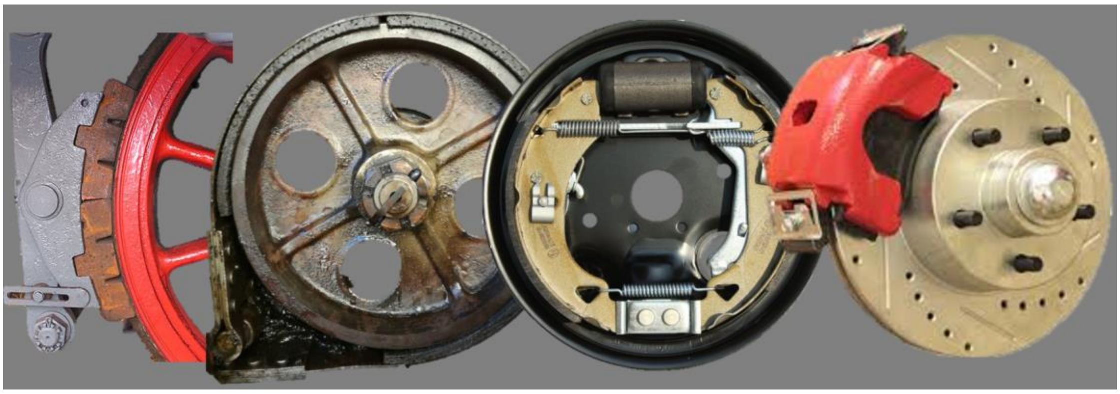

Figure 1.2: Types of brakes: from left, *clamp* brake, *band* brake, *drum* brake, *disc* brake

Drum brakes can be compared to disc brakes in terms of average performances. Main characteristics are efficiency, actuation force, rate of wearing, weight, cost, heat capacity, robustness.

1. **Efficiency**: drum brakes generate *four times higher braking torques* compared to disc brakes with same dimensions; conversely, they are poorly regular in stroke.
2. **Actuation force and working stroke**: in rest position, clearance between brake pad and disc is 0.1-0.3 mm, so disc brakes guarantee lower working stroke of the brake pedal; on the other hand, disc brakes allow to balance actuation forces with low reaction forces.

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[2] V. B. Bhandari, *Design of Machine Elements*, 2010, New Delhi, McGraw-Hill India Private Ltd, p.472

3. **Rate of wearing**: in drum brakes, the contact pressure is not uniform, conversely to disc brakes, that show a more regular wearing. Maintenance of drum brakes is far complex.
4. **Design specifications**: disc brakes are simpler compared to drum brakes: the amount of adopted parts is half the one on the drum brakes. This factor has a deep influence on the weight of the final assembly: disc brakes weigh 20% less than a drum brake. On the other hand, drum brakes have a *higher thermal capacity*: disc brakes reach higher temperature, that is directly disposed in the atmosphere conversely to drums, that tends to accumulate temperature before dissipation, and this is responsible for large temperature oscillations.
5. **Heavy duty working condition**: fastest heat dissipation and null temperature distortion in disc brakes allow them to be indicated in case of repetitive braking cycles.

1.2.2 Description of the drum brake

Drum brake is a mechanism used to modulate the speed of the vehicle moreover, to stop and park it in safety conditions. It is essentially made by two elements: a dynamic part hinged to the wheel and a fixed part, mounted on the vehicle frame, interacting when the sliding friction occurs.

The stopping action is performed exclusively by sliding friction between two surfaces: the friction element (on the fixed part) is pushed against the revolving element of the brake, either disc or drum brake.

As a result, the kinetic energy of the vehicle is dissipated by heat; therefore, it is necessary to design the device efficiently, to avoid overheating or low performance levels.

Last but not the least effect is the generation of a significant braking torque in any driving situation (wet or dry roads), to ensure safety and high performances to the vehicle.

Brakes are defined by five physical parameters:

- **Actuation Force**: a constant maximum force exerted by the driver on the brake actuator.
- **Working stroke**: the linear displacement of the actuator in the range of rest position and the maximum braking position.
- **Actuation Index**: the product of Actuating Force times the Working Stroke, characterizing the performances of brakes and powertrain transmission.
- **Efficiency**: it can be expressed either in the French or the British ways:

$$E_0 = \frac{Braking\ Torque}{Actuating\ Index} \qquad E_0 = \frac{Friction\ Force}{Actuating\ Force}$$

- **Regularity**: world-wide defined as:

$$r = \frac{Effective\ variation\ of\ the\ Braking\ Torque}{Relative\ variation\ of\ the\ Friction\ Coefficient}$$

To design a drum brake, it must be remembered to deal with the following aspects: moderate actuating force, high performance level (smooth enough to not to generate excessive variations of speed and consequent variations in the inertia forces), absence of noxious vibrations, low maintenance levels, easiness in manufacturability, low production costs.

On general, expansion brakes are composed by one or more shoes, which active surface (usually cylindrical) pushes against a drum with equivalent radius of curvature, external to the shoes and integral with the rolling element (that must be braked). Shoes are bound to the back plate of the brake thanks to a hinge or to a tailor-shaped stand (**Figure 1.3**).

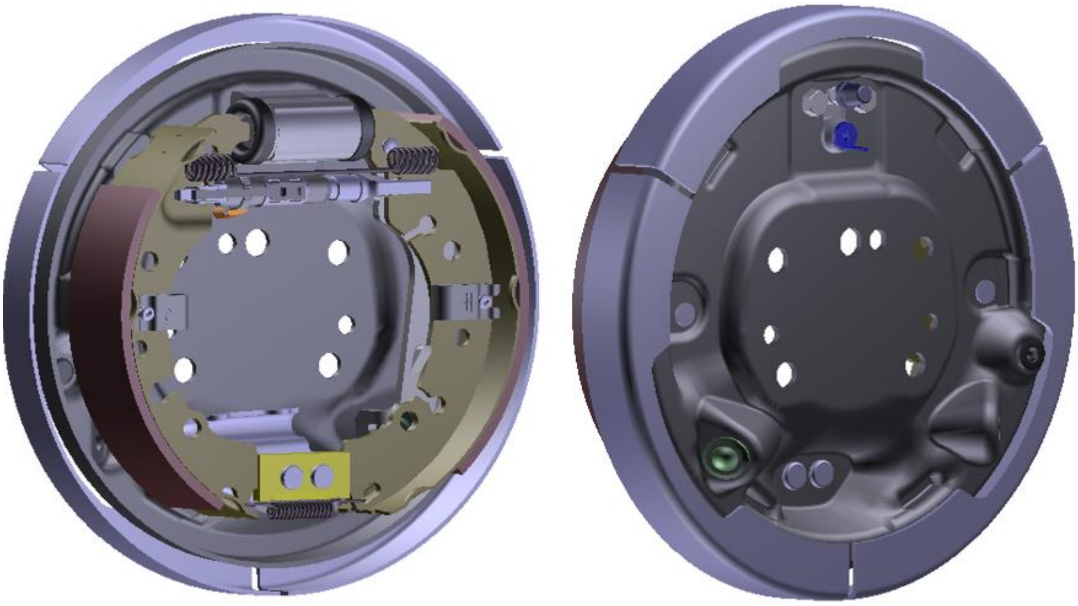

Figure 1.3. Depiction of a drum brake (front and rear view)

In the first case, fixed points shoes are concerned: they have got just one degree of freedom, represented by the free rotation of the element around the constraint.

The second typology concerns floating shoes: they have got two degrees of freedom, so they can turn around without sliding on the surface of the constraint.

The last solution allows to the lining to lean against the drum in a better way, despite natural manufacturing defects on surface.

During rest phases, shoes are detached from the drum by means of several springs; in addition, the lower spring must provide the contact between the shoe and the constraint.

According to the sense of rotation, the force applied to the drum tends to:

- Push the shoe away from its support: in this case it is referred to as compression (or winding) shoe.
- Push to shoe toward the support: tension (or unwinding) shoes.

Clearly, for the same amount of actioning force the maximum torque that the brake can exploit is higher in case of compression of the shoe against the drum.

Shoes can be configurated in many ways (**Figure 1.4**):

- **a compression shoe matched with a tension shoe (*Simplex*)**: most adopted on vehicles, it needs just an actuator due to the proximity of the points on which the braking forces are exerted; moreover, the brake works unconcerned of the sense of rotation of the wheel.
- **Two compression shoes (*Duplex*)**: a higher efficiency can be exploited compared to the Simplex brake, but showing drawbacks: two actuators are needed and turning the sense of rotation the mechanism behaves like a two-tension shoes brake (-30/-40% efficiency)
- **Two tension shoes**: small efficiency can be exploited, so in case of hydraulic actuation it needs two cylinders with larger bore, worsening the applications on vehicles
- **Two compression shoes, one actuated by the reaction of the other (*Duo-Servo Brake*)**: the actuation force acts on a shoe and it is transmitted on the second shoe by a con-rod. The leading shoe pushes against the drum and friction behaves like a self-braking reaction. The con-rod guarantees perfect adherence of the shoes on the drum, and it transfers the braking pressure on the trailing shoe, so that it is now under compression, enhancing braking torque. This kind of braking system is one of the most efficient on the market.

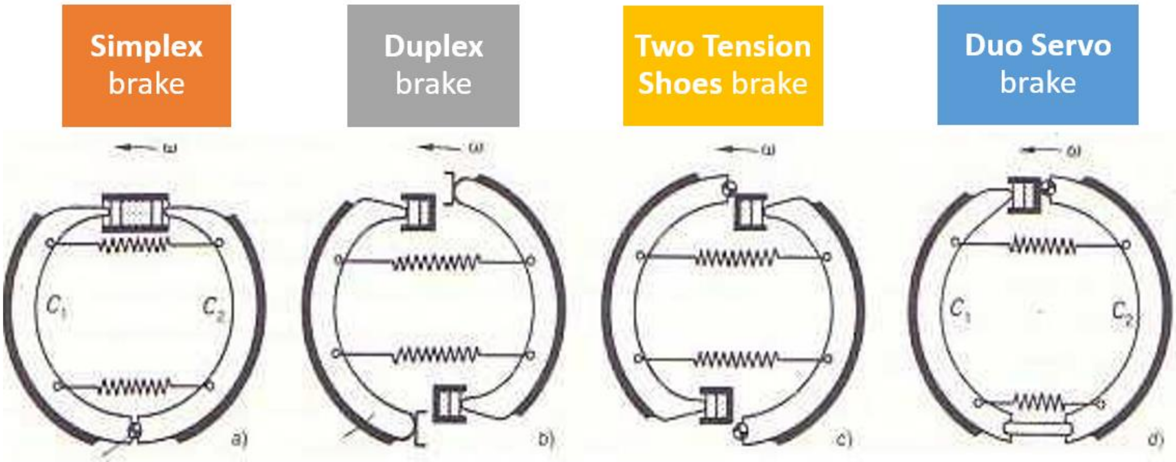

Figure 1.4. Different brakes configuration: *Simplex*, *Duplex*, *Double tension shoes*, *Duo Servo*

The main components of the drum brakes are the plate/drum assembly and the shoes assembled to the friction linings; in addition, elements for actuation and support of the shoes are present (**Figure 1.5**):

1. **Drum**: it is coupled to the wheel hub, and it stays in contact with the friction linings; it is required to generate stable friction coefficients for long period usage, nevertheless a good resistance to wear. Moreover, it must easily dissipate the heat and resist to mechanical stresses and fatigue.

   Those features can be achieved by making the drum by metal alloys capable of high thermal conductivity and capacity (to dissipate heat in a fastest way), high tensile strength, elevated surface hardness and dedicated metallurgic structure. All these factors must also lower the cost of the final product: the optimal choice would be grey cast iron drums.

2. **Shoes**: usually manufactured in steel, they have a t-shaped cross-section and are built by web and table, two stamped metal parts joined together by riveting or welding.
3. **Linings**: linings are made by different chemical compounds, and they must guarantee endurance in time, enough friction between parts, resistance to stresses, low production costs
4. **Actuators**: shoes are actuated by means of *hydraulic wheel cylinders*, through a piston pushing on their extremities. The return to the rest position is possible by springs. The biggest inconvenient of this system is the location of the piston inside the drum, where it is exposed to high temperature (risk is fluid vaporization and fast wearing of gaskets.
6. **Adjusters**: The brake adjuster is a fundamental component for the brake functioning. During brake life cycle, the friction component (the lining) consumes, causing an increase of the stroke of the brake pedal. To avoid this inconvenient, the adjuster is adopted, to keep constant the distance between lining and the internal surface of the drum.
5. **Plate**: fixed to the axle strut, it supports the shoes and the actuating components and with the drum it encloses the whole drum brake system.

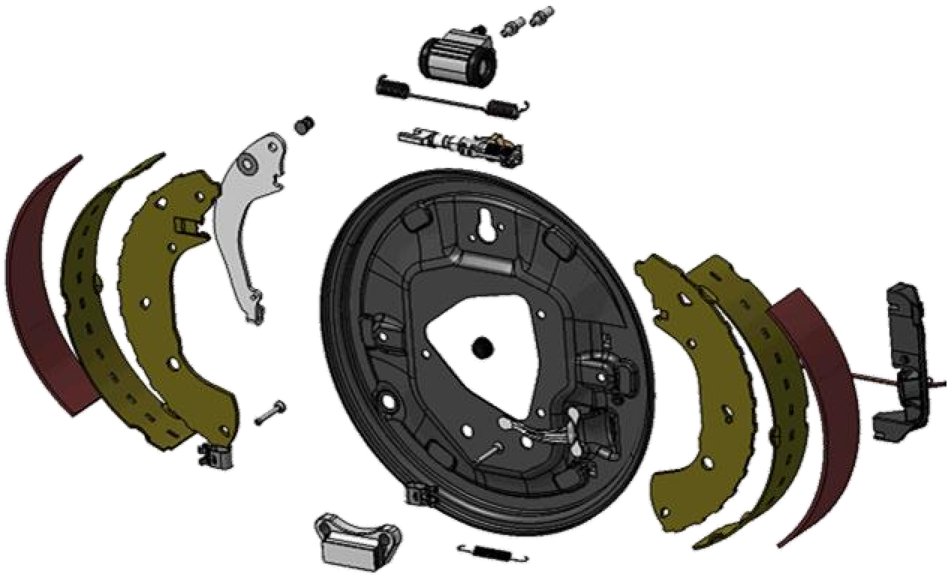

Figure 1.5. Exploded view diagram of the Simplex drum brake,

It is important to remember that drum brakes must accomplish triple functions: *service brake*, *parking brake*, *emergency brake*.

Service brake functions are actuated by the wheel cylinder: pistons act directly on the shoes, enlarging the upper extremity of the shoes, while the lower extremity is constrained by the abutment and the spring that guarantee the contact.

Parking brake function and emergency brake is obtained by a *lever*, riveted to the upper extremity of the trailing shoe, and linked to a metal truss to the hand brake lever inside the passenger compartment. The movement of the leading shoe is obtained by reaction of the drum to the trailing shoe, and it is transmitted to the adjuster.

Production in Continental Brakes Italy is subdivided into six workshops, each one dedicated to different operations, but linked in the provision of subassemblies that will be used to complete the finished product.

1.2.3 Production processes of a drum brake

Manufacturing of a drum brake is performed in different steps, starting from the transformation of raw material (as the aluminium for the wheel cylinder) or components into sub-assemblies up to the intermediate processes on semifinished components and the final assembly. The production process is common to different manufacturers, in the following chapter it will be put the accent on the manufacturing process as it takes place at Continental Brakes Italy, where the main steps concern about the manufacturing of shoes, the creation of the wheel cylinder, the assembly of incremental adjusters, the paintjob on backplates and other stamped parts and the final assembly of the components in the finished product.

1.2.3.1 Shoes assembly

Shoes are the most important component in the brake system: without their presence the action between drum and hub would be impossible, as their existence implies the presence in the brake of many other parts. They could be considered as fulcrum of the drum brakes and around them the brake itself is built.

Shoes are assembled starting from a web and a plate.

These components reach the plant as raw stamped parts, arriving from metal stamping suppliers, delivered by in bulk metal boxes. The first operation to be performed is to wash the protective film oil away, in other to not to compromise the next operations. The web and the table are joined together by means of riveting machines; the plant assembles many typologies of brakes, that differ in terms of dimensions and application: to perform the assembly operation in the most proficient way, only highly specialized manpower is applied. The program followed to assemble shoes is determined on final assemblies' schedule and warehouse stocks. Riveting is the important phase, because a well-performed process guarantees the correct production flow without any later stops (it acts as a bottleneck for production timing) (**Figure 1.6**).

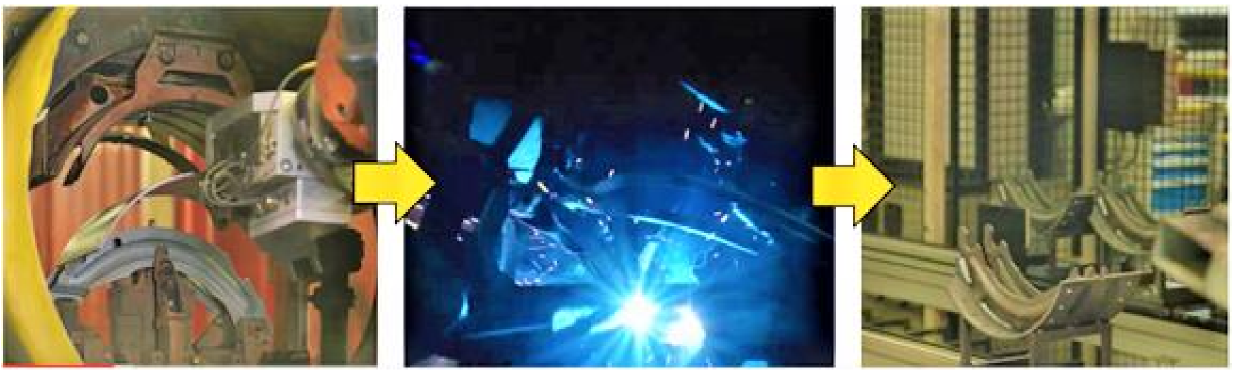

Figure 1.6. Shoe welding procedure: from the left to the right, web and table placement on the clamping jig, welding and finished product (source: BWP Bergische Achsen KG)

After riveting, the assembled shoes wait for the glued lining in buffers, then they are sent for heating in dedicated furnaces.

1.2.3.2 Lining gluing workshop

During this phase, the workers draw linings from a batch of raw products, containing around hundred thousand ceramic linings.

After having been rubbed on with glue on the internal side (**Figure 1.7**), spread linings are placed in a furnace that heat them up to the desired temperature, allowing the glue to stick to the lining and at the same time to bind to the shoe.

Glazed linings are placed in batches, ready for the final assembly with the shoe.

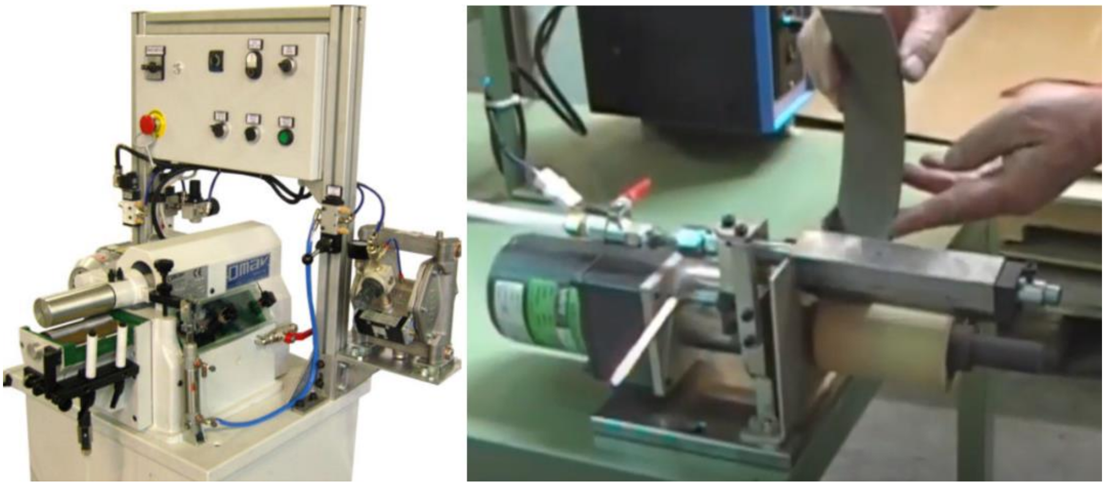

Figure 1.7. On the left: lining bonding machine; on the right: how glue is applied (source: Omav S.r.l. and Chemex Industrial Co. Ltd.)

1.2.3.3 Wheel cylinder workshop

The shop is organized in two different sectors: one for the machining of cylinder bodies and pistons, the second for assembly of wheel cylinders.

The workshop receives at inbound batches of **extruded aluminium bars**: cylindrical bars for pistons and complex cross-section bars for the cylinder body. The bars are stored in the extruded bars warehouse close to the machining sector.

Multi-spindle machining mills, called **transfers** (**Figure 1.8**),Figure 1.8. Transfer machine for manufacturing of machined components (source: Sistech Srl) and lathes use one batch of bars at a time to produce respectively one batch of pistons/bodies. The machined parts leave the transfers to be stocked in containers, waiting for the dimensional quality controls by the operators.

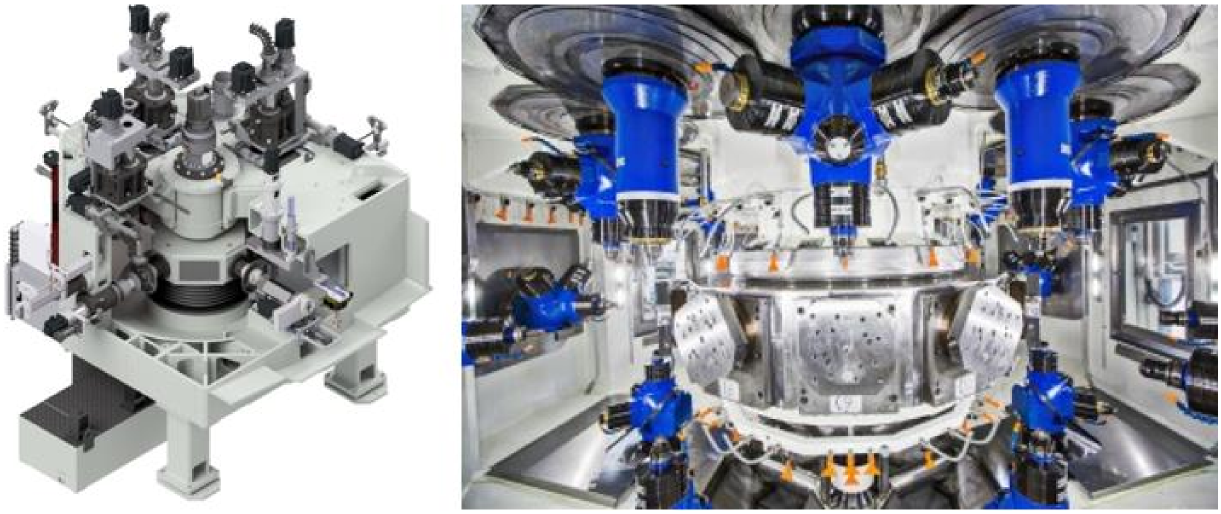

Figure 1.8. Transfer machine for manufacturing of machined components (source: Sistech Srl)

Later, the components are shipped to a third-part supplier, that applies an anodization treatment: after the treatment has been applied, the parts come back to the plant, where they are sent to the assembly workshop. Once the cylinders have been assembled, they are stocked in the warehouses, ready to be installed on the final assembly.

Again, the type of cylinder to be produced is chosen according to the scheduled production and to the stock volumes.

1.2.3.4 Adjuster workshop

The shoe adjuster workshop works independently from the rest of the plant: production takes place according to a kan-ban working method for production. Once a batch of adjusters has been produced, it is stored to satisfy the plant needs, influencing the final assembly lines production as well, because depending on the number of adjusters present in the plant warehouses.

Such method is explained by the high standardization that affects these components, so that they do not differ too much amongst automotive manufacturers, reducing the variety of product portfolio to be produced in the Ligurian facility.

Figure 1.9. Example of incremental adjuster manual lines (source: HLBS Co. Ltd.)

The shop has a personal warehouse for the output, that is arranged in boxes stacked on pallets (as in **Figure 1.9**); in addition, the shop contains on a supermarket warehouse for the parts directly applied on the assembly lines, separated from the central warehouse and able to guarantee a fast supply of manufacturing components.

1.2.3.5 Backplate painting workshop

Backplates are manufactured from third-part companies, that supply Continental Brakes Italy according to subcontracting formula (Continental Brakes Italy accounts for steel coils and supply them to the part supplier directly from foundries by just-in-time methods).

Backplates are delivered to Continental Brakes Italy in large metal bins; they are delivered without any protective coatings, apart from a thin oil film to prevent rusting: so, the first step is to apply a paint coat on the parts: the efficiency and the quality of this process is of great importance for the final output, guaranteeing long-lasting life to the product and resistance to corrosion.

Figure 1.10. Painting line (source: Moldow A/S)

Painting is performed through tubs, where the backplate travels on hangers while drowned in a paint moist (**Figure 1.10**): the process takes place for ninety minutes, then they are buffered until they are drawn for replenishing assembly lines.

1.2.3.6 Final output assembly line

The assembly line (**Figure 1.11**) for the final output is the last section of the productive process, nevertheless the part in which the real commercial output is created, delivering an asset to the customer.

Figure 1.11. Continental Brakes Italy assembly lines (source: Savonauno.it)

Continental Brakes Italy plant organizes the final assembly according to four specific sections:

a. **Assembly of backplate and auxiliaries**: one of the two line-branches leading to the final output, it consists of nine steps to obtain a finished product.

   It starts by feeding the line with the hand brake cable strain relief plate and the abutment, through vibrational feeders, that automatically provide the components. Then it follows the instalment of the wheel cylinder: it is manually inserted by the operator on a specific jig pallet, where next other components are going to be placed. The wheel cylinder is than screwed in position, and different fixation pins are placed, proceeding than with application of grease in strategic points of the backplate, to be filled in the next assembly segments.

b. **Baking and grinding of the shoes**: linings and shoes are bonded together by catalyst mechanisms activated by specific furnaces, where the two components are baked. The process is possible by several steps: the parts are automatically loaded by robots onto the furnace replenishment system (conveyor), checking by cameras if the shoes correspond to the scheduled production program. Then, the parts are heated and pressed one each other, checking the perfect definition of the bond. After a standard cooling period in buffers, the parts are withdrawn by production operators.

c. **Assembly of the hand brake lever**: it is one of main sublines of the assembly, and it concerns six operations to have a finished output.

   The shoes hailing from the furnace are picked up by a robot, to be visually controlled: in case of positive result, they are placed on an assembly jig. Then the levers join the pallet jig for assembly: they are checked for quality and then pinned by a riveting machine. Then the lever free rotation is tested by a robot equipped with a torsionmeter. In case of positive result, they are picked up again and placed on a pallet.

   The last step concerns the placement of the subassembly on manual assembly tables, to install springs, the incremental adjuster, to perform the rectification of the diameter of shoes, leaving the line as a “top kit”.

d. **Final assembly of the complete brake system**: it is the last step of the assembly process, and it manages all the flows of product, coming from internal production or from suppliers, to have the final output. Based on a semiautomatic line, manpower is accountant for feeding the line by correctly loading the parts, while the assembly is performed by automated machineries. The assembly is based in several stations: first, the backplate is placed automatically by a fast gantry robot, that pick it up to move it on the final testing area. Then the shoes are placed on automated station from the parking lever assembly, to be mounted on the plate. where the shoes subassembly is picked from the parking brake line and placed on the plate. The tolerances are checked, and subassembly liquidated to next step, where retaining clips are mounted by automatic machines, with the purpose to centre the shoe and maintain it in position. After a small testing cycle on the drum, the diameter of the brake is calibrated, and then final quality inspection is performed through a camera that inspects tolerances and aesthetical damages to the product. After that, the next move will be packaging he product, directed to the final customer.

2. Introduction to the supply chain in automotive industry

2.1 Definition of a supply chain

Nowadays, the trend of globalization sprung during the Eighties has led to an exponential increase in the complexity of the mechanism that rules the delivery of goods and services between industrial and consumer worlds, all together with the increase in the amount of information that correlates such an exchange.

Differently from the early decades of the Twentieth Century, nowadays production is based on many aspects concerning the development and the distribution of a valuable goods, pivoting between suppliers of raw material and the final customer, who is willing to pay for the value delivered by the good.

The term ***supply chain*** identifies the set of activities required by industrial organizations to produce and deliver goods or service to internal or final customers, from the very beginning stage of sourcing raw material up to the delivery of the product to the market.

Supply chain is not just related to merely logistic aspects, but it is involved also in the management of information correlated to the value attribution at each production stage and of the resources adopted in the production process, such as manpower, equipment, production facilities, raw material, etc.

The supply chain makes tangible the response to the market stimuli after the creation of the demand. It encompasses different activities to achieve the task: *planning*, *purchasing*, *manufacturing*, *procurement*, *freighting* and *warehousing*. [3]

The supply chain is defined by four stages, that are well depicted by the Porter's Value Chain model, developed by Michael Porter in 1985 (**Figure 2.1**): [4]

- *Logistics*
- *Operations*
- *Marketing and Sales*
- *Services*

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[3] Timothy McLean, *On Time, In Full: Achieving Perfect Delivery with Lean Thinking in Purchasing, Supply Chain, and Production Planning*, 2017, Boca Raton, Taylor and Francis.

[4] Michael E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance*, 1985, New York, Simon & Schuster.

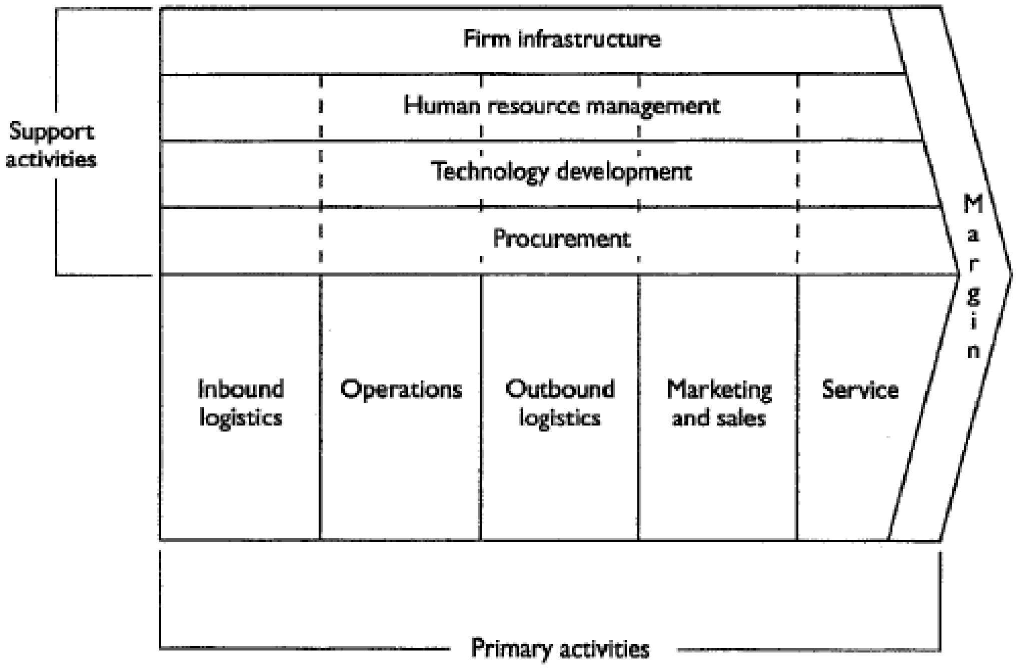

Figure 2.1. The value Chain based on Porter's model (source: Cheltenham Tutorial College)

The model, designed after a compendium dating back to 1980, is the depiction of the organizational structure of a company, based on a group of limited processes. [5]

The concept described by Porter can be summed up as:

> *[…] The idea of the value chain is based in the process view of the organizations, the idea of seeing a manufacturing organization as a system, made up of subsystems each with inputs, transformation processes and outputs involve the acquisition and consumption of resources […]. How value chain activities are carried out determines costs and affects profits […]* [6]

Porter then expanded this concept of a value chain into a value system. This consists of a series of linked value chains. By this joining together of value chains into a value system, in effect we create a supply chain. Where the value is, according to Porter, is dependent on the way a customer uses the product and not just totally on the costs incurred in buying, making, and moving it. These costs, including all the raw materials and activities that create the product, then represent its value. But it is only when the product is purchased that this value

[5] Michael E. Porter, *How competitive forces shape strategy*, 1979, Boston, Harvard Business Review.

[6] Vv. Aa., *Decision support tools: Porter's Value Chain*, October 29th, 2013, Cambridge, University of Cambridge: Institute for Manufacturing.

can be measured; and, finally, it is not until the product reaches the final customer/consumer that the real value is to be found.[7]

Defined as primary activities, the four stages are the base for the physical creation and follow-up of a product/service, linking the activities in the production plant and binding all together the whole value network outside the firm itself, in the vision of the *extended enterprise*.[8]

That's why it is a core aspect for a company to map the supply chain out of its organization: multiple benefits can be highlighted when the company's strategic plan is rolled out, especially because it is possible to set a clear path for the initiative: by understanding which are the purposes of the company as well as the long-term targets, by better focusing on what can be obtained in terms of profit by operating by certain methods, looking for the position of the organization in the market.

As it has been already stated, every kind of activity concurring at delivering a product to the customers is part of the supply chain: the main starting point for the company who runs those operations is to transform raw material (or semifinished assemblies) in finished products.

During these activities, it is possible to identify two distinguished flows: *information flow* and *material flow*, connected by the *financial flow* (**Figure 2.2**).

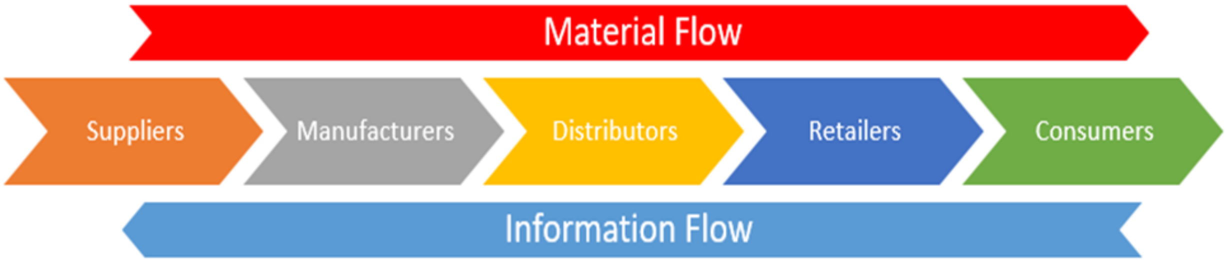

Figure 2.2. Flows along the Supply Chain

2.1.1 Material flow

The ***material flow*** is a stream composed of raw material, semifinished components and final assembled components, linking company's cluster of suppliers to the final customer (or customers), moving downstream along the product completion: after the order is placed by the customers, raw materials are ordered to the suppliers by means of procurement systems (usually based on an ERP – Enterprise Resource Planning – structures) and then, once

[7] Stuart Emmett, *Excellence in Warehouse Management: How to Minimise Costs and Maximise Value*, 2005, Chichester, John Wiley&Sons Ltd.

[8] Jeanne W. Ross, *Enterprise architecture as strategy: creating a foundation for business execution*, 2006, Boston, Harvard Business School Press.

delivered to the facility, the material is stored in different warehouses, and moving from storage to storage according to the completion state of the final product.

The task of supply chain logistics experts is to play any mean possible to ensure that the flow moves seamlessly, avoiding sudden stops to the production process, usually because of missing components or delays in deliveries; in order to do it, it is possible to operate according to different techniques, such as *RFID tagging on loading units* (to know real time position of the material), *consignment stock* (material is delivered in advance to the production facility and then stored until the retrieval by the warehouse operators, until then its costs will impact on the supplier's inventory, even if not physically present in its warehouses), *just in time methods* (through digital means and satellite tracking of freights, it is possible to ensure the arrival of the raw material at the plant, just when they are needed and furthermore reducing impact on inventory costs of the warehouses) .

To demonstrate a real example, here it is how the material flow is managed in real companies, as well as Continental Brakes Italy.

Modern companies deal not only with a single supplier, but many: according to the complexity of the product, the number of suppliers can vary between tens to hundreds, national or international based, each one supplying to the plant dozens of part numbers on a daily basis. The material stream results to be pretty complex, and its management can be faced by splitting the different part in subgroups, gathered according to common aspects.

The first aspect to be considered is the ***typology of material***: due to its heterogeneous nature, material can be grouped by similarity, creating families of products, and skimming the complexity of warehouse management; this approach is valid either for raw material or finished goods.

The second aspects are for sure the ***typology of transport means*** and the ***distance of customers/suppliers from the plant***: an important aspect to state the logistic costs due to transportation, a factor impacting on the final price of the product and on environmental footprint of the production process as well, so that the trend is to shorten the link whenever possible and to deal with intermodal transportation.

The third aspect is represented by ***InCoTerms***: also known as a compendium of the assignment of responsibility to supplier or customer, it is the contraction for International Commercial Terms, a set of trade agreements defined by the International Chamber of Commerce (ICC) in 1923.[9] Their adoption is largely encouraged by trade organizations during procurement and exchange of goods between different countries: the obligation, cost and risk of an exchange of goods between two parties are implicitly contained in the *three-letters code* associated to a specific transaction. Their main purpose has been overcoming eventual uncertainties deriving from misleading interpretations of local trade regulations. (**Figure 2.3**)

[9] Vv. Aa., *The World Trade Press Illustrated Guide to InCoTerms© 2010*, 2013, Traverse City, World Trade Press

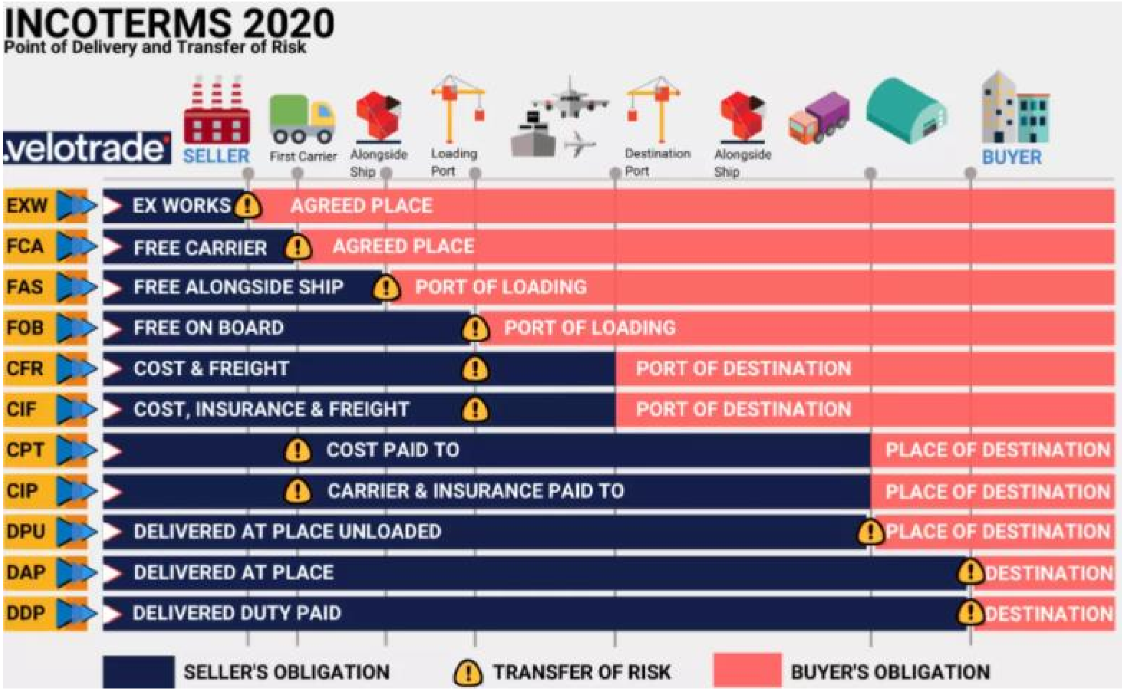

Figure 2.3. Table of InCoTerms© (source: velotrade.com)

InCoTerms are updated every 10 years, in order to face the new challenges placed by the market dynamics; two main categories based on the method of delivery are considered (delivery is meant to be point when the risk of loss or damage passes from seller to buyer).

The fourth aspect is ***transportation of goods***, that deals with several aspects: *requirements of the goods*, *level of the service*, *transport methodology*.

By physical requirements of the goods are meant aspect related on how the goods can be carried around; usually it is referred to density (occupied volume with respect to the weight of the loading unit, a load is referred to as bulk if density overcomes 300 kg/m^3), perishability (goods that need to maintain unaltered their qualities by changing the environmental conditions, especially important for frozen foods or dangerous substances), hazard (ADR regulated freights: gasoline, gases, chemicals).

The level of the service embeds all the characteristics related to how the transportation is performed: urgency of the delivery, frequency, reliability of the carrier, time for delivering, tracking systems of freights.

Transport methodology is the field concerning how the goods are carried to the plant. The main player in this category is road transport, by which goods are delivered from the supplier plant to the manufacturing facility by specialist carriers, companies with experience in moving freights. Starting from the Sixties, goods started to move on the fresh new road network, that in Italy has started to be built since the economic growth of the country, at the end of WW2. Road network started competing with railroads, until setting their predominance during the Seventies; nowadays 90% of industrial transportation is performed by trucks, that share the scene with intermodal ways of carrying freights.

Deliveries are performed by **Full Truck Load** (FLT) and **Less-than Truck Load** (LTL): the main difference between the two is the number of picking point visited by the vector (**Figure 2.4**).

Figure 2.4. Explicative picture of the difference among LTL and FTL (source: Riteway Transport)

FTL is performed when there is only one pick up point, so that a full truck is loaded and shipped to a single delivery point; conversely, LTL is adopted by couriering companies to perform a *milk run* between suppliers to fulfil the vehicle at its top, then the goods are distributed to many delivery points.

The usual means of transport are *commercial vehicles* and, according to the characteristics of the load and the EU transport regulations, companies can choose among a vast range of vehicles ().

When small loads and many delivery points are concerned, ***light-duty vehicles*** are the suitable option: they are car-sized, and the maximum allowed gross weight is lower than 3.5 tons. According to this feature no particular driving license is required for conduction. This class includes *ultra-light trucks*, *van-rigged cars*, *minivans*, *va*ns, *minitrucks*.

Medium-duty vehicles show improved dimensions with respect to small vans: this feature allows to carry a larger quantity of goods, with a weight limit between 3.5 and 15 tons.

The top category in transportation is the one of ***heavy-duty vehicles***: this class includes vehicles with GWT of 16 tons (rigid truck) and 44 tons (articulated truck and trailer, according to Italian legislation, 40 tons abroad): over that limit, the freight is overload.

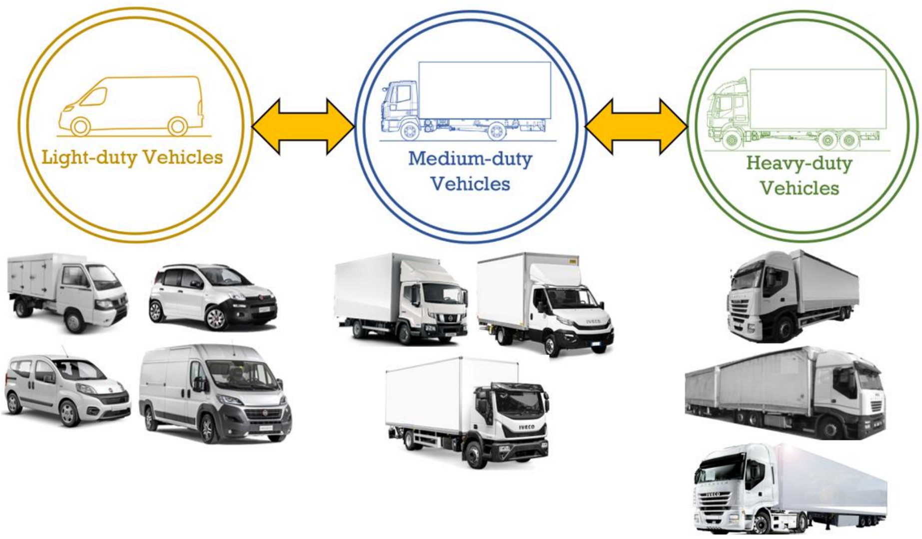

Figure 2.5. Examples of commercial vehicles (source: CNH Industrial, Piaggio S.p.A., Nissan NV)

The last relevant aspect in material flow definition is the ***loading unit packaging***: how components are delivered to the manufacturing plant. The type of loading unit is defined in advance between the logistics experts and the customer/supplier plant ones, as part of the stipulated commercial contracts.

Three types of loading units are usually considered (**Figure 2.6**):

Figure 2.6. Different typologies of containers

- *Carton boxes on pallet* made by cardboard and wood, they are expendable and not to be sent back to the supplier.
- *Returnable standard plastic container*: they are standard-dimension plastic boxes put on plastic pallet, that reached the status of standard method for carrying material in the automotive industry (since the Eighties); more expensive than expendable packaging, but highly re-usable, so that their high initial investment is reduced by high utilization.
- *Returnable metal container*: used to haul bulky and massive components, they are very common in the automotive industry. They can be *rigid* or *foldable*, according to the utilization: rigid for heavy-duty tasks; foldable to save space during transportation while empty.

2.1.2 Information flow

Conversely to the material stream, the ***information flow*** moves upstream, starting from the customer sending the production commission up to the suppliers.

The process begins with the order creation by the customer, that is later transmitted to the endorsed manufacturer. After a processing phase, a new order is emitted, directed from the production plant up to the supplier, on which are reported the required quantity of material to be embedded in the assembly of the final product.

Information is not transmitted by fax or mail-attached PDF anymore: since the factory digitization of the last two decades, everything is managed through ERP systems, a digital way to manage all information related to production, as well as bookkeeping all financial flows related to production, for enhanced transparency in operations.

Information flow between customer and plant: orders are emitted on the daily basis by the customers on predefined portals, by means of *call-offs*. The planning of the orders is based on strategic planning, a tool used to foresee the production over a five-year time span, based on past production volumes, consumption forecast from customers and market trend. This is a crucial phase, in which the synergic work between Sales and Marketing is important to understand the market stimuli.

Data are the bricks on which the company can build its own strategy, especially when thinking about the replenishment of the raw material warehouse, with raw material amount scaled to the quantity of finite products ordered by the customer, and scheduling of the production program of assembly lines.

Nevertheless, it is also important to evaluate the way orders comes to the plant: the mode, considering that orders can be provided in many ways, but the most suitable one is the application of EDI/WebEDI protocols for the exchange digital data, by means of ERP platforms; the frequency of orders, considering that the orders can be submitted within different time horizon: daily, weekly, etc.; according to the product characteristics (volume of sales, phase of the product, etc.) it is possible to have different order submission.

The information flow between customer and plant corresponds to the operative planning phase of Production planning: it is performed on a weekly basis, according to a process starting from the customer order and ending with the production schedules (**Figure 2.7**).

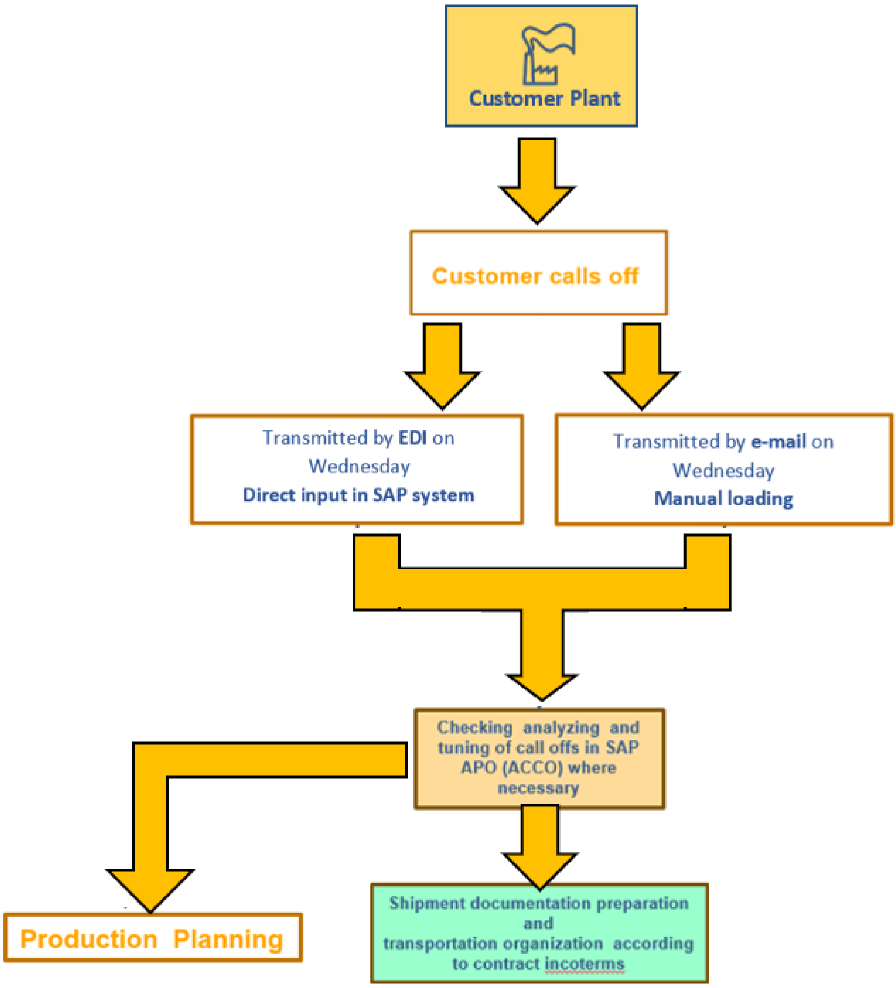

Figure 2.7 Chart of the reception of customer calls off

Each customer has an established day for the order invoice, consisting of the volumes for the current week and a forecast on the following weeks, that week by week will be updated; usually the day for order invoicing is around the middle of the week: on that day, orders are directly updated on the systems, through EDI.

SCM Customer Logistics managers analyse the orders, identifying any possible variations in volumes. Once they have been authorized, orders are updated on the ERP system, by special transactions allowing to visualize the order characteristics and to perform changes by hand.

Data coming from orders are necessary to draw the basic necessities of production: by crossing those elements, a table reporting the orders by the customers, correlated by the part number information, in a defined time schedule.

These elements are than useful in the production planning because of the necessity of them for drafting the Allocation, a file useful to balance the workload among the assembly lines according to the customer's request, obtaining as an output the work shift schedule.

After that customers' orders are processed, it is possible to submit orders to the supplier.

On supplier side, Material Planning managers are in charge of deciding the quantity of raw material to be ordered to supplier, having been provided data about customer demand and production capacity by the Production Planning team.

Once the Production planning team has received the customer call offs, it manages them according to production needs on a specific ERP program used for production scheduling, that is based on analysis of the MRP (Material Requirement Planning) to turn the demand in feasible production (**Figure 2.8**).

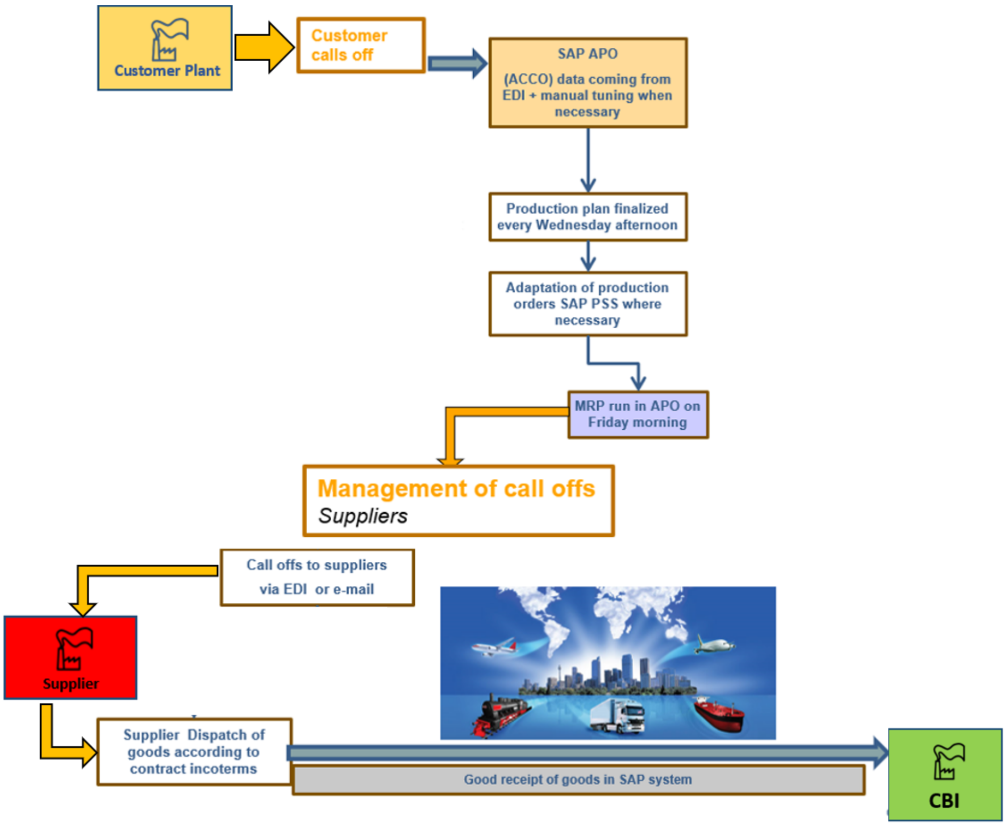

Figure 2.8. Chart of information flow plant-supplier

Every week on Friday the MRP is run, in order to provide to Material Planning the data about replenishment; then a request is submitted to suppliers by means of e-mails or EDI.

On the other hand, there is back flow from the supplier to the plant: when the product is ready and then shipped on the hauler, the supplier sends a ASN transmission to make aware that the shipment has be submitted and the load is on the road, allowing the plant to compute timing for the reception of the parts and track down with the freighter the position of the goods on tour. ASN can be send through EDI or e-mail/PDF.

After that the product has been manufacturer and ready to be shipped, the customer is provided of a ASN transmission, to be aware that the shipment has been submitted and the load is on the road to him (**Figure 2.9**), allowing the customer to compute timing for the reception of the parts and track down with the freighter the position of the goods on tour.

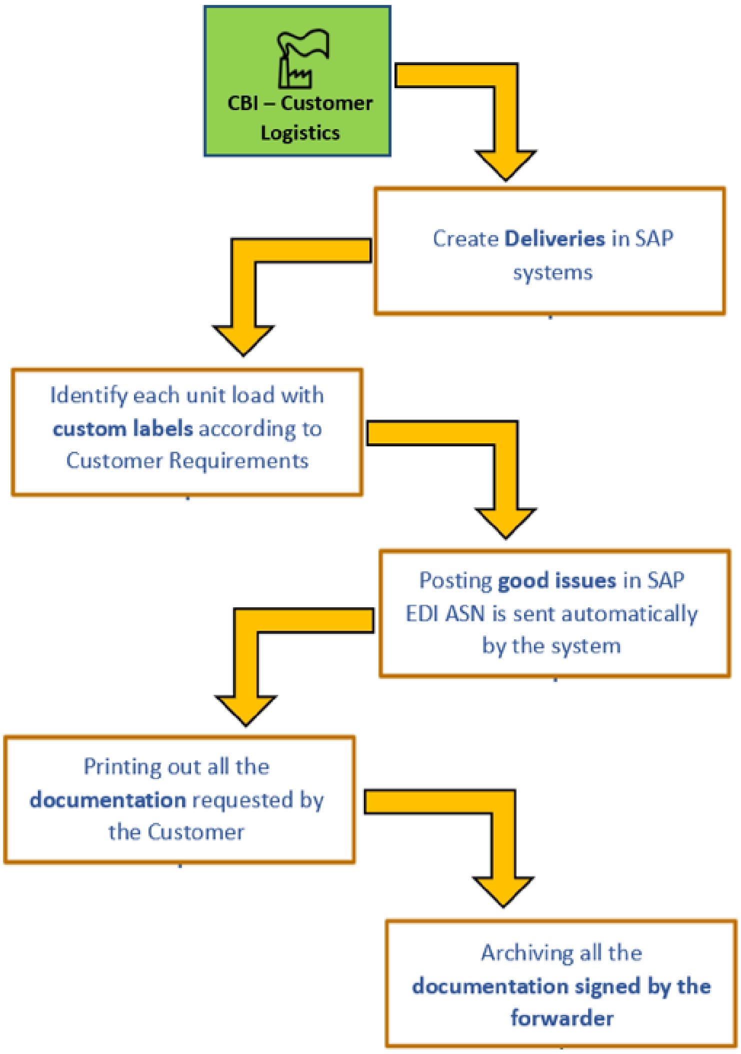

Figure 2.9. Communication chart plant-customer

2.1.3 Financial flow

At last, the ***financial flow***: to resume, it is considered as the guidance flow, just because cashflow plays an important role in making possible the operations between supplier, manufacturer, and customer, as well as becoming a physical entity for displacement of value from one side to another of the production game.

It must be considered from two different perspectives: the first one is related to cost and investment, while the second to flow of capital. Cost and investment add on as moving forward along the supply chain, pointless to remark how optimization of supply chain costs gives a direct contribution to the overall profitability of operations.

On the other side, funds (meant as *revenues*) flow from the final customer, going back through the other links of the chain

2.2 The Supply Chain Management

By the term *supply chain management*, it is meant the core of modern logistics, expanding its core importance to the whole industry.

Supply chain management consists in the improvement of basic logistics, by the integration of several activities that back in time were assumed to be stand-alone actors in the logistic network stretching from supplier to customer.

In a not-so-far past time, the different activities performed in production plants were meant to be separated one each other: each department was struggling in a competition for the pursuit of its own targets and benefits, without sharing efforts and strategies with the others, because it was a common belief that the pursuit of whole company success depended on the maximum efficiency of each clank of the industrial mechanism, but without keeping an eye on the "*neighbour's yard*": because of that, the logistic departments used to have hard times at keeping the same pace of the other departments, first because, differently from production department, logistics does not add direct value to the final product (generating only indirect costs), and second because performance indicators and efficiency targets were different from the ones involved in production tasks.

The introduction of supply chain management was the definition of a common target, linking all the departments in just a single entity, capable of reaching the highest success with the minimum effort in terms of costs and time.

The first definition of supply chain management dates back to 1982, from an article written by Arnold Krasdorff with the assistance by Keith Oliver, consultants of logistics and fathers of the modern concept of supply chain management.

In the essay, Oliver described supply chain management as:

"[…] [Supply chain management] is the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption. […]"[10]

Then, based on Krasdorff and Oliver definition, the council of logistics management introduced other definition to enrich that statement, so nowadays literature report many descriptions of what in practice is assumed to be the supply chain management.[11]

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[10] Arnold Krasdorff, Keith Oliver, *Booz Allen's rather grandly titled Supply Chain Management concept*, Financial Times. June 4th, 1982.

[11] For completeness of knowledge, here are presented some journals relative to supply chain management:

John T. Mentzer, Soonhong Min & Robert T. Ladd, *A market orientation in supply chain management*, in *Journal of the Academy of Marketing Science nr. 35*, March 24th, 2007, Berlin – New York, Springer.

Supply chain management is the central link between different organization in the company, involving many players in its deployment; a cluster of activities related to management and strategic thinking of all aspects concerning the flows of raw materials and information up to the delivery of a final product and after-sales services.

To better understand the importance of supply chain management in modern industry, it must be considered that nowadays these aspects represent about half of the annual incomes.[12] For a company, its correct management represents a valuable asset, allowing improvements of the processes and economical savings along the whole chain.

Supply chain management deals with 4 macro-processes[13]:

- **Material stock**: it plans the storage and transfer of material, defining the level of stock for each of the different nodes composing the production process and the timing/method for transferring material between two consecutive nodes. The main elements to be considered to improve stock management are:
    - planning of the replenishment of the warehouse: transfer of material from the suppliers (internal or external) according to the demand of raw material inside different nodes. The planning starts downstream the demand forecast and focus on the reduction of stock between nodes.
    - Demand forecast: recognition of the material requirements for the different nodes, depending on the customer's demand according to the forecast on future demand of raw material. It is important the way in which customer orders are processed.
    - Planning of the raw material quantity: the definition of material flow parameters such as the level of stock, reorder point and the economic order quantity to establish the efficiency of planning. It is a periodic activity to define the needed parameters for planning the replenishment and the demand forecast.

  Two basic elements are the stock and the order: stock is measured according to temporal dimension, to storage location and part number; the order is evaluated according to storage capacity, to requirement and to part number.

James R. Stock, Stefanie L. Boyer, *Developing a consensus definition of supply chain management: a qualitative study*, in *International Journal of Physical Distribution and Logistics Management*, September 4th, 2009, Bingley, Emerald Publishing Limited.

Dag Näslund, Hana Hulthen, *Supply chain management integration: a critical analysis*, in *Benchmarking: an International Journal*, July 6th, 2012, Bingley, Emerald Publishing Limited.

Robert M. Monczka, Robert B. Handfield, Larry C. Giunipero, James L. Patterson, *Purchasing and Supply Chain Management*, Sixth Edition, 2016, Boston, Cengage Learning.

[12] Mark Johnson, Simon Templar, *The relationship between Supply Chain and firm performance: the development and testing of a unified proxy*, in *International Journal of Physical Distribution and Logistics Management nr. 41*, March 15th, 2011, Bingley, Emerald Publishing Limited.

[13] Mark Johnson, Graham C. Stevens, *Integrating the Supply Chain...25 years on*, in *International Journal of Physical Distribution and Logistics Management nr. 46*, February 2016, Bingley, Emerald Publishing Limited.

- **Inventory**: it deals with the management of the stock between nodes; the warehouse management deals with:
    - Inbound reception: this process operates by identifying the inbound material and assigning it to a specific place in the logistic flow. Reception deals with the unloading of the loading units of raw material, identification of the material according to what declared on the delivery note, storage in a waiting area, loading of the inbound material in the ERP system, check of material quantity/quality and break-bulking, with consequent storage location. An improvement could be given by reducing the waiting time by speeding up this process (scanner, mat-label, etc.).
    - Storage of raw material and finished goods: material is stored in different storage systems, according to its nature and future employment.
    - Pick up of raw material and semi-finished products: material is picked up to be transferred in the next logistic node; the improvement of this phase would reduce mistakes during identification and sorting steps.
    - Shipping of finished goods: material is prepared to be transferred to be sent to the customer; there is the need to define loading units, the documentation (kan-ban card for internal logistics or delivery note for external shipping) and place the material in the shipping area waiting for being sent to the customer (or to the next production node).
    - Inventory of the stored material: here the accountable and the physical stocks are aligned to be compared and to detect imbalances. It can be a continuous (like the inventory-in-rotation) or seasonal (like the yearly inventory) process. The activity should reduce at the maximum extent the time necessary for its completion, avoiding the introduction of fresh errors in the accountable stock.
- **Transports**: this section deals with the management of the transfer of material between the different nodes of the supply network, making a first distinction between the internal nodes of the company (e.g., transports between different plants), then distinguishing between the internal nodes of a company plant (e.g., transport between production shops or between warehouse and shops) and at last considering transport between the company facility to the customer.
- **Information flows**: by creating a network of value and data, it binds together the nodes, and in the meanwhile coordinating the various activities carried out in the processes.

During the latest decades, supply chain management evolved according to the megatrends involved in industrial transformation, such as globalization and digitization of processes. The evolution stages of supply chain management can be summed up by six phases: [14]

- the *creation era*: dating back to the eighties with the coining by Oliver, the supply chain in that era was just a theoretical concept of something that was scarcely applied in industry since the advent of logistics in the early years of twentieth century; the core

[14] Robert B. Handfield, Ernest L. Nichols, *Introduction to Supply Chain Management*, 1999, New York, Prentice Hall.

element of the first era of supply chain management was the need for large-scale changes, re-engineering, downsizing driven by cost reduction programs, keeping an eye on Japanese new techniques for lean manufacturing (Toyota).

- The *integration* era: devoted to the study about interaction between physical industry and the development of Electronic Data Interchange (EDI) from Sixties, further enhanced by the introduction of Enterprise Resource Planning (ERP) during the Nineties; further expansion during the new millennium with the adoption of Internet based platforms. Furthermore, it is possible to consider three stages:
  - stage 1: each sector of the manufacturing company is independent one from the other.
  - stage 2: presence of a common plan and usage of ERP systems.
  - stage 3: vertical integration between customers and suppliers.
- The *globalization* era: devoted to study the global systems of supplier relationships and the expansion of supply chains beyond national boundaries and into other continents. Globalization in supply chain became preponderant in companies just starting from the eighties, in order to scale down costs and to integrate with supplier performing the activity in a leaner way.
- The *mark I specialization* era: there was outsourcing in manufacturing and distribution, die to specialization of companies in their core competencies, outsourcing auxiliary activities to other companies (creation of a network of values). There was the creation of manufacturing and distribution networks composed of several individual supply chains specific to producers, suppliers, and customers, working together to deliver a finished product.
- The *mark II specialization* era: at this time supply chain management has become a service with the inception of transportation brokerages, warehouse management (storage and inventory), and non-asset-based carriers, going beyond traditional concepts of transportation and logistics (supply planning, collaboration, execution, and performance management). The high variability in demand by the market has pushed toward the definition of such asset: supply chain specialization enables companies to improve their overall competencies, focusing on core competencies and assembling networks of best-in-class partners to contribute to the overall value chain itself: better performances and efficiency.
- The *supply chain management 2.0* era: based on the current concept of globalization and specialization and strongly linked to the new economy based on digital information and web resources (as highlighted by the name itself).

Since its introduction in the industrial environment, supply chain management took a playmaker role in the modern production process, on which companies have been fitted. In general, three aspects have been highlighted (**Figure 2.10**): [15]

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[15] For better comprehension, consult:
Donald Bowersox, David Closs, Bixby M. Cooper, *Supply Chain Logistics Management*, 2007, New York, McGraw Hill.

- *Enhanced speed of the company on the market*: new millennium market has reached a top level of concurrence between market players, due to the new challenges proposed by the jig economy (large scale adoption of internet in commerce, faster ways to communicate worldwide, click-to-buy policies, etc.) And globalization, that reduced distances between countries and their internal markets, allowing a company to have suppliers and customers placed in different continents.
- *Reduction of stock levels*: the reduction of the inventory level by the introduction of the concept of just-in-time (JIT) by the Japanese manufacturer Toyota in the Eighties and other similar methodologies of reduction of the material in the production facility; the material is provided at the right time of the assembly, reducing the level of inventory (that impacts on final costs of the product) and the physical dimensions of the warehouses.
- *Improved flexibility*: aligned with the philosophy of guaranteeing the highest service level to the customer, it considers fast delivery of the final product and high reactivity to sudden changes to the customer's order.
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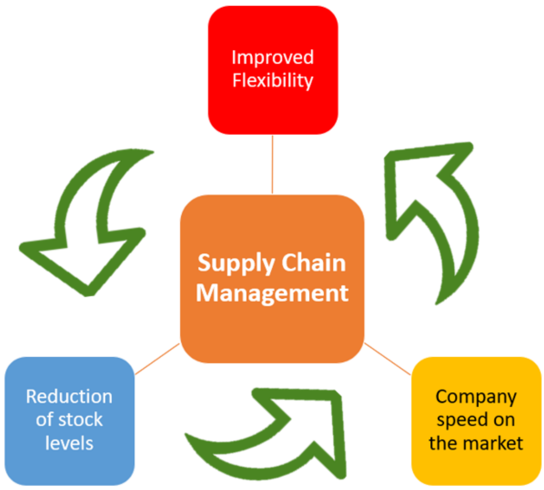

Figure 2.10. The chain of root values of supply chain management

In conclusion, it is remarkable to highlight how the supply chain management has been founded on a series of activities that used to be part of the logistic management in the first years of Twentieth Century industrialization: their cooperation leads to the elimination of the uncertainty, that risks propagating along the whole manufacturing network. [16]

To sum up, the supply chain management is a vital process among the operations carried out in modern industry. When planning a supply chain management system for the company, it

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John T. Mentzer, William DeWitt, *et al.*, *Defining Supply Chain Management*, in *Journal of Business Logistics nr. 22*, May 10th, 2011, Hoboken, John Wiley & Sons.

[16] Tom Davis, *Effective Supply Chain Management*, in *Sloan Management Review vol. 34*, 1993, Cambridge, MIT Sloan School of Management

should be kept in mind that it will be a gathering of powerful tools that are used for management of logistics as well.

The first element to be concerned about is the *management of production activities* and of the distribution network: in other words, the control over the physical and information flows connecting either suppliers or customers to the production facility.

The second point is to accurately *plan the demand forecast*, by setting good inventory management and provide just-in-time replenishment of the warehouses: the supply chain manager should set a strategy in advance, merging the customer demand to a forecast based on the observation of market trends, to punctually perform the replenishment of the raw materials and avoid the *stock-out* in case of excessive demand or the *overstock* in case of stagnating markets.

The third aspect is to manage properly the *material handling*: all the aspects concerning in-bounding (raw material entering the plant) and out-bounding (finish products leaving the plant) of loading units, management of the warehouses, warehouse layout, material handling equipment and resources.

The fourth aspect is *order processing*, the way the order coming from the customer is turned from the software level to the workshop floor, triggering the order from the plant to the customer. Dealing with the right tools is fundamental and nowadays, on the edge of Industry 4.0, to be ready to react to faster responses due to Internet-based systems for data collection and hyper-connectivity of industrial sites.

The last aspect is *transport management*: it is managed according to the InCoTerms statement, defining the responsibility of the company over the transportation of the good to the final customer facility, the kind of packaging, ensuring the highest service level and reducing risks in this crucial step of the logistic chain.

To have a better insight on how supply chain management works in the everyday industrial environment, here a brief description on how it is structured in the Continental Brake Italy plant.

In the plant taken as an example, the supply chain management department acts as a clank, connecting the environment external to the plant (represented by customers and supplier) and the internal one (production department and related auxiliary services).

Supply chain management is one of the eight departments composing the operational unit of Continental Brakes Italy (**Figure 2.11**):

1. **Factory Production Direction**: represented by the plant operational manager, it has many responsibilities, among them those about factory production plans and improvement projects.
2. **Quality Department**: responsible for the management of quality level in supplies and final products, checking for reliability of the product to the standards imposed by the customers and finding solutions to issues for non-quality.
3. **Manufacturing Department**: the team is responsible for the management of assembly lines and outputs.
4. **Engineering Department**: the people involved in that department are the link between the German designer (who turn the customers' needs into a feasible project) and the manufacturing technicians, interfacing manufacturing methods to the part to be produced.

5. **Human Resources Department**: management of direct and indirect manpower hired at the plant.
6. **Purchasing Department**: responsible of economical transaction between customer-plant and supplier-plant.
7. **Administration Department**.
8. **Supply Chain Management Department**.
9. **CBS – Lean Manufacturing**: improvement of production standards and control over line efficiency

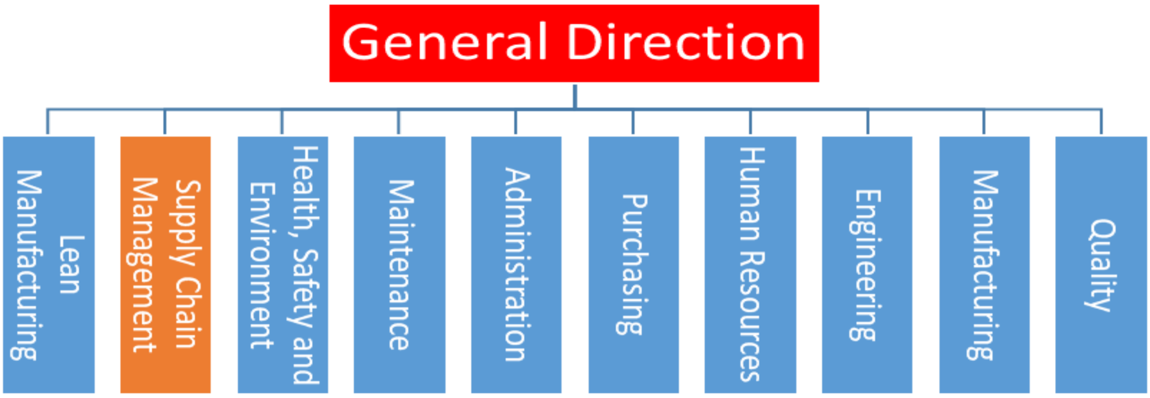

Figure 2.11. Continental Brakes Italy organizational chart

At the plant, the supply chain management department is structured according to four specific areas, dealing with all different aspects concerning the management of information and material flows (**Figure 2.12**):

1. **Production Planning**: responsible for the definition of the automatic assembly line schedule, according to the demand acquired from the customer orders.
2. **Customer Logistics Management**: relating with the customers and collecting the orders on that side; management of OEM customers and Aftersales customers, together with freighter and logistic partners for transport solution at outbound
3. **Material Planning**: forward of order to suppliers by customer demand arrival, in accord also to production scheduling; parallel to that the management of the warehouse and the inventory, to establish stock parameters and KPIs
4. **Plant Material Flow**: warehouse managers in charge of recording inbound/outbound products and physically applying what is done by ERP system at office level. Forklift operators handle material at inbound and at outbound.

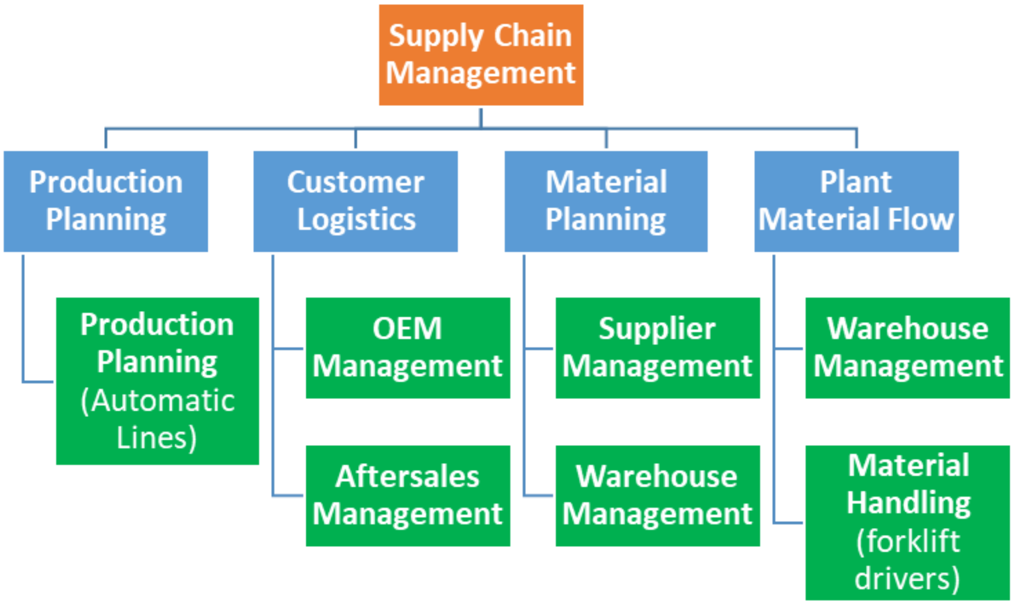

Figure 2.12. Structural chart of Supply Chain Department

Each of these branches has its own area responsible, and the four area managers are coordinated by the supply chain manager, that has to accomplish several tasks during the working routine: office task coordination, problem solving, brainstorming with customers and suppliers about criticalities, etc. The plant supply chain manager is subdued to the control of two parties: the local Plant Manager and the Global Supply Chain Manager, based in Continental headquarter in Frankfurt, Germany.

The logistic process starts with the reception of orders from the customer side, then they are processed by the Production Planning area, completing the process with the emission of orders to the suppliers. Cooperation between the different phases allow a clockwork management of the internal processes and the scoring of target KPIs, obtaining high service level scores to the customers and adequate safety stocks, to respond quickly to swifts in customer demands, supplier capacity or plant productivity.

2.3 Warehousing and material handling: theory, tools, and methods

As a fundamental aspect of the supply chain, warehousing is actively involved in the acquisition of company goals related to increased service level and seamless operations.

In demand-driven supply chains, warehousing could be erroneously considered as a mere exercise of keeping-storing goods: that is wrong, just because warehousing is more than that, involving other sorting activities and management tasks, both being required to largely feed external customers. Conversely, in the supply-driven supply chains warehouses get renamed as *storages*, and they are purposely designed to hold stocks for replenishment internal activities, such as production.

Warehouses are therefore an integral part of the supply/demand chain/pipeline infrastructure.

To link to the previous chapters, the term 'supply chain' is the process that integrates, coordinates, and controls the movement of goods and materials from a supplier to a customer to the final consumer. [17] The essential point with a supply chain is that it links all the activities between suppliers and customers to the consumer in a timely manner. Supply chains therefore involve the activities of buying/sourcing, making, moving, and selling.

Therefore, the supply chain 'takes care of business' following from the initial customer/consumer demand. Nothing happens with supply until there is an order; it is the order that drives the whole process. Leading to the fact to turn the supply chain into a *demand chain*.

Modern industry requires to base the organization dimensions based on the definition of the customer demand: it comes naturally to link every aspect of the future plant life to the demand in terms of products, because production and supplies are dimensioned according to it.

The customer demand is based on two different aspects:

- *Market stimuli* influencing the customer's demand: the orders sent to the plant are based on the market behaviour, so the production is susceptible on global economic variations, that usually varies according to raw material prices or geopolitical situations, that can have reflection on stock exchanges. Usually, orders are based on annual forecast made by Marketing department (that makes survey on the customer needs) and then organized in a production plan according to the Master Production Schedule (MPS). The consequence of MPS is the creation of the MRP to establish the amount of raw material to be ordered to the suppliers to start the production.
- *Seasonality* of the customer's demand: in this case, the demand of finished goods is independent on market trends, but usually it is led by periodical demand pattern, that can be predictable and re-occurring during time. This type of demand makes forecast arrangements hard for businesses, that risk to fail into stock-outs during peak demand seasons or program very huge stocks of goods in the wrong period.

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[17] Stuart Emmett, *Excellence in Warehouse Management: How to Minimise Costs and Maximise Value*, 2005, Chichester, John Wiley&Sons Ltd.

According to the two aspects, it is possible to understand the needs in terms of warehouse availability, floor space and number of bins.

Another important fact in the definition of the warehousing facility is to choose properly its *location*: for business that is involved in manufacturing, raw materials warehouses should be placed close to the production sites, and the stores location is therefore determined by the location variables of the production sites, unless they are managed according to just-in-time techniques, that allows to reduce the inventory at its minimum extent to reduce costs, just having the component on the line at the right moment (when it is needed).

Another important aspect is the definition of the type of agreement between the supplier and the plant about the type of supply: purchasing of parts, consignment stock, subcontracting, material provided to vendor. According to it, dimensioning the warehousing facilities can be eased, considering the amount of goods they are going to store: the main purpose of this kind of analysis is to reduce the warehouse space, as well as the inventory, to reduce the fixed costs related to them and to improve the JIT methodology, that allows to save capitals and space in the plant.

For years, warehouse management has been thought to be just a day-to-day operational task: nothing but false. Warehousing plays an important role in the strategic planning of the business, especially when dealing with production forecast, product deployment, management of suppliers and customer forecasts, volumes, and throughput.[18]

Warehousing includes a series of activities that culminate with the primary purpose of storing goods (finished products or raw materials), waiting for shipment to customer or to be assembled on a final product (in case of raw materials).[19]

Storing products safely and in an organized way, allowing to track the item position along the value chain, is the core aspect of the warehousing activity (**Figure 2.13**); the team in charge of the warehouse management must deal mainly with:

- the quantity of material to be stored: how much it will impact the warehouse in terms of saturation
- The typology of loading unit: the efficient consolidation of goods into manageable units.
- The days on hand: the time span that the product will spend in the warehouse.[20]

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[18] Stuart Emmett, *Excellence in Warehouse Management: How to Minimise Costs and Maximise Value*, 2005, Chichester, John Wiley&Sons Ltd.

[19] Kenneth B. Ackerman *et al*., *Practical handbook of warehousing*, 1997, Berlin – New York, Springer.

[20] Tony Arnold, Stephen N. Chapman, *Introduction to material management*, 1998, Upper Saddle River, Prentice-Hall.

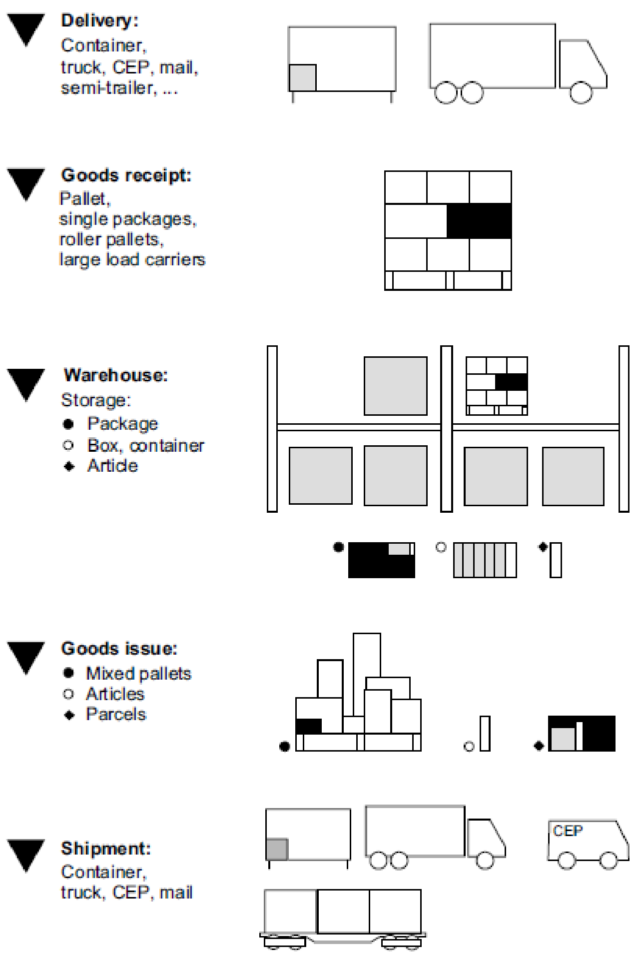

Figure 2.13. Deployment of the logistic chain (source: Hompel & Schmidt)

An interesting aspect in the demand analysis to get to the dimensioning of the warehousing facility is the adoption of the ABC analysis to analyse the products in terms of fast/slow movers by. This involves the classic Pareto analysis, theorized in 1906 by the Italian economist Wilfried Pareto, who reckoned that 80% of the wealth lay in the hands of 20% of the population. An alternative name for this type of analysis is the 80/20 rule, where a high incidence in one set of variables equates to a smaller incidence in a corresponding set of variables.

After computation, it clearly results that high percentage of volume movement is found from a small number of lines (the A items above, the fast movers), and the converse, that the slow movers (the C items above), will account for a high number of lines for a low percentage of volume movement. Thus, to summarize: A items (fast movers) = high volume, few lines; B items = medium volume, medium lines; C items (slow movers) = low volume, many lines. (**Figure 2.14**)

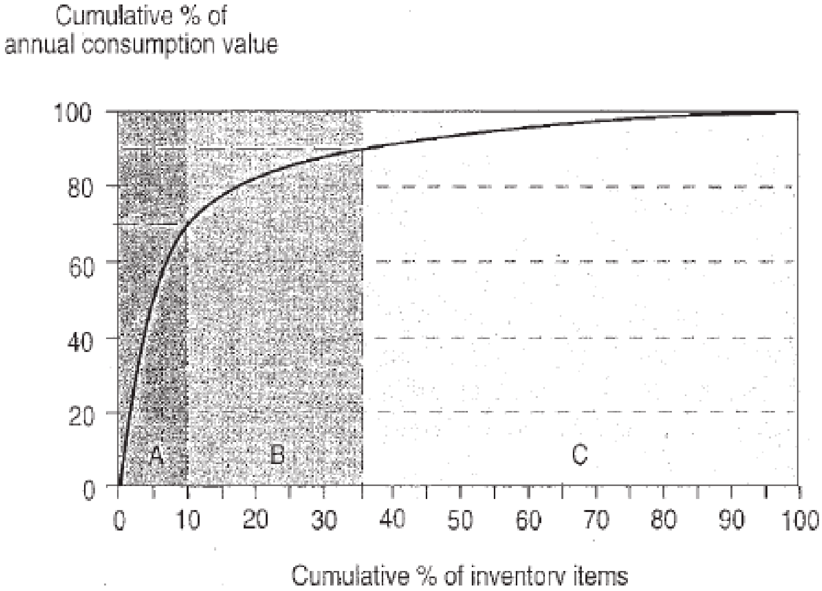

Figure 2.14. ABC analysis on value

The base concept of warehousing has not changed since the birth of the logistics theory, though the system solutions evolved during the last years.

The best way to design a warehouse facility is to work according to classes of features, that are common to different layouts or type of operations. The main ones are:

- Typologies of product to be stored.
- Type of building: outdoor compounds, sheds, logistic centres.
- Material flows: according to storage of raw materials, semifinished or finished products.
- Geographical location.
- Automation degree: it is possible to distinguish between traditional warehouses (manual operations) and automated warehouses (AGVs and automated management systems). [21]

An important aspect is to consider the warehouse as a dynamic system, differently from the past situation: the warehouse is not relegated to the storage itself, but it embeds also other complex operations, such as:

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[21] For designing the warehouse:

Peter Baker, Marco Canessa, *Warehouse design: A structured approach*, in *European Journal of Operational Research*, November 17th, 2007, Bedford, Cranfield School of Management.

Peter Baker, *The Principles of Warehouse Design*, 2010, Corby Northants, The Chartered Institute of Logistics and Transports.

- *Inbound operations*: goods receipt (checking and registering) activities on raw material, usually by WMS (Warehouse Management Systems) tools.
- *Internal transportation*: by means of forklift trucks, water-spider trains or AGVs.
- *Break-bulking and bin sorting activities*.
- *Uploading of warehouse status information* on ERP (Enterprise Resource Planning) systems.

All these aspects are part of the Warehouse Management System (**Figure 2.15**).

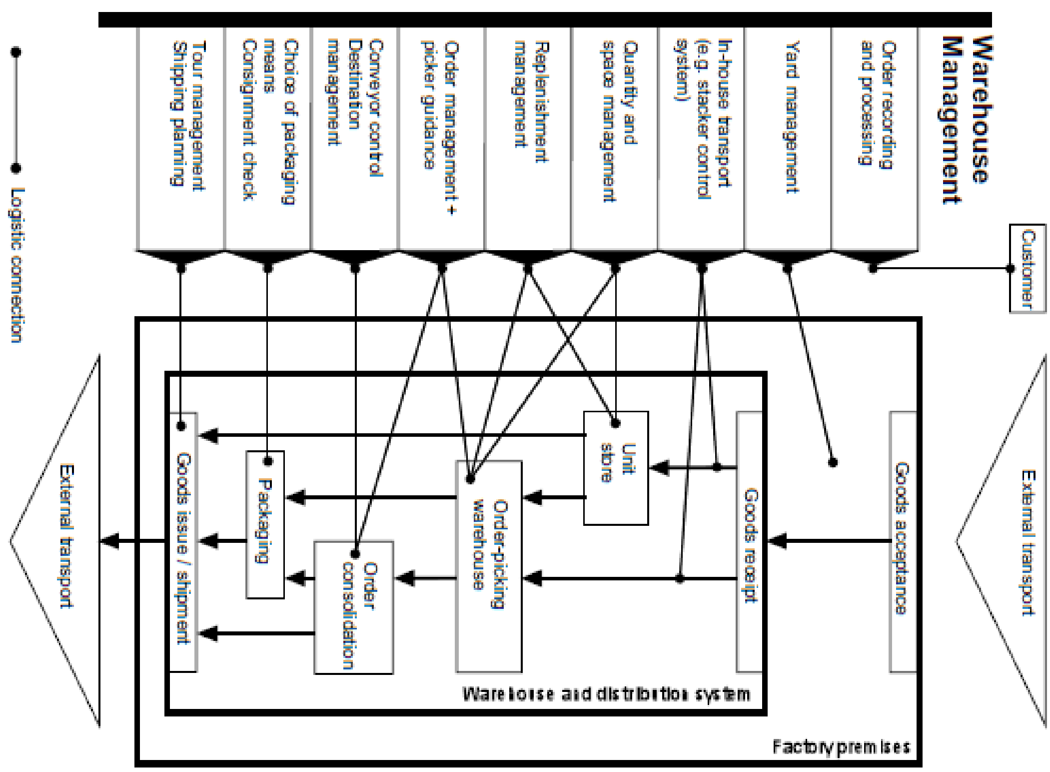

Figure 2.15. Basic elements of the warehouse management system and their role related to warehouse operations (source: Hompel & Schmidt)

Warehouses are based on three functional areas: *receiving areas* (docks and inbound where goods receipt is performed), *storage areas* (for storage of raw material, semifinished and finished goods), *shipping areas* (devoted to picking and packaging operations, close to the shipping docks, where goods leave the plant).

Many aspects concerning the information to run the warehouse: product related (Material characteristics, typologies of loading units, ABC classification, quantities, queue processing technique (FIFO-LIFO), frequency of material handling); logistic related (order fulfilment); Inventory level related (turnover, utilization, selectivity, etc.); system management (IT systems, automation degree, etc.).

But which are the design criteria adopted in warehouse design? Mainly four:

- *Capacity*: max utilization of floor/cubic space
- *Selectivity*: access to everything and good location system

- *Safekeep stored material*:
- *Design for efficiency*: minimize the average travelled distance, effectiveness of MHE, organization modes/IT systems efficiency.

Material to be stored can be of two kinds: *unit* and *bulk*. Unit is made of separate and discrete items, varying in size (from small components, such as nuts to whole vehicle bodies) and easily distinguished in entities. Instead, bulk material is stored in volume, often unpackaged (dry powders, granules, etc.), and managed by continuous-flow operations based on aggregation of material. Unit material is managed by forklift trucks and storage racks; conversely to that, bulk material is handled throughout bins, silos, conveyors, feeders.[22]

Incoming goods are consolidated into volume and quantity-optimized loading units with the aim to minimize shipping and transport costs. Here, the goods have to be refilled in company-specific containers and consumption units to fit the material flow system. The same applies to units on standard pallets (e.g., europallets or industrial pallets). Often, the quality of the delivered units is questionable with regard to the downstream automatic systems like a high-bay warehouse. Damaged pallets, for example, may exceed the tolerances and thus get stuck at certain sections of the conveyor belt. For this reason, such units often are restored on tailor-made storage units (undamaged high-quality standardized pallets) even if this means a worse utilization of the storage space. This method allows for the permanent tagging of pallets for a better control. If highly dynamic automatic storage technologies are used incoming loading units may have to be secured additionally. If the volume of the goods to be stored is much smaller than the available minimum storage volume (e.g., the shelf of a rack) usually mixed pallets are built to improve the utilization of storage space. This is of special importance for the controlling warehouse management system. The additional storage of articles with widely differing characteristics which call for the precise management of article dimensions and available storage capacities is not the only problem. When goods are retrieved it has to be taken care that only a certain article is taken from a mixed pallet. It has to be avoided that the number of partially loaded pallets becomes too large. This may require a volume control and restorage, repackaging or densification.

The next element to be considered are storage equipment systems.

Corresponding to the variety of problems and tasks concerning the storage and transport of piece goods, there is a similar multitude of systems for their effective solution.

The correct evaluation and choice of warehouse systems calls for a systematic and general knowledge of the system performance; warehouse systems are classified into statical and dynamical systems depending on whether they require a relocation during the storage process. The restorage in a classical rack system is not considered as a dynamical storage.

The primary parameters for the choice of a storage system are the number of different articles to be stored, the article dimensions and weights, the quantity of each article, the required

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[22] Raymond A. Kulwiec, *Basic Material Handling Concepts*, in *Material Handling Handbook*, edited by Raymond A. Kulwiec, 1985, New York, John Wiley & Sons, p. 6

storage/retrieval performance or throughput, the space requirement, the retrieval behaviour, and strategies.

The most commonly used systems are classified with regard to their applications and requirements on the system control. They can further be systematized according to the storage function, the type of construction and the used conveyors.

Material storage equipment can be of two kinds:

- *Person-to-item* system: stationary racks and picking operated by the warehouse users.
- *Item-to-person* system: items are picked by turret picker or automated means and then placed at the end of the aisle, where are collected and moved away from the storage area.

Storage methods are usually based on placing a loading unit in a specific bin, a numbered space lot placed on a racking structure. Nowadays, it exists many kinds of these structures, the most common ones include *ground storage*, *traditional racks* (stacking frames), *cantilever racks*, *drive-in/drive-through racks*, *moveable shelves*, *flow racks* (gravity or live).[23]

In ground storage, the goods are stored or stacked directly on the floor (). The stacking height depends on the characteristics of the goods or on the used loading aids, the handling facilities (e.g., stacker or crane) and on the construction layout.

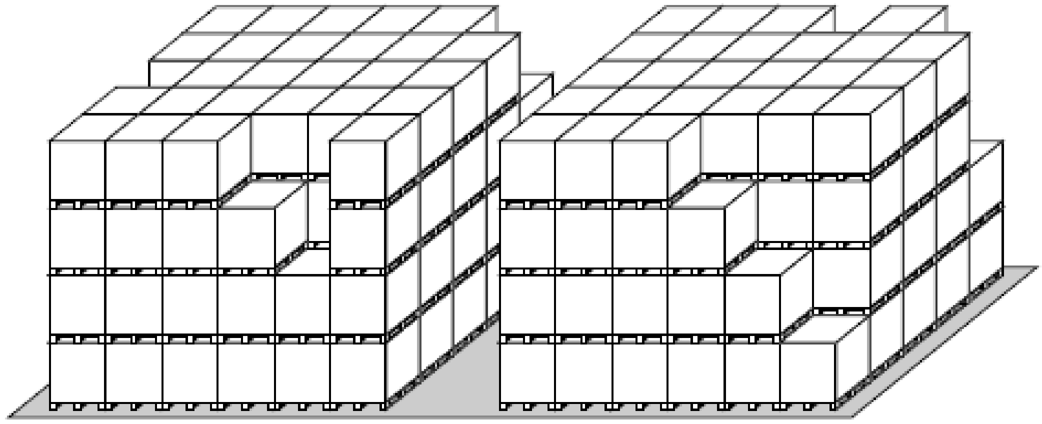

Figure 2.16. Grounded storage systems (source: Hompel & Schmidt)

This is the simplest way for storage, due to the fact it requires only requires only little investment costs and it can be adapted flexibly to the constructional conditions (layout and form of the building) of the plant. When the aisles are wide enough, relatively high transhipment performance can be achieved with a corresponding number of transporters. This type of warehouse is operated mainly manually, by means of conventional forklifts. Goods can be arranged according to ground block storage or line storage: in the first case, the goods

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[23] Herbert H. Klein, et al., *Basic Storage Equipment and Methods*, in *Material Handling Handbook*, edited by Raymond A. Kulwiec, 1985, New York, John Wiley & Sons, p. 533-588

are arranged in a compact block, optimizing at the maximum extent the volume occupation of the storage place, but in this way, it is possible to access only the first row of the block, so that it is necessary to work according to a LIFO strategy (Last In – First Out); it is a good option when dealing with construction. Line storage allows to access to products by aisles in the middle.

The disadvantage of this simple system is the difficult control of the material flow. Since only ground space is recorded as the storage location and the storage and retrieval is controlled manually and according to the article type, it is not possible to record a single unit load. The same applies to the direct assignment of a storage location to an operator (stacker driver) since precise reference points such as the shelf numbers on a rack are missing. There is no exact bin management, quantities are managed by recording the incoming and outgoing units.

This situation possibly leads to problems with the tracking and tracing of batches. If such a tracking is required single batches can be stored in separate fields. In more advanced systems the exact position is recorded during the storage and retrieval process by GPS (global positioning system) or based on the AGV (automated guided vehicle) technology to ensure the tracking of the material flow.

Traditional racks are mostly used to optimally utilize the space and height of a warehouse. The unit loads are placed on a separate shelf or a specified bin in a rack. This allows for the efficient storage also of not stackable goods. The rack height is mainly determined by the used operating facilities: accordingly, the rack heights range from 2 m (manual operation) to about 50 m (for rack feeders).

Figure 2.17. Conventional rack systems (source: Noega Systems)

In addition to the problems of the physical storage, questions arise with regard to the choice of a racking system. A great advantage of this system is the possibility to clearly assign unit loads to storage locations and the almost complete implementation of necessary strategies. This sets the basis for the automation of storage processes and ensures that the storage area is ordered and well-organized during the daily operation.

Conversely to goods stored in blocks, line racks can be accessed from many sides, losing the advantage of a more compact storage and a high utilization of space in line with a high throughput.

Most racking systems, however, are suitable only for single-type goods and standardized loading aids. If only complete unit loads are stored and retrieved, they are also called *unit warehouses*.[24]

Pallet racks are the most common type of pallet storage systems and are designed for use of a standardized loading aid. In the classical case the stored unit load (pallet or skeleton box) is supported only at both front ends, whereas the unit load is stored lengthwise or crosswise.

In case of a lengthwise storage two traverses are fixed (screwed, fitted, or welded) between the front and rear rack supports where the unit loads are stored side by side. Due to their construction, standard pallets (800mm×1200mm, 1000mm×1200mm) have to be stored lengthwise referred to the shelf depth. Because several unit loads may be stored side by side this principle is considered a multi-bin storage system. Generally, three up to maximum five loading units can be stored side by side in a so-called *field*.

For a crosswise storage, an angular support is mounted between a front and rear support and the unit load is stored frontal to the support and thus crosswise. There is only one unit load between the rack supports so that this system is a single bin storage system.

The lengthwise storage allows for a more efficient utilization of storage space since the racks require less supports and security distances. Most rack feeders are not so small as to allow for narrower aisles. In manual order picking operations, however, the crosswise storage ensures a better accessibility of the shelved articles.

On cantilever racks, the goods are placed on cantilever arms which are mounted at vertical or inclined rack props. The cantilever arms can also be used to separate standing goods. Similar to pallet racks continuous shelves can be built for goods with different dimensions by inserting additional shelf plates.

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[24] Michael ten Hompel, Thorsten Schmidt, *Warehouse Management: Automation and Organization of Warehouse and Order Picking Systems*, 2007, Berlin, Springer, p. 94

Figure 2.18. Cantilever racks (source: Schaefer)

The cantilever system is ideal for the storage of long goods (pipes or rods) or boards. Usually, these racks have a high loading capacity and can thus be used for universal storage purposes. Because of the flexible use of shelves, however, the stored goods have to be managed very carefully since the unit loads may be stored at any location. In line racks each article can be accessed directly.

The racks are served with different systems. In addition to the manual operation in case of light loads above all stackers and cranes are used. In some cases, the cantilever arms or shelves may also be mobile to allow for a vertical access (from above).

Drive-in and drive-through racks, as part of selective racking systems, they represent the simplest kind of a statical block storage system. The rack supports form vertical aisles for the rack feeders. Similar to the single bin storage angular profiles are mounted at the supports to hold the unit loads. When the unit loads are stored and retrieved, they are moved slightly above the angle profile.

Figure 2.19. Drive-in/Drive-through rack system (source: AR racking)

The system is operated solely with front stackers and accessed from the side. Two kinds of movement are made to serve the racks: drive-in, where the unit loads are stored and retrieved at the same side, requiring a LIFO strategy; drive-through, where the units are stored and retrieved on opposite sides, according to a FIFO strategy.

The occupancy of the rack highly depends on the storage and retrieval frequency and furthermore, the unit loads cannot be transferred in the aisles.

Because of these characteristics this system is not very suitable for the supply of different articles but for the storage of similar articles per aisle and the transhipment of complete units. The storage locations can be recorded and managed individually; this is difficult to realize due to the manual operation and the required identification of locations. However, this principle is ideal for the buffering of incoming or outgoing consignments.

Another category regards the utilization of dynamical racking systems: for different reasons, warehouse systems are designed to be dynamical, especially when the unit loads are moved between storage and retrieval. This tactical choice allows to shorter order-picking distances and higher picking performance, to improve transhipment in line with a compact storage, and to merge the benefits of a block and line storage

There are two basic principles for a dynamical storage: *static loading units in mobile racks* and *mobile loading units in static racks*.

Movable aisle racks are made up of statical line racks extended by a mobile platform (sub-frame); this system is suitable for every kind of rack system, being limited in a height of 10 meters maximum. The racks can be compacted in a single block, making the aisles disappear.

In such a system each single unit load can be accessed when an aisle has been opened or the rack has been activated. The relatively slow motion of the large and heavy racks limits the throughput. Therefore, the storage and retrieval strategy, which should focus on the minimization of rack movements, has a large effect on the throughput.

Then there are rotary racks, that can be vertical (*paternoster*) or horizontal (*carousel*) made: in the first case, long trays are horizontally mounted between two vertical chains. The picker is located at the central transfer point. By utilizing the full height of the room, a relatively large number of articles with a small or medium number per article can be stored in a small space, guaranteeing safety in operations for the operator, due to casing system. In the second case, racks are placed one close to the other, and the operator can sort parts by calling a rack at the picking point: this system is able to store many parts, due to considerable lengths (up to 50 meters)

The last rack to be shown is the flow rack: by adding a conveyor level to a fixed block of racks, the unit loads can be moved within these blocks (also called live storage). For this purpose, the unit loads are either transferred in a storage channel at the rear end of a rack, moved to the frontend where they are retrieved or are pushed into the channel at the front end where they are also retrieved (push-in system). In the channels the units are stored one behind the other and can be accessed only from the frontend of a rack.

According to the flow principle, storage and retrieval are separated and thus independent from each other. Furthermore, such systems inevitably work according to the FIFO principle (or LIFO in case of a push-in system) without additional controls. An advantage in addition to the compact storage is the possibility to store many articles with direct access and a guaranteed supply.

The front side of the storage system may also be reduced what leads to shorter distances during order-picking and operation. Flow racks are used for light as well as for heavy piece goods.

Of operational importance is the fact that single items or single order unit loads are built in the single channels. It is almost impossible to restore units to get access to articles which are not stored at the front end of a rack. For this reason, such systems are only suitable for order-picking where several units have to be stored without having to provide complete pallets.

Figure 2.20. Paternoster and carouse racks (source: Jungheinrich AG, Cisco Eagle Ltd)

Warehouses are served by Material Handling Equipment (MHE), that are represented by the most common *forklift truck*, a three - four wheels vehicle with a telescopic front mast, usually equipped with pallet forks (or, depending on the material to be handled, other kinds of attachment, such as buckets for bulk products, tiltable forks to dump containers, grapple forks to grasp pipes, barrels, logs).

MHE, or *transporters*, are single devices which transport single or a few goods from a source to a target while traveling with the goods. This process is called *working cycle*. Depending on the construction type any point along a line, in an area or room can be approached. For this reason, these systems are ideal to serve a high number of transfer and pick-up points, to transport heavy goods and to cover large distances. Depending on the system design, the requirements on the control and automation increase in line with the flexibility of use.

While in a steady conveying system the complete line is designed for the heaviest or most sensible goods the dimensioning of a transporter system mainly focusses on the design of the transport means. This reduces investments in driving routes. Furthermore, different kinds of vehicles can be operated within a larger system as long as the requirements are met.

Depending on the size of the loading unit, different kind of MHE can be adopted **(Figure 2.21**):

- *Manual carts*: for transport of small containers/boxes, they are manually operated by the workers to move small loading units and replenish manual workbenches.

- *Hand pallet jacks* (*transpallets*): to move around pallet-sized loading units, they are equipped with forks and manual hydraulic systems to lift the load.[25]
- *Low lift pallet jacks*: nowadays they are no more manually operated, instead they are equipped with electric motors. Some have an onboard platform on which the operator can stand still and drive, instead ow walking and pulling the cart; the high lift version is equipped with a telescopic mast that allows to stack loading units at different heights or feed storage racks.

Figure 2.21. Example of electric stackers for material handling (source: Jungheinrich AG)

- *Forklift trucks*: nowadays forklift trucks market is saturated by different versions, available for many field of industry: counterbalance trucks (widely adopted, especially for compound operations, docks and heavy-duty handling); retractable mast reach trucks (for narrow space aisles and commissioning); narrow aisle trucks; side loaders turret trucks (bilateral and trilateral, able to move in high density / narrow aisle warehouses); turret picking trucks, to perform collection of boxes from warehouses.[26]
- *Automated systems*: referred to as AGVs, they can be driven by electromagnetic patterns on ground or RFID systems; they are of paramount interest in current warehousing improvement studies, because the increment proficiency of warehousing activities, eliminating the presence of human operators on board. Where the presence of operators could represent a safety risk during operations, the use of AGV can reduce it at the

[25] Irving M. Footlik, *Industrial Hand Trucks*, in *Material Handling Handbook*, edited by Raymond A. Kulwiec, 1985, New York, John Wiley & Sons, p. 165-186

[26] William O'Connell, *et al.*, *Powered Industrial Trucks*, in *Material Handling Handbook*, edited by Raymond A. Kulwiec, 1985, New York, John Wiley & Sons, p. 187-272

maximum extent, preventing the falling of loading units from the high ground, that could accidental hitting of people during lifting or picking operations.[27]

[27] Garry A. Koff, *Automated Guided Vehicles*, in *Material Handling Handbook*, edited by Raymond A. Kulwiec, 1985, New York, John Wiley & Sons, p. 273-314

3. Warehousing scenario in the company

3.1 The warehouse layout

In Continental Brakes Italy plant, warehousing activities have been reserved around 3,400 square metres floorspace (equivalent to one sixth of the total indoor space).

The main effort of the company is to balance dimensions of the warehouses with the material stored inside, with the purpose of reducing the inventory costs, one of the most impacting aspects on annual budget.

In modern literature, the reduction of wastes in every aspect of industry has become a golden rule, to be applied in every field of industry, especially in warehousing.

Even if today management science overindulged concepts like lean manufacturing and continuous improvement, it is important to remember that these subjects where almost unknown and started to take place only during the Sixties: at that time the Japanese manufacturer Toyota, that was starting to get the giant manufacturer that actually it is, decided to invest resources in the development of the concept of Lean Manufacturing, having pioneer in a young engineering, a beautiful mind that improved the science related to industrial engineering: Taiichi Ohno, engineer at Toyota Corporation and creator of the ***Toyota Production System***, or **TPS** (**Figure 3.1**).

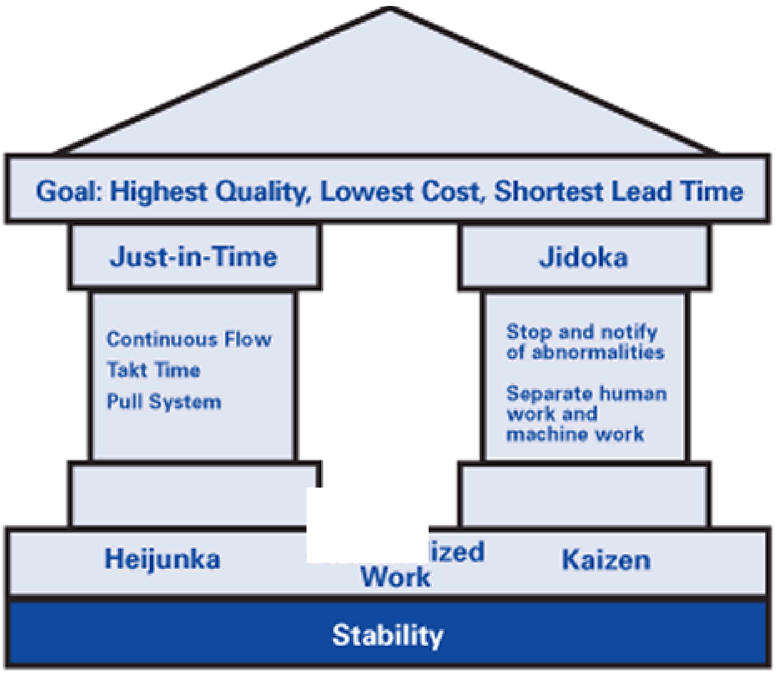

Figure 3.1. Toyota Production System House (source: Lean Enterprise Institute Inc.)

The objective of Toyota Production System is the elimination of overload (*muri*), discrepancies (*mura*) and wastes (*muda*). The main objective is to design a lean production process, to get goals in a simple way: the secret is in the creation of a flexible process able to overcome stresses (*muri*) to avoid the subsequent creation of waste (*muda*). The improvement leads to economic benefits. Seven types of *muda* (here their English transliteration is shown, according to the job done by Daniel T. Jones [28]) can be evaluated (**Figure 3.2**):

- **Inventory**: when companies overstock themselves in order to meet unexpected demand or protect from production delays, unwanted costs arise, impacting on the customer expenses and leading to depreciation costs.
- **Waiting**: whenever goods or tasks are not moving.
- **Overprocessing**: extra working or features that do not lead to recognizable advantages but only extra costs.
- **Overproduction**: producing more means that the customer's demand is exceeded, leading to additional costs.
- **Defects**: they are responsible for reworking that, eventually, can lead to scrap: in that case spent work has been wasted as well as the monetary value of the material.
- **Transportation**: when resources (materials) are moved by transport means, movement does not add any value to the final product, increasing costs and menacing quality.
- **Motion**: all the movements of employees (or machinery), which are complicated and unnecessary. They can cause injuries, extended production time, and more.

Figure 3.2. Seven wastes in modern industry (source: kanbanize.com)

[28] For further reading:

Daniel T. Jones, *Lean Thinking - Banish Waste and Create Wealth In Your Corporation.* s.l., 1995, New York, Simon and Schuster, p. 400.

Muda elimination is based on an in-depth analysis of the production process, based on step-by-step continuous improvement (*kaizen*). The great results of Toyota Production System in industry lead to the worldwide success of Ohno's philosophy, setting the pace to introduction of lean manufacturing in current industrial methodology.

Another important aspect of Toyota Production System is the concept of Just-In-Time, an approach finalized to the elimination of stock in the plant: it is based on targeted production, so the raw material is supplied only when needed. This has been possible only with the introduction of the ERP systems (EDI) and SMED (Single Minute Exchanging Die), that implemented:

- the reduction of time in order receipt and order emission.
- The increase in speed in equipment set-up.

In this way, the takt time for the production of the final goods has been reduced from days to hours. This methodology is called *pull system*, and it is more reliable about the effective request by the customer. The used system is the kan-ban, a card linked to the part bin, that notice the warehouse men when the raw material should be replenished on the assembly line. No overproduction is triggered, and supplier are completely embedded in the production system.

To reduce the impact on inventory, a possible solution is to look for trade-off with the supplier, in order to push the adoption on its side of the consignment stock methodology for supplying: nowadays, according to the lean manufacturing concepts, consignment stock represents one of the best methods to keep low the level of material stock in the plant, with the side effect of reducing the inventory as well.

The company, according to literature and consolidated method in the industrial environment, tends to distinguish the nature of the different storage areas according to the typology of material that is stored inside; so, basically in the plant three typologies of warehouses are present (**Figure 3.3**):

- ***Raw Material warehouses***: on traditional storage racks, loading units containing small components and WIP subassemblies delivered by the suppliers are stored awaiting for their introduction in the production floor, to be directly assembled on the final product or integrated in semifinished assemblies; stamped material, that are bulkier and heavier, are stacked in a dedicated area of the plant (they are provide in steel containers, so the traditional rack system would result non adequate for them).
- ***Work in Process warehouses***: semi-finished goods and intermediate subassemblies are stored in that part of the logistic area; they consist of components manufactured by the plant or third-part suppliers, with the task of performing operations on the raw materials. They are generally placed close to the lines, in order to improve cycle time and simplifying routing.
- ***Finished Goods warehouses***: the finished product, ready to be shipped to the customers, are stacked in Odette plastic containers or steel boxes, that are provided by the customer itself. Shipments are stored in three warehouses of the ground storage typology, while shipment preparation is done in an adjacent area to each warehouse, to reduce unnecessary material handling.

#	Description	bins	sqm
FG-1	Finished Good 1	650	400
FG-2	Finished Good 2	400	395
FG-3	Shipment Preparation FG1	62	40
FG-4	Shipment Preparation FG2	28	40
RM-1	Aluminium extrusion warehouse	142	60
RM-2	Small components warehouse	400	238
RM-3	Linings warehouse	150	45
RM-4	Web and Table warehouse	210	200
RM-5	Backplates warehouse	320	255
RM-6	Comm. Vehicle brake components	180	52
WP-1	Finished IA		
WP-2	Finished WC		
WP-3	Riveted Shoes		
WP-4	Glued Linings		
WP-5	Painted Backplates		

Figure 3.3. Blueprint of the warehouses layout

The available floor space for raw material is 2070 square metres (60% of available space for Logistics: 73 square metres are reserved for the inbounding preparation), while the space available for storing the finished product is 1210 square metres (35% of total warehouse floorspace, of which 1/3 is dedicated to shipment preparation, about 280 square metres). The remaining space is dedicated to store WIP material (5%, about 170 square metres).

The total number of bins available in the plant is 4825, distributed in the following way:

- 1140 bins for storage of finished goods (among them, 90 are reserved for shipments preparation).
- 1400 bins for storage of raw material goods.
- Around 200 extra bins for WIP storage, not counted in the definition of warehousing activities.

The bins are organized according to three main methods, used to store containers or pallets according to the kind of storage system and the availability of space:

- ***Traditional rack system***: the method is mainly adopted or storage of small assembly components, mainly because they are delivered to the plant by means of standard Europallets, that can be easily stored in this typology of storage system.

  Traditional racks are mainly used in the warehouse for small components, in the lining warehouse, and in the warehouse of components for small commercial vehicles brakes (**Figure 3.4**).

  They allow a rationalised storage of loading units, thanks to improved allocation, safety in operations and easy management of the loading units and their ubication on the Warehouse Management System. Thanks to the fact they are finely designed to meet high requirements in terms of static and dynamic behaviour, this solution allows the user to stack goods at considerable heights, ensuring either optimal floor utilization or cubic exploitation of the warehousing available area.

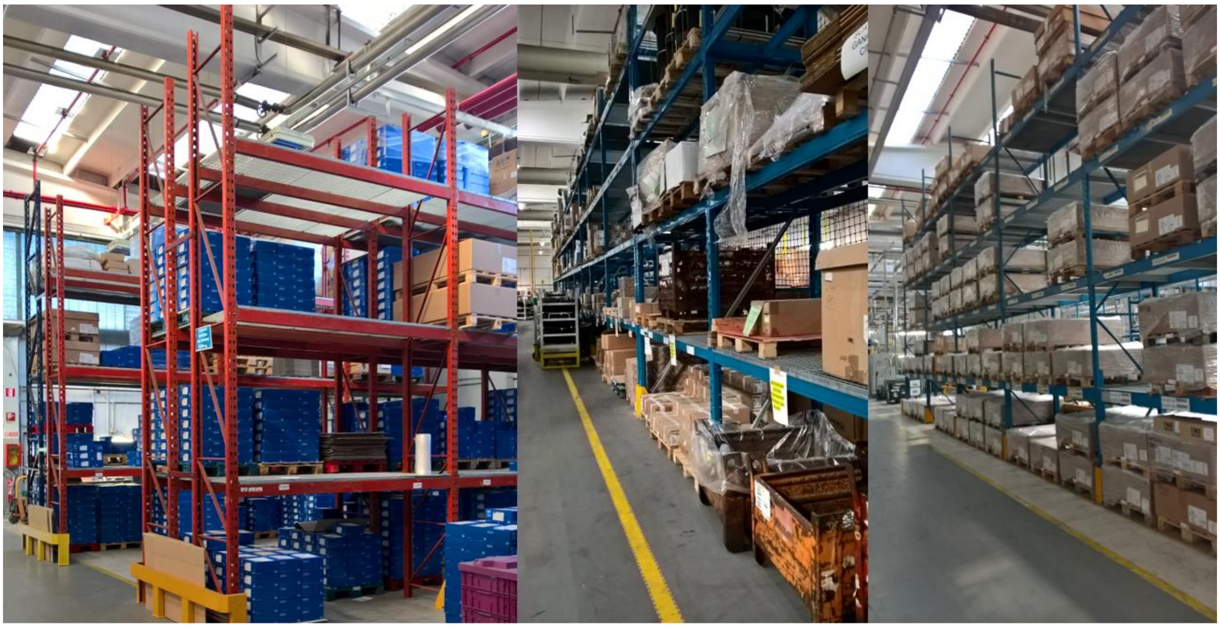

Figure 3.4. Traditional rack systems

- ***Cantilever rack system***: for storage of packs of long aluminium bars, used for feeding the transfer machines and to obtain finished wheel cylinders bodies, they are designed for heavy duty operating conditions, due to the notable weight of material in game and the heterogeneous shape of the loading units.
- ***Stacks on floor***: mainly used to store the finished product waiting for shipment and the stamped raw material, too heavy to be placed on a rack (provided in steel containers). The adopted sorting method is the LIFO one: the last loading unit placed in the warehouse is the first one to be extracted for utilization or shipment. This method is advantageous when dealing with stacks but needs proper fine assessment in order to not to generate issues related to incorrect sorting sequences and, as a consequence, losses in time or delays in shipment. (**Figure 3.5**)

Figure 3.5. Example of stacks on floor of finished goods loading units

The main method to stack loading units is based on traditional forklift trucks: Continental Brakes Italy can count on a fleet of various trucks, electrically powered for indoor use.

For logistic use, the plant can count on reach trucks and counterbalanced trucks (**Figure 3.6**):

- Three *reach trucks*: mainly used as commissioners, their geometry helps to move in narrow spaces, reaching considerably high levels (around 8 meters). The particular characteristic of this kind of forklift is the short cab, that made possible for manufacturers to reduce the overall length of the vehicle, defining an improvement of manoeuvrability in tight space.

  This unique design allowed to introduce an innovative system based on a retractable mast, that means that the whole mast system (the turret that elongating in the vertical direction allows the forks to reach notable heights) can be stretched out in order to pick loading units and then *retract* towards the driving cab, including the loading unit in the overall vehicle length: the main benefits are the saving in space and an increased stability of the load on truck.

- Two *counterbalanced forklifts trucks*: generally meant for heavy duty applications, they are equipped with high strength forks, suitable for loading / unloading operations.

  The trucks are characterized by heavy weight, meaning that they can handle large and heavy loading units (even two at a time), ranging payloads between 1500 and 6000 kilograms: these unique features allow them to perform loading and unloading operations at the plant docks.

  Counterbalanced forklifts are extremely versatile: according to their features, it is possible to use them indoor and outdoor; they can handle large loads without sacrificing manoeuvrability.

  The only drawback stays in the height limits, due to the fact that the maximum reached height is around 6.50 meters, conversely to higher height reached by other types of trucks (reach trucks and turret side loaders, that can reach loading units placed at heights superior to 12.0 meters)

Figure 3.6. Reach truck and counterbalanced forklift truck (source: Jungheinrich AG)

3.2 The Warehouse Management System process

Although the requirements on a distribution centre are quite diverse as are the processes, technical system designs, and control functions each system still includes certain standardized processes. This is of vital importance since each distribution centre is only a link in a subordinate supply chain.[29]

It is interesting to see what literature says about how the warehouse income and later stages are managed in modern distribution systems, as reported by Michel ten Hompel and Thorsten Schmidt in their essay, "*Warehouse Management*".

The first step is the *notification of goods receipt* and delivery date: depending on the delivery status, a precise delivery date has been fixed especially in cases with a high number of deliveries and a low goods reception capacity. Such time schedules should help to avoid or reduce waiting times for trucks and, on the consignee's or loader's side, help to coordinate system loads and to avoid load peaks. This, however, depends on many parameters like the size and value of the consignment, the delivery distance and the general traffic situation, official working times (e.g., customs clearance) and, of course, on the location of the consignee and the ideal can hardly be achieved.

The second step is *good acceptance*: based on the delivery note, the consignment is compared with the order and the bill of lading is compared with the notification. Then the notification data are temporarily entered into the inventory system. This process accelerates the goods receipt process considerably because in case of a positive check the data just have to be confirmed.

While in small warehouse systems goods acceptance and goods receipt may be in a physical vicinity due to the spatial separation in larger systems, arriving trucks have to be directed and assigned to the loading gates. The spatial separation mainly aims at a better control of the yard traffics. For this purpose, yard management systems (also stock management systems) are used to guarantee for a coordinated traffic on the premises and above all to minimize unnecessary searching and switching trips.

The it follows goods receipt: according to the notification data, the goods receipt department can also be informed about the pending delivery. This is of special advantage in case of larger deliveries (with regard to the reception system). This includes, for example, the planning and reservation of buffer space, the choice of a suitable terminal (e.g., loading gates or bays) or the print of in-house labels for the internal identification of goods. Cross-company labelling systems similar to EAN128 used in trade or Odette in the automotive industry are advisable although they are not the state of the art in most warehouses.[30] One reason, among others, is the fact that a material flow control puts other requirements on a labelling and identification system than the trade.

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[29] Michael ten Hompel, Thorsten Schmidt, *Warehouse Management: Automation and Organization of Warehouse and Order Picking Systems*, 2007, Berlin, Springer, p. 20

[30] Michael ten Hompel, Thorsten Schmidt, *Warehouse Management: Automation and Organization of Warehouse and Order Picking Systems*, 2007, Berlin, Springer, p. 22

Once that the good receipt has been performed, it is time for *incoming goods inspection*, a physical check of the freight. This includes the inspection of all goods with regard to type and quantity is generally performed by the unloading staff. The condition of some goods is carefully checked by the quality assurance according to the company rules: these inspections may be a simple visual test, laboratory tests of samples or a complete full-scale control. Faulty goods are marked and quarantined waiting for further clarifications.

Article master data are vital for a number of control and optimization functions further down the material flow process. Exact weights have to be known for order-picking tests so that it can be checked if customer orders are complete.

The dimensions of an article are also of importance to optimize the volume utilization along the material flow. The racks in a high-bay warehouse can be adapted to the article range by changing the shelf heights and thus to optimize the utilization of the storage capacity. Furthermore, according to the volume of a picking order, the optimal shipping containers can be found and thus shipping costs can be minimized.

Then, one of the core aspects of warehousing: *storage*.

In case of a manual storage system (e.g., stacker-operated block warehouse), the process is continuous because the loading unit is taken up and then directly moved to its final storage bin where it is stored or transferred. In larger automatic systems, however, the process is performed stepwise up to the final storage in the storage bin. For this reason, the overall process is described below. In a manual warehouse it only consists of specific partial steps.

In a first step the backorders have to be checked (especially in manual systems), so that articles may be transported directly to the place of consumption or into the shipping area. This process is also called split-lot storage. Another term used simultaneously is Cross Docking, which more precisely describes an extensive concept and thus is not the right term here.

Then the articles are moved to the storage areas. For this purpose, the transport targets have to be determined in the warehouse management system. Above all in large systems, there are large optimization potentials because of the long transport distances and large quantities, especially when manual unsteady conveyors (e.g., stackers or tractors) are used. The in-house transports can be optimized with different methods. On the organizational side, there is the collection and pre-sorting of tours what requires sufficient buffers and room for action. This method may result in different handling times for the goods to be transported. This can be avoided by using an automatic transport control system which controls the transport of articles into the different storage areas by means of deterministic strategies and rules. For this purpose, the stacker cranes can be equipped with a control system which provides an optimal order sequence.

An important aspect is the transparency of the material flow, above all in larger material flow systems. For example, when a transport unit is moved to a wrong location this typically requires a physical search. A suitable measure to trace the goods and identify possible errors is to treat the conveyor like a virtual storage bin and to rebook the goods to these conveyors during transports.

This results in a continuous documentation chain and single units can easily be tracked and traced.

If the storage unit has not yet been identified during the goods receipt check this identity control is now carried out at the so-called identification point. This is often done in the pre-storage zone of automatic warehouse systems like high-bay warehouses. For this purpose, it is checked whether the article and quantity correspond with the loading unit and if the master data is available. At the same time the material flow is synchronized with the information flow. When automatic warehouse systems are used this happens at interfaces between the manual and the automatic system. From now on the order cannot be changed.

At the same time, the stackability has to be proven. This includes first of all the contour check (check of the dimensions of the goods to be stored) and, if necessary, a weight control, especially in systems with non-uniform shelf capacities. This may be followed by a physical stock taking. Directly related to storage is the *assignment of the storage bin and put-away*. The first step in a storage process is the determination of the storage bin. This may be done according to quite a variety of criteria which result from the physical requirements of the goods to be stored, the operational and technical warehouse operation as well as from security and legal requirements.

The requirements concerning the physical dimensions and weights of goods to be stored arise from the construction of economical shelves where specific dimensions and loads have to be determined from the current and future range of articles. When the article range can be segmented in such a way (sufficient classification) the allowed loads usually are reduced for each shelf in upward direction or corresponding load areas are built. In manual warehouses, lighter goods are stored in the top shelves for ergometric reasons.

In some dynamic warehouse systems, a one-sided load has to be avoided for functional reasons. Here, the system control has to distribute the goods evenly to optimally utilize the available storage volume. For this reason, shelf heights should be graded to take up goods of different heights.

A variety of strategies can be used to optimize the operating process of a warehouse system which is partly incompatible: in this context, the shortest way strategy is a generally applicable secondary strategy and mentioned for the sake of completeness.

Of course, security and legal regulations have priority, above all with regard to hazardous goods and food. Here, a large variety of special regulations have to be observed, which in the following are only described with regard to their effects onto warehouse management. The storage monitoring is also an integral part of a modern warehouse management which terminates the storage process. For this purpose, a feedback is given showing the storage bin and time. While in automatic warehouses this step is carried out automatically in manual warehouse systems (with a computer-aided control, e.g., stacker control system), it has to be verified by an operator.

The previous paragraphs expose the good behaviour as implicitly prescribed by modern literature about warehouse management, but it is possible to state that this time theory and real case stick together, because, how it has been possible to observe in Continental Brakes Italy, the modus operandi in logistics follows a well-established path, that use to reduce at minimum risks and losses at Incoming operation and warehouse management.

The first aspect to be considered in the analysis of the warehouse management at Continental starts with the description of the incoming of material process, that involves the raw material at the inbound phase: as already advised in the previous parts, it is necessary to make a distinction between what happens at the physical level (material side) and what is going on at the information level (exchange of information in the process).

The process is very simple, and it involves the following key players: the warehouse managers, the supply logistics managers, storage management software.

The physical playground of the Material Management is the warehouse area of the plant, that is divided into an incoming area and the storage area; the action field of the information data related to the material instead is split between Inventory Management (MM-IM on SAP GUI and so called from now on in the paper) and the Warehouse Management (WMS on SAP GUI and so called from now on in the paper)

The incoming process starts with the arrival of the raw material in the plant: the raw material reaches Continental Brakes Italy plant by loading units delivered by trucks; such loading units are unloaded at the designated docks by means of docking forklifts.

The forklift drivers place the loading units in the specific incoming area, that is simply represented by a floor area delimited by coloured strips. Once the whole truckload has been placed in the incoming area the warehouse manager checks if the received goods are compliant to what declared on the delivery notes that accompanied the load (delivered by the truck driver).

The next step consists into the loading of the delivery note on the internal logistics database: the warehouse manager transmits a scanning of the delivery note to the SCM office by means of the NOOS database (database for the incoming area documents).

Meanwhile, in the SCM office, the Material Planning is in charge of transferring the delivery notes transmitted by NOOS on SAP GUI system, suffering some misalignment between real arrival time of the goods and uploading on SAP, especially when dealing with raw material that arrive at the plant after the office closure (so it cannot be properly loaded on the system).

SAP system now defines a location of the inbound material in the Inventory management of the plant: now the material has been registered on the system and it has officially entered the plant. SAP locates the raw material in the incoming area, that corresponds to the interim storage type 902.

The interim storage type corresponds to the step between the MM-IM and the WMS, but generally it should be stated that every material movement between MM-IM and WMS must pass through this element.

Now, to move the material from the Incoming area to the warehouse, it is necessary to use a transfer requirement, a document that pass information on goods movements between MM-IM and WMS and allows to fulfil the WMS bin with the incoming material (also physically, because it allows the creation of a transfer order to move material in the warehouse).

The warehouse manager downloads a list of transfer requirements from SAP GUI, each one corresponding to a delivery note code previously uploaded on NOOS: the list relates each transfer requirements to a transfer order, in order to physically locate the goods at WMS level.

It is necessary now to move the goods from 902 to 99, a storage type for the palletization of the loading units: indeed, many of the loading units that reach Continental Brakes Italy are not containing a single code of raw material, but it may happen that many codes are present on one pallet, so a break-bulking operation is necessary by the warehouse men.

Now the warehouse manager proceeds with the palletization phase: this process consists of defining the personal information of the loading unit inside Continental Brakes Italy, that are rallied on the storage unit label, an adhesive label stick on the loading unit reporting part number, quantity, and storage unit of the loading unit.

The material is moved along WMS: by a scanner, the warehouse manager move the loading unit (still physically placed in the Incoming area) from 99 to a destination storage type. The process is called put-away: the bar code of the storage unit is matched with the one present on the storage type (area or pallet rack) and the one related to a storage bin (single position on the rack/storage area).

Once the material has been located in the warehouse, it is under control of WMS: if the material is required on the assembly line, the warehouse men checks the position of the loading unit on SAP GUI (paying attention to the incoming order of the material –FIFO–); then the material is withdrawn and delivered to the production area: the system reacts by making a replenishment, that is a transfer of material from the warehouse to the production line: the transfer is equivalent to a good issue and the management is now by MM-IM.

The Incoming process, and the whole warehousing process, can be schematized by means of Value Stream Mapping, also known as material-and-information mapping, a lean-management method to analyse the current state of a process and define a future strategy for it, from the beginning up to reaching the customer. According to Tony Manos, via the American Society for Quality (ASQ):

"[VSM] can be an extremely powerful tool, combining material processing steps with information flows, as well as other important related data. VSM is arguably one of the most powerful lean tools for and organization wanting to plan. […] [VSM] shows the process steps from order entry to delivery. […] if you are not adding value, you are probably adding muda."[31]

VSM (that is part of the Lean Six Sigma methodologies) displays all the critical steps of the process and quantifies time and volume of each stage, together with the material and information flows: the core task is the elimination of wastes that could affect the process itself, thereby increasing productivity.

According to Yasuhiro Monden, professor at the Japanese Tsukuba University and instrumental in the introduction of the JIT production system in the United States, it is possible to distinguish different kinds of activities: [32]

- ***non-value adding operations*** (NVA): actions that should be eliminated (e.g., waiting).
- ***necessary but non-value adding operations*** (NNVA): actions that are wasteful but necessary under current operating procedures.
- ***value-adding operations*** (VA): conversion of raw materials into finished goods.

Two kinds of methods can be adopted: current state (what is the process like at the moment) and future state (how the process will look like after the improvement occurrence) VSM diagrams.

The common standard for VSM is to link the supplier, plant, and customer facilities by arrows, that are a representation of the information flows across the organizations and define as a box (reporting cycle time and other production parameters) the intermediate phases composing

[31] Tony Manos, *Lean Lessons: Value Stream Mapping - an Introduction*., June 2006, www.asq.org, [Online]

[32] Yasuhiro Monden, *Toyota Production System - An Integrated Approach to Just-In-Time*, 1994, Osaka, Springer Science and Business Media, p. 424.

the production process. Other elements are used to describe kan-ban, warehouse supermarket, withdrawal etc. (**Figure 3.7**)

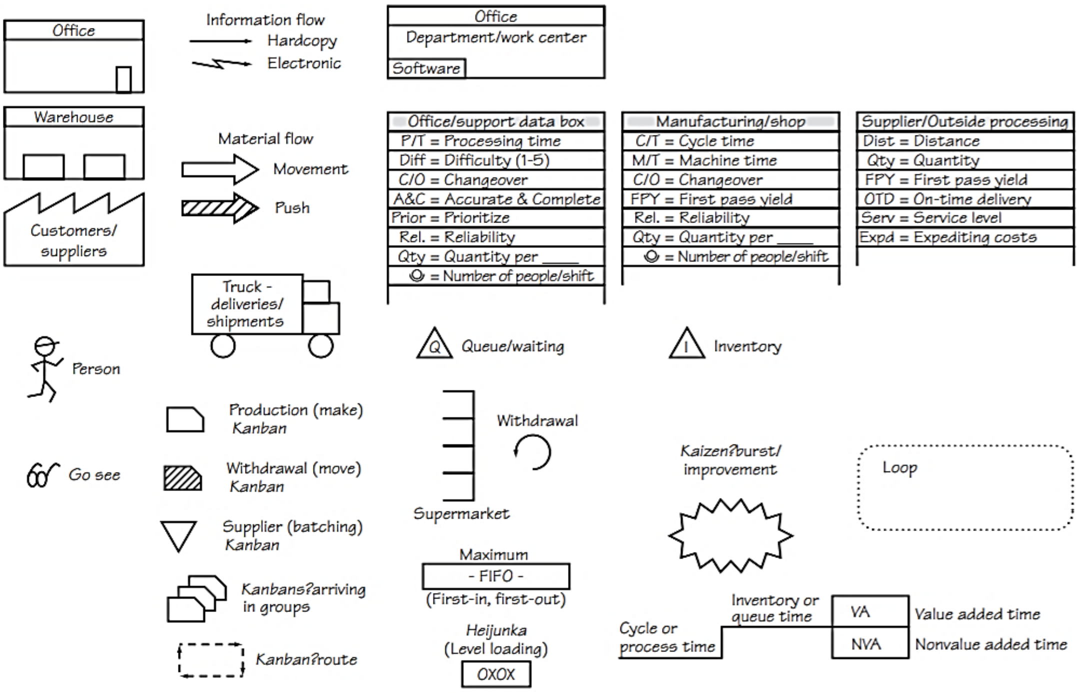

Figure 3.7. Common VSM icons (source: American Society for Quality)

The complete process of Incoming is represented according to VSM (**Figure 3.8**): it is clearly evident that the main waste in time is the passage related to the delivery notes loading on NOOS system, because the warehouse operator has to manually load the notes in order to transmit them to the SCM office. By automation of this process (by optical scanning or MAT-Label) it would be possible to eliminate that action and reduce the total time necessary to implement the uploading to system.

Another point of stress is the break-bulking operation: in case of rearrangement of delivery terms with the supplier, it would be possible to reduce further the operation of breaking the pallet into sub loading units, because the pallet arrives at Continental Brakes Italy already shipped according to part number, so the warehouse operator could skip the sorting activities to create new pallet by equal code and a full pallet could be directly stored in WMS.

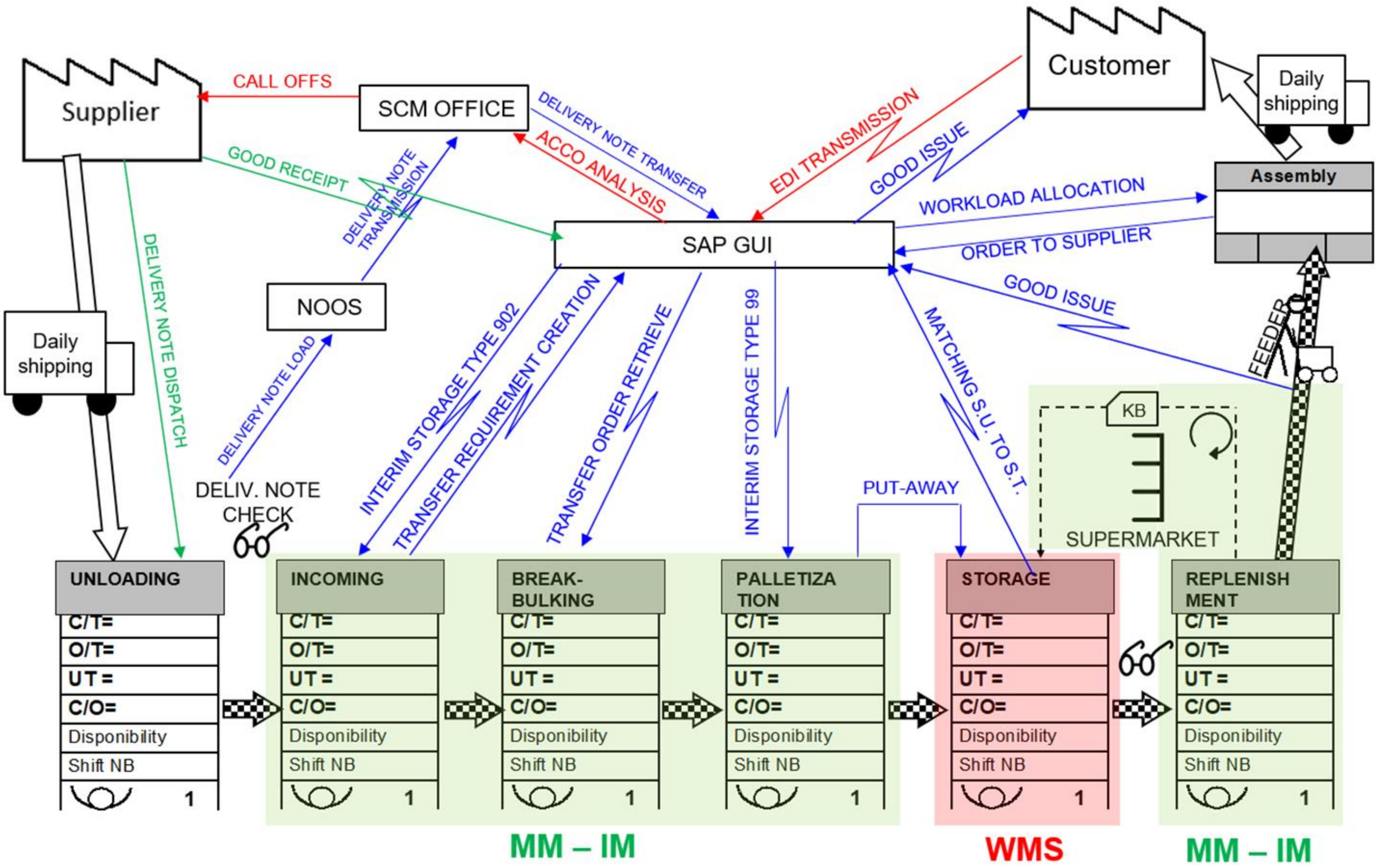

Figure 3.8. Value stream mapping of the warehouse management activities

3.3 Distress in activities: incoming growth in production volumes

During the year 2018 and the initial part of 2019, the practice stated how the forecasted production volumes (which projection have been defined during the previous semesters) would not be affected by any cause of disturbance in usual operation at warehouse management level, making pointless to engineer any kind of changes in the dimensions or in the layout of the warehousing spaces.

Not the same could have been saw during the following months: the definition of the Strategic Plan for the next five years period (from 2018 to 2022) demonstrate the definition of a perturbing situation in the normal behaviour and volumes of the Ligurian plant, starting from the late part of 2019. The definition of the production targets has become herald for hard times, so needs for rethinking of the whole supply chain at Continental became imperative.

The cause of distress has been signed by a planned increase in production: as some could say, increase in production are never cause of diseases or problems; nothing but that in industrial planning.

The profitability of the new project is strictly related to the careful planning of the needed resources to perform a finely tuned management of the improved situation and to define a proper infrastructure, in that specific case a rebuilt supply chain. And this means to calibrate again cycle times, sources of wastes and adaptability of current logistic layout to the new situation, needing for improvement when necessary

In the specific case of Continental Brakes Italy, the increase in production dates back to the introduction in 2017 of new projects: together with a big European manufacturer, Continental developed a new set of products, to enrich the company's portfolio: the electronic drum brake.

The future of automotive resides in the electrification of the vehicular systems, together with the widespread application of electronics in components that originally were actuated by electro-mechanical devices, as the world is witnessing today.

This aspect has become important also in the field of hydraulic braking systems, with the introduction of electronical systems for the actuation of braking elements: sensors for ABS systems, Electronic Brake Distribution, brake-by-wire technology, and electric parking brake.

Especially the latest technology, also known by the acronym EPB, has a paramount interest in the close future of Continental Brakes Italy, due to the spreading interest towards this product of more and more manufacturers.

The introduction of the new lines of products has the effect to determine a neat increase in the production volume of the plant. As a consequence, the space adhibited for warehousing activities should face a re-thinking of its organization in order to react positively to the distressing situation.

The case under analysis focuses on the analysis of the number of bins registered in Continental in 2018, in which the families of stored products have been grouped in terms of features similarity, obtaining as a result several *macro groups*:

- Small components.
- Linings.
- Webs and tables.
- Backplate warehouse.

- Commercial vehicle components.
- Aluminium extrusion bars.

The table reports the evolution of the demand for production in plant, expressed as a increment or decrement in storage bins: to be consistent of the rules related to treatment of personal information or commercial data, it has been decided to obscure the values, in order to not to infringe the use of business review data and at the same time to supply the reader with a description of the demand behaviour, expressed as a *percentual values* related to the storage needed capacity of 2018 (**Table 3.1**).

WH	Description	Installed Bins	Floor space	Needed Capacity				
				2018	2019	2020	2021	2022
FG-01	Finished good #1	650	400	α	34%	43%	46%	880
FG-02	Finished good #2	400	395	β	25%	90%	128%	883
RM-01	Aluminum extrusions	142	60	γ	23%	39%	54%	200
RM-02	Small components nr.1	400	242	δ	25%	53%	67%	714
RM-03	Linings	150	45	ε	15%	33%	43%	168
RM-04	Webs and Tables	208	210	ζ	11%	22%	26%	376
RM-05	Backplates	320	255	η	12%	27%	63%	330
RM-06	Small components nr.2	180	52	θ	-13%	-31%	-49%	45

Table 3.1. The distress situation in number of bins

At first sight, it can be noticed that the largest cause of distress is mainly related to second area for storage of the finished product: the reason it is simple, due to the fact that in the initial phase of process design, the finished loading units containing the new range of drum brakes would be stored in that area, mostly because the storage area and the assembly line shared the same area of the production plant.

For better comprehension, it has been provided a graphical representation of the situation, highlighting the great gap in between the two progressive demand development (**Figure 3.9**).

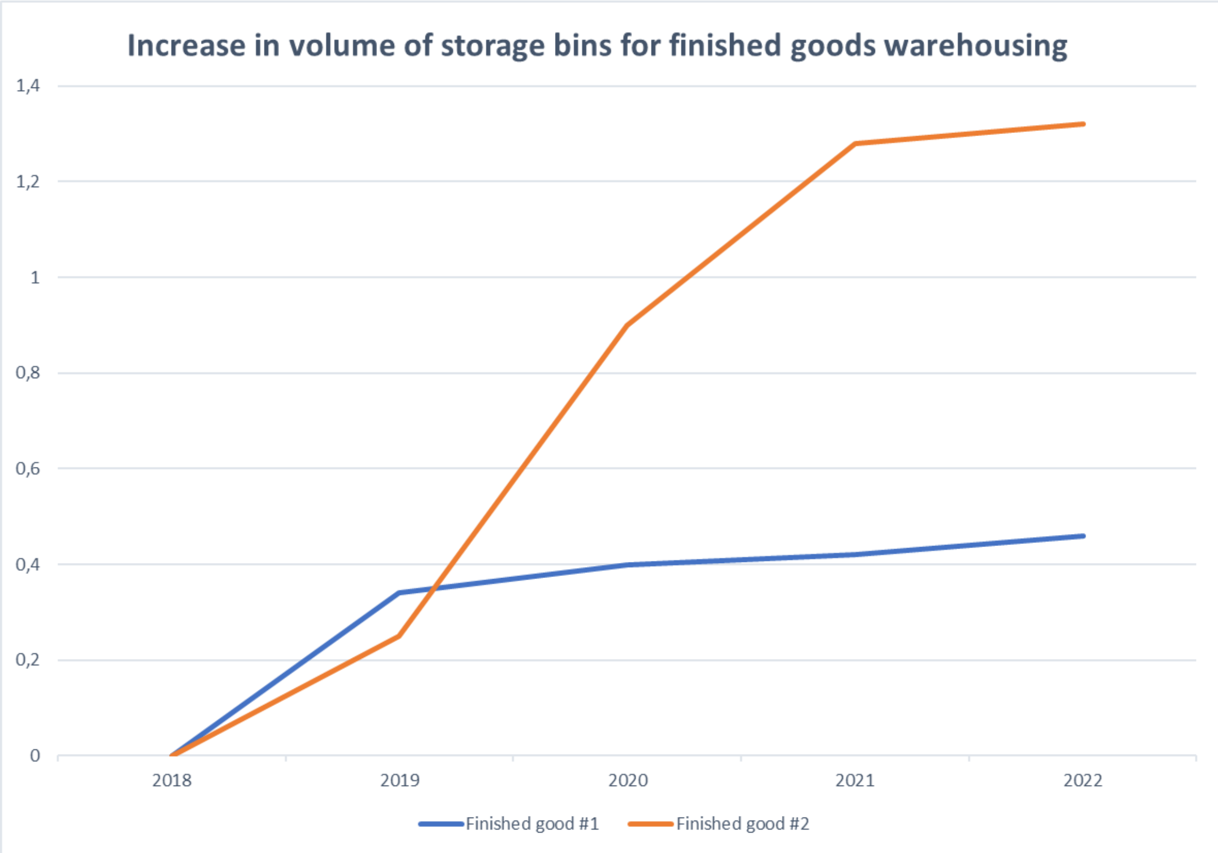

Figure 3.9. Finished goods: five-year trend increments of storage bins

According to the case-study analysis (depicted in **Table 3.1**), from the forecast developed in 2018, it is clear how the plant was going to deal with a general increase of the need for space in the storage activity areas: as a domino effect, the discomfort situation in the increase of volumes has a bullwhip effect on the raw material compartment of the inventory, due to obvious tight linkage between the two aspects; directly related to the increase in bins number of finished goods are the amounts of bins for raw material, especially in the warehouse for small components and stamped parts (webs, table and backplate).

The trend shows a rapid escalating ramp-up curve for each of the main subgroups of raw material, apart in case of the second warehouse for storage of small components (used in the assembly of commercial vehicles brakes): the contradictory behaviour of the demand is mainly due to a lowering in the volume of a range of brakes, that negatively impacts on the warehouse performances of the range of products sharing the same warehouse facility (**Figure 3.10**).

The new product is of paramount importance for the re-assessment of the raw material warehouses, especially because of the abrupt request in bins for small components and stamped parts, that will undergo a radical optimization and design, to satisfy the saturation without noxious collapsing of the warehouse capacity.

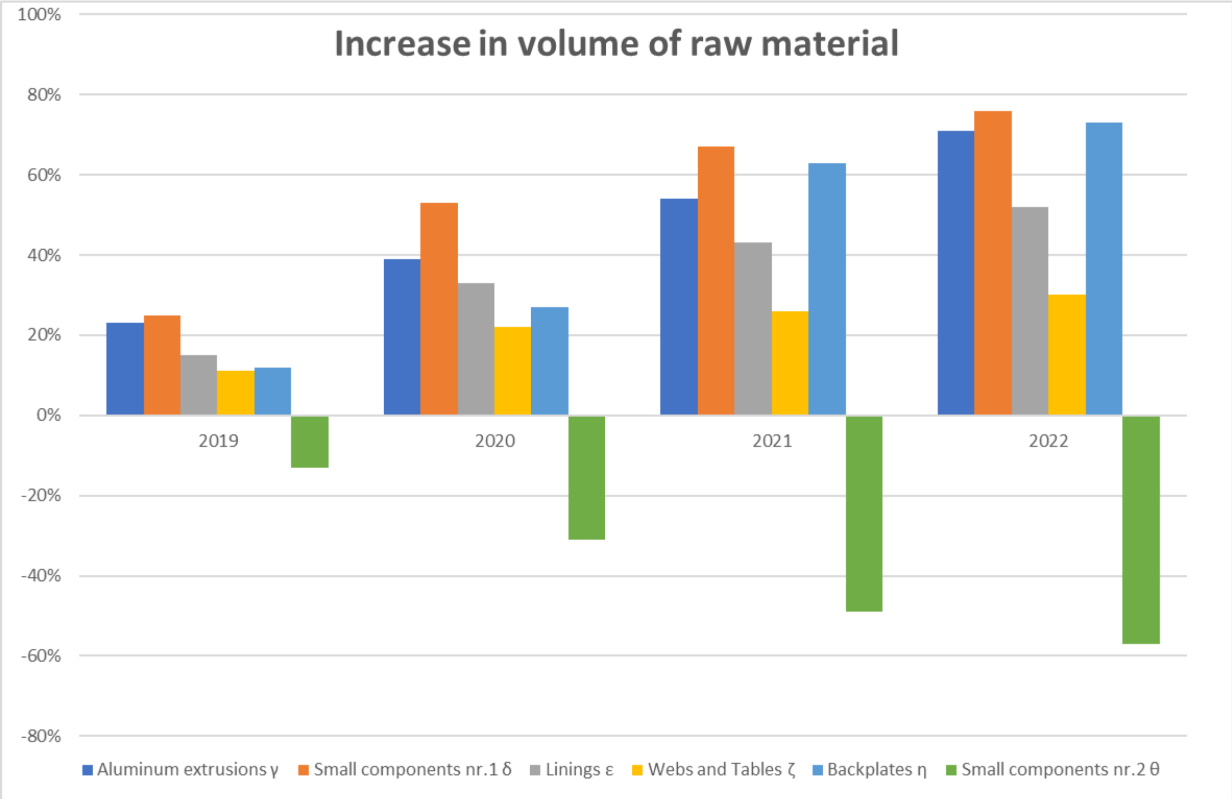

Figure 3.10. Increase in volume of raw materials

It can be easily acknowledged the massive aspect due to the phase in of the new brake range: the push due to its introduction has a strong impact on the radical structure of the warehousing system for raw material of the plant, putting the accent on the redesign of the facilities, looking for a new strategy for storing goods and improving the distribution and handling of the loading units, looking for the smartest and cheapest solution able to brings benefits to the production and becoming the cornerstone on which hinging the assembly process of Continental Brakes Italy drum brakes.

4. Optimization of the warehousing space

4.1 Evaluation of the previous configuration

In Continental Brakes Italy a great relevance is given to warehousing: the main effort to SCM department is to balance the dimension of the warehouse with the content, in order to maintain low inventory costs, that are one of the main aspects impacting on annual budget.

As seen previously about Logistic Costs, the main effort by the SCM department is to push at the maximum extent the adoption by the supplier of the consignment stock methodology for supplying: actually, the best way to reduce tock of material in the plant, because it impacts on inventory costs of the supplier.

According to the company, the warehousing areas are distinguished according to the type of material that is stored in each area:

- **Raw Material** (RM): material and components delivered by the supplier to be processed in WIP subcomponents or assembled in the final product.
- **Work in Process** (WIP): semi-finished goods, intermediate products manufactured by the plant or by third-part suppliers, that has the task to perform operations on the raw material components.
- **Finished Goods** (FG): the finished product, stored and waiting for shipment to the final customer.

The actual layout for raw material is organized in the following way:

1. **Small components warehouse**: it consists of a warehouse spaces based on three traditional storage pallet racks, arranged according to a U-shaped layout.

   The goods are shipped from the supplier on Europallets, sized 1200 x 800 mm, that allows the bins to be standardized on that dimension.

   The loading units are managed by means of a dedicated material handling equipment: a reach truck equipped with a retractable mast: this model of truck has a 2 tons capacity, allowing to manage also heavy loads; nevertheless, its unique features permit it to lift loading units at high levels, thanks to the maximum reachable working height equal to 8 meters.

   The loading units are placed on 7 levels, arranged in such a way to host around 400 bins according to a U-shaped layout: considering a rectangular floor utilization, the layout perimeter is 17 x 14 meters, with a floor footprint equal to 238 square meters.

   The bins are disposed according to the following scheme: on the left and the right sides, the racks can store 21 bins per each row, for a total of 294 bins; on the other hand, the bottom rack can store 15 bins per each row, leading to a total of 105 bins.

   These features made possible for the warehouse to avoid the need for an aisle, while it is present only a central manoeuvring space for the forklift, 12 meters wide.

2. **Lining warehouse**: made by a linear traditional pallet rack, it counts on 75 bins, developed over 5 levels. Due to the particular conformation of the loading unit, a pallet-box with reinforced sides, it is possible to stack two pallets one over the other: this particular feature allows to double the number of bins, reaching a total capacity of 150 bins.

   The rack is managed by common reach trucks.

3. **Web and tables / backplates warehouses**: the available space for storage is equal to 210 bins in the web and tables warehouse, and 320 bins for storage of backplates bins in their dedicated storage place.

   The loading units consists of metal containers (also referred to as *bins*), entirely made in folded steel sheets, made to resist heavy stresses and to be stacked also in outdoor situations. They are heavy and bulky, so at the moment of the inquiry no storage equipment was meant to be used for them.

   The only solution is to stack them according to a LIFO methodology, in order to maximize the volumetric occupation of the storage volume and improving the storage efficiency as well. The only constraint to this kind of operation is the material keeping methods, that shall tightly cope with the production program schedule, to avoid losses of time to re-arrange stacked loading units to extract the correct one. Metal containers are transported from the unloading dock by cargo forklifts and then stacked by traditional counterbalanced forklift or retractable one in the assigned position.

4. **Second small components warehouse**: the system is based on two simple traditional rack systems, bolt-on along the longitudinal direction, accessible only on one side, storing wooden Europallets loading units. They are accessed by retractable forklift systems.

5. **Aluminium extrusion warehouse**: pipe racking with storage capacity for 142 loading units, managed by a retractable mast forklift. The warehouse is placed nearby the operation area, to reduce movement of the loading units (that are quite bulky).

4.2 Analysis of the warehouse

The analysis process started with the analysis of the volume improvement as determined by the strategic planning for the time span ranging from the year 2018 up to 2022.

The first aspect to consider is to understand what a strategic planning is.

Strategic planning is meant as the process adopted by companies to set the path of production: by analysis of the market, the organization is able to define its commercial / industrial strategy, furthermore, taking decisions about how to allocate resources and budget to get to the established target. Another aspect of strategic planning is to guide the implementation of the strategy.

Since the Sixties, strategic planning has set itself as an important aspect of company management. It is led by dedicated figures in the companies, called *strategic planners* or *strategists*: their task is to involve many parties and research sources in the organization analytical process, relating the decisional process to the environment in which the firm is competing for economic dominance.

Strategy can be defined in many different ways, but it is commonly referred to as to set of strategic goals, to determine which action should be taken to achieve them and the amount of resources to be applied in the pursuit of goals achievement. Strategy can be *planned* (intended) or can be *observed* as a pattern of activity (emergent) as the organization adapts to its environment or competes.

Strategic planning is a process and thus has inputs, activities, outputs, and outcomes.

Typical strategic planning efforts include the evaluation of the organization's mission and strategic issues to strengthen current practices and determine the need for new programming.[33]

The end result is the organization's strategy, including a diagnosis of the environment and competitive situation, a guiding policy on what the organization intends to accomplish, and key initiatives or action plans for achieving the guiding policy.

In 1980, Michael Porter defines the guideline for strategic planning, focusing the attention on four aspects of company strategy:

- To deal with company strengths and weaknesses.
- To include personal values of the key implementers (i.e., management and the board).
- To understand which are opportunities and threats in the field of interest.
- To consider societal expectations.[34]

A remarkable aspect of Porter’s theory is how the first two aspects relates to internal company environment, the latter ones to external factors (market)

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[33] Richard T. Ingram, *Ten Basic Responsibilities Of Non-Profit Boards*, 2015, Washington, Boardsource

[34] Michael E. Porter, *Competitive Strategy: Techniques for Analysing Industries and Competitors*, 1980, New York, Simon & Schuster

In strategic planning, the input is made of data, gathered from various sources: interviews with key executives, review of publicly available documents on the competition or market, primary research (e.g., visiting or observing competitor places of business or comparing prices), industry studies, etc. Inputs are gathered to better understand the competitive environment, its opportunities, and risks. Other inputs include an understanding of the values of key stakeholders, later captured in vision and mission statements of the company.

The output of strategic planning is made of a collection of documentation and communication, describing the organization's strategy and how it should be implemented, sometimes referred to as the strategic plan. The strategy may include a diagnosis of the competitive situation, a guiding policy for achieving the organization's goals, and specific action plans to be implemented. As it will be seen, the common method is to make a strategic planning covering large time span, usually several years. It is up to the company strategists to update the plan periodically.

In the case examined in this paper, the strategic planning outcome is expresses as a resuming spreadsheet table: this tool contains numerical data, that are collected by company marketing specialists, by means of different methods: interviews with the customer, analysis of annual reports from industrial experts, market analysis, etc.

The strategic planning table is then filled by the company strategists: according to each finished product part number, a production volume projection is set (usually over a five-year time span), establishing for each category of finished product, the expected volume.

The purpose of the tools is to understand which will be the causes of distress (if any) and the increment or decrease in volume of certain product categories.

The spreadsheet is based on the collection of data related to each finished good part number.

Once the volume trend has been established, the supply chain specialists have the task to explode each finished good according to the components it is made of. In other words, the Bill of Material, or BoM (**Figure 4.1**).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	2018	2019	2020	2021	2022	2023	materiale	descrizione	peso	qty/pallet	material	descrizione	fornitore
2437	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q135-8100-0-00	hexagon head screw M6 x 1x 10,5 10.9	348124
2438	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q135-8110-0-00	trunnion M9 RH-TH	348124
2439	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q135-8110-0-00	trunnion M9 RH-TH	348431
2440	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q435-8100-0-00	SHOE RETAINING CLIP	348560
2441	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q435-8100-0-00	SHOE RETAINING CLIP	348566
2442	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q635-5030-0-00	trunnion molded	348670
2443	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q691-H420-0-00	parking brake lever RH 203	355305
2444	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q835-8100-0-00	riveting pin 5,95x 6,25 (2 diam.)	348124
2445	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BT-Q835-8200-0-00	shoe retaining pin	348124
2446	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BU-Q235-6400-0-50	ABUTMENT	348124
2447	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BU-Q735-8100-0-00	clamping spring	348560
2448	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BU-Q735-8110-0-00	sleeve	348560
2449	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BV-Q010-Q700-0-00	brake shoe web trail. 203	351808
2450	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BV-Q010-Q720-0-00	brake shoe web lead. RH 203	351808
2451	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BW-Q536-4300-0-00	sealing ring D= 19,05mm	389428
2452	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BW-Q635-1200-0-55	plug 10 BK BKP	389428
2453	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BW-Q635-5300-0-00	W.C. PLUG (BLACK)	348670
2454	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BW-Q635-5900-0-00	W.C. PLUG (BLACK)	348670
2455	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BW-Q735-9000-0-55	piston dust boot	389428
2456	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BY-Q535-8500-0-00	spindle 33t M9 RH-TH	348315
2457	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-N543-4030-0-90	PASTE QT31-9570 TO STD 12/05/15	375988
2458	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-N544-0010-0-90	BINDER QT30-0570 to std 12/05/15	375988
2459	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-N639-0500-0-00	ALCOOL ISOPROP.SP.TEC. 20/01/16	348532
2460	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-N639-1651-0-00	ADES. GAN. A73IT/2 S.TEC. 06/03/12	348209
2461	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-N639-1652-0-00	ADES. SEGM. A73IT S.TEC. 06/03/12	348209
2462	84.816,00	89.322,00	99.000,00	94.923,00	84.538,00	65.861,00	BX-QH10-Q72T-X-00	DRBR RH 203x 38 IA 19AI AVT2180 ABS	2.107,000 G	144,00	BZ-Q235-2000-0-00	bimetallic strip	348560
2463	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	B9-A435-8083-5-00	Steel S355MC for abutment	376983
2464	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	B9-C348-3004-2-00	ACCIAIO COSTE 203	378989
2465	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	B9-F219-150D-3-00	Steel for Renault X44 table	352088
2466	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	B9-L319-4005-0-00	Steel for VW MQB 8" hand brake lever	378989
2467	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	B9-P542-245D-4-00	Steel for VW MQB 8" backplate	378989
2468	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BB-Q017-R410-0-90	Lh backplate VW MQB 8", not painted	351808
2469	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BD-Q035-8100-0-00	TABLE	355305
2470	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BE-Q082-L725-0-00	wheel cylinder body RAP (20,64 mm)	348272
2471	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BE-Q882-L720-0-00	wheel cylinder body 20,64	348587
2472	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BF-Q235-8100-0-00	bleed screw SW7 M7x1	348677
2473	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BG-Q035-8800-0-00	W.C. SPRING	348529
2474	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BG-Q512-B710-0-00	LOWER SPRING	750083
2475	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BG-Q591-2500-0-00	UPPER SPRING	750083
2476	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BG-Q635-9010-0-00	adjusting spring	348560
2477	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BH-Q086-7805-0-00	piston 20,64mm RAP	348380
2478	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BH-Q186-7800-0-00	piston 20,64mm	348587
2479	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BL-Q035-8100-0-00	retaining ring 11,50x0,900	348560
2480	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BL-Q491-2500-0-00	spring washer 7,1x 0,5 PKB	348566
2481	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BN-Q091-250T-Z-00	brake shoe lining trail. 203 D8475FF	348555
2482	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BN-Q0A4-010T-Z-00	brake shoe lining lead. 203 D8475FF	348555
2483	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BR-Q079-9600-0-00	rivet 8x 18,2	348124
2484	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BT-Q135-8100-0-00	hexagon head screw M6 x 1x 10,5 10.9	348124
2485	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BT-Q135-8110-0-00	trunnion M9 RH-TH	348124
2486	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BT-Q135-8110-0-00	trunnion M9 RH-TH	348431
2487	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BT-Q435-8100-0-00	SHOE RETAINING CLIP	348560
2488	86.104,00	65.561,00	67.204,00	80.495,00	88.765,00	88.441,00	BX-QH17-R51T-Z-00	DRBR LH 203x 38 IA 20AI VWMQB-A0	1.974,000 G	165,00	BT-Q435-8100-0-00	SHOE RETAINING CLIP	348566

Figure 4.1. Strategic planning associated to the Bill of Material of each product.

The purpose of the spreadsheet is to link finished product to raw material, to understand how variations in the volume of finished products can bounce all over the supply chain, creating variations in the raw material demand and unbalancing the whole system.

A disruptive effect due to this aspect is the Forrester effect (also known in logistics as the *bullwhip effect*): due to lack of information or disorganization along the whole distribution channel, companies could react to sudden increase in demand by increasing too much safety stock level (to avoid stock-outs), changing production programs, going out of phase with production planning and shipments (due to misalignment to customer requests).

The purpose of planning is to totally overreact to this problematic: planning in advance, gathering information together with customer and supplier and constant check of the market behaviour could help the firm to manage well changes and finely tune its supply chain set-up.

Knowing the BoM of the product and so the amount of raw material needed to assemble one finished good, it is possible to relate the amount of raw material to the time it will spend in the plant warehouses: the parameters used to quantify it is the *Days of Inventory on Hand* (DoH).

The DoH is a parameter that expresses the amount of time passing from the incoming of the raw material to the plant and its introduction on the assembly line. The purpose of the company is to maintain adequate stock levels, to avoid stock-outs and loss in production volume due to missing raw material. On the other hand, it is also important to limit excessive inventories, due to the fact that inventory mean high warehousing costs or, alternatively, excessive costs for storing of goods that pass time in the plant without undergoing capitalization, a frozen asset waiting for utilization in the production process.

For stakeholders, the best option is to have low days of inventory on hand: reducing cost in inventory can save several thousands of euros on annual budget, improving organization performances and enhancing efficiency.

Relying with Continental plant, the average days on hand value has been set to ten days (one working week), in order to ensure low inventories and at the same time sufficiently covering the production needs in terms of supplies.

The value of DoH is used to understand the average value of stock for each component, according to the volumes and the quantity per finished product: the value that is obtained is the stock value to be maintained in the plant:

$$Yearly\ RM\ Storage\ Bins = \left\{ \frac{\left[\frac{(A \cdot B)}{C}\right]}{Yearly\ Working\ Days} \right\} \cdot DoH$$

Where:

- A is the production volume of a finished good in a year.
- B is the number of raw material parts assembled on a finished good.
- C is the quantity of raw material contained in each raw material loading unit.

Once the value has been computed, it is possible to establish a connection between the increase in demand and the future requirement on the suppliers' side, the starting point for the analysis of the warehouse improvement.

According to the previous formulation is it possible to compute the number of necessary bins for raw materials. Hereafter the results of the computation, as an increment of the warehouse occupational volume, is described for analysis by the audience.

Results were calculated on the basis of numerical values: for reasons of infringement of classified data, those were just shown to the author for the analysis, so the results are shown as expression of a percentage value.

The result shown on the strategic planning table is essentially the quantity of bins required by each warehouse to store the raw materials to be used on the assembly lines. The result is of paramount interest for the next steps because the definition of the new layout is strictly dependent on the stored quantity, in order to: not to stress the system out by under-dimensioning it; no to result in higher warehouse management costs by over-dimensioning the warehouse layout.

From a first rough evaluation, it sounds clear a net increment in the space / bins requirement for the different categories of raw materials, expressing that the whole warehouse layout is no more adequate to future plant volumes, needing for re-thinking and a refreshment of the system (**Figure 4.2**).

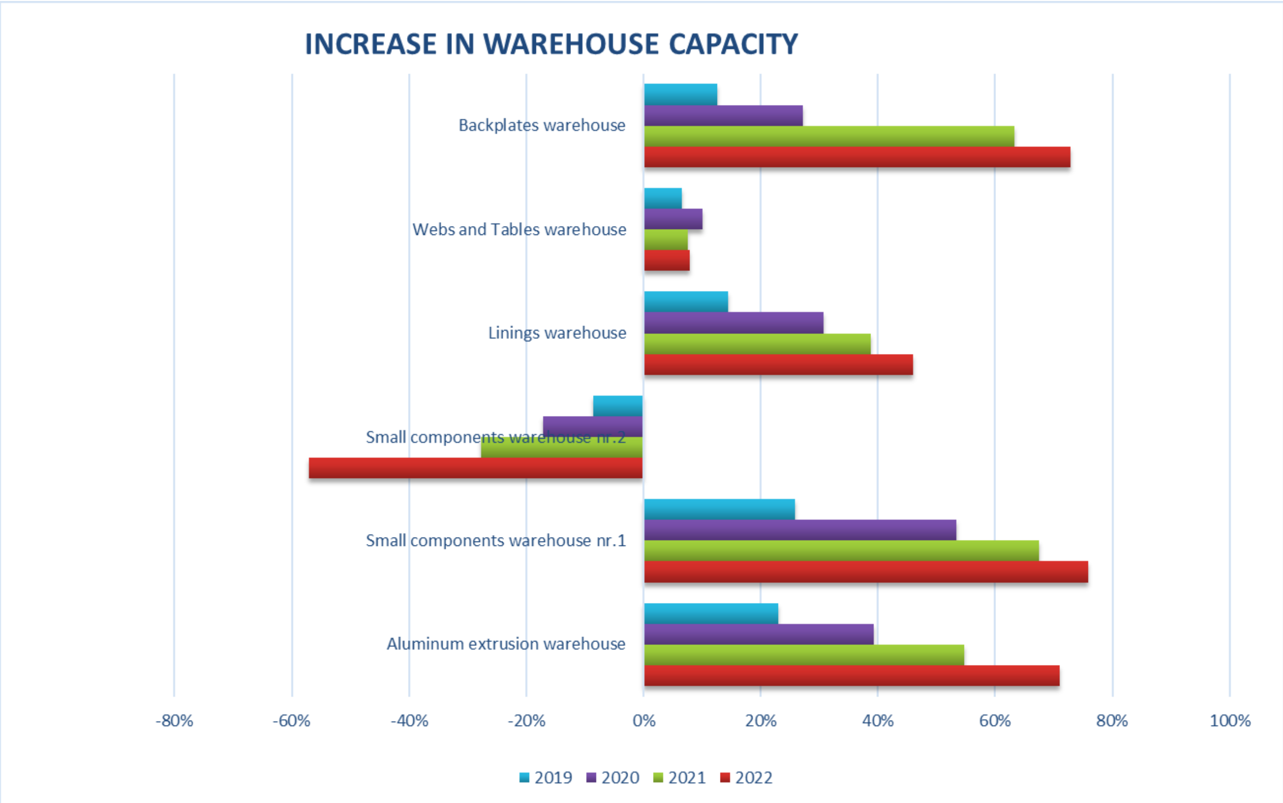

Figure 4.2. Increment in total bins number for storage of raw material

That means that the system will suffer by introducing new part number in the inventory, furthermore it is clear that without any improvement, the sensitivity index of the warehouses will show critical points that will make unacceptable operability of the system without inventory issues and warehouse stability collapse.

An aspect that can be detected is the inversion in trend of the commercial vehicle brakes components warehouse: conversely to the other warehouses, that one shows a decreasing trend, suggesting a phase out of that specific finished product in the next years. This aspect is relevant, because a reduction in volume can also means a reduction of unused space for storage: using it as an advantage, il could leads to a significant improvement in the floor space utilization and of the performances of the warehouse. (**Figure 4.3**)

Analysing the phenomenon in detail, it emerges that the cause of the decreasing trend stands in the phasing out of a specific product, the drum brake nr. 07 for applications on small commercial vehicle: such a decrease in volume exerts a notable influence on the warehouse, added to the fact that the other two products sharing the warehousing space with it maintain their production rate on constant levels or at least with a slightly increase, but due to their low impact on volumes (they are *niche* products with low production rate), the overall effect is the general decrease of bins occupied by the products and its raw material capacity need.

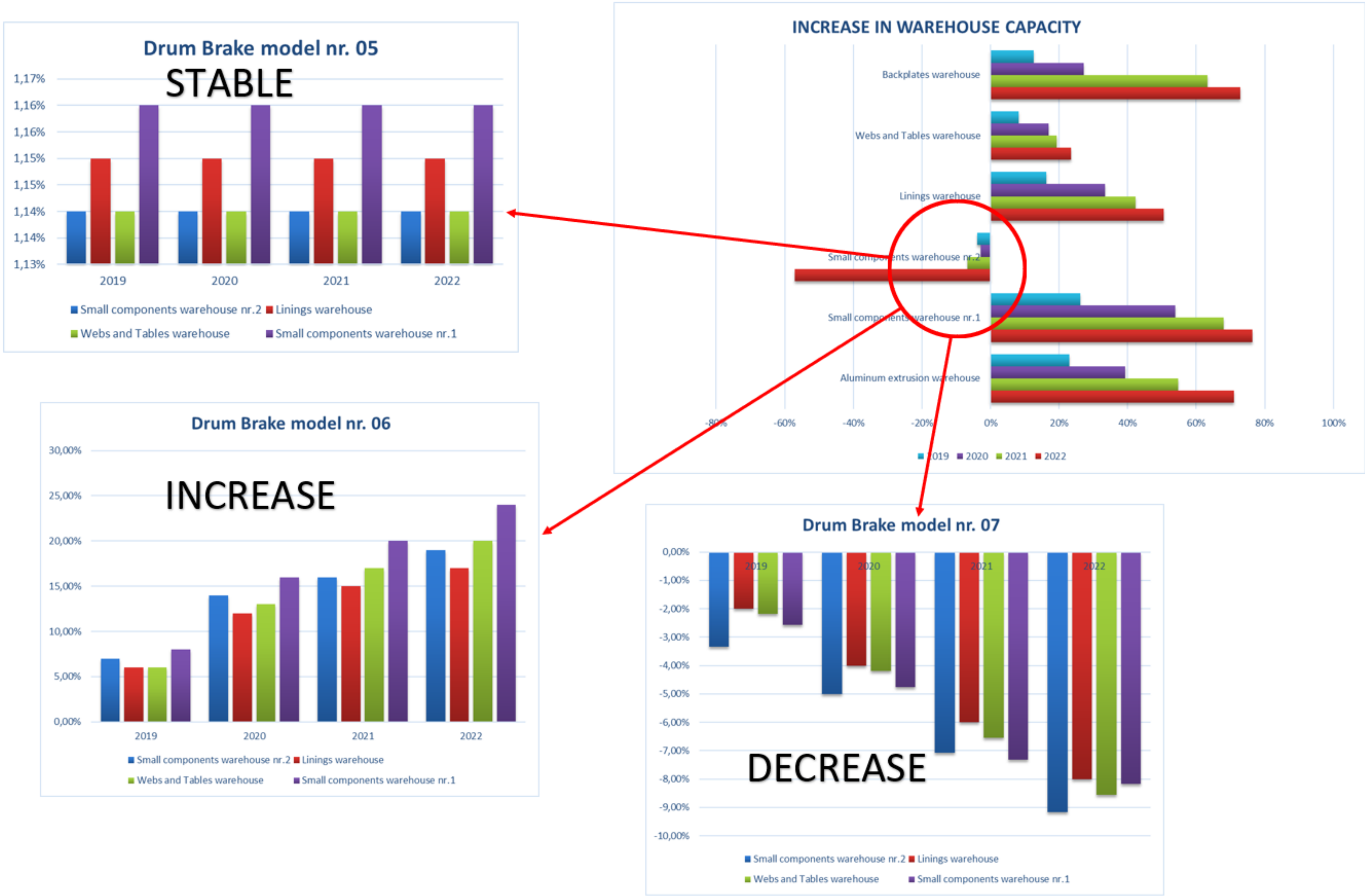

Figure 4.3. Decrement in bins occupation for the Commercial vehicle brake components warehouse

4.3 Warehouse improvement: the proposal

The previous paragraphs, through different examples, shown a clear need for rationality in the warehousing layout of Continental Brakes Italy plant.

The solution provided during the past years has been capable of resisting to constant production volumes, that have impacted on the warehousing solution unaltered in time, without producing failures or stresses in the system, that has proved to be a good solution for standard operations.

But the incoming distress situation due to the introduction of a new product, together with a slightly increase in the common production rates, made necessary to define a strategy to react crisis, in order to get a fast solution and at the same time to not to lose resources (e.g., time, capital, products).

For that reason, the purpose of the paper is to understand, after the analysis of the background situation, if a reasonable solution can be applied in the case under study.

According to the scenario, several improvement options can be considered, but it is furthermore important to understand the drivers to be applied when analysing a warehouse solution.

The improvement can be done according to three *must-be* drivers:

1. *Typology of rack systems*.
2. *Material handling equipment*.
3. *Methods for material distribution*.

An optional driver (*nice-to-have*) can be identified in the *optimization of vacant warehousing spaces*, especially in case when extra space is available for storage activity.

The inquiry will base its development on the definition of a new layout for each warehouse space, starting from the rack system, then the material handling equipment and at last the definition of a distribution method for moving the raw material around the plant, linking the assembly stations to the store.

4.3.1 Finished goods warehouse

The previous layout for storage of finished goods was based on a bare floor area, without any storage facility, for storing the crates containing products waiting for shipment.

The storage areas extended over a surface of around 795 square meters in total, divided according to the following ratio:

- 400 square meters total floor area for finished goods warehouse nr. 1, placed in between to the loading bay area and the production line of segment A-B car brakes.
- 395 square meters total floor area for finished goods warehouse nr. 2, placed on the opposite side of the facility, close to the lines of production of small commercial vehicle brakes.

At the time, the actual layout did not consider the installation of pallet racks for storage, because storage was just accomplished by stacking onto the ground the finished goods containers, inserting, and retrieving finished product batches according to a FIFO strategy.

The *First-In First-Out* (shortened to FIFO) rotation of physical goods is a common method used for management of inventories. Even if the methods have been a preferred choice by companies during history of industry, nowadays many organizations have not a gift for the application of this tool.

The ultimate goal of FIFO is to achieve an excellent stock turnover in the warehouse, giving priority to the output of products that have been stored the longest and can spoil or become obsolete.[35]

FIFO type stock management is not only applicable in a warehouse environment but is also used daily to manage the product in supermarkets and consumer outlets.

The reason stands in the obstacles that a firm can face while implementing FIFO process in the inventory or strictly enforcing it.

To perform a better analysis of the finished good warehouse, it is important to distinguish between advantages and drawbacks of utilizing that method in management of warehouses.[36]

Concerning advantages, by implementing FIFO strategy in the warehouse can lead to extensive benefits to the inventory: by applying the right Warehouse Management System it is possible to obtain several benefits:

- *Lower waste due to obsolescence*: obsolescence is an issue with a great impact on inventories; unsold products represent frozen assets, just growing up costs of warehousing. FIFO ensures they are picked and shipped as quickly as possible.
- *Quality control improvements*: long the same lines, by picking the oldest products you stock for distribution, you provide a better user experience. Your customers will receive a consistent product when ordering from you, making it easier for them to use their own

[35] Vv. Aa., *FIFO Warehouse Management Method: What it is and when it is used*, www.ar-racking.com [Online].

[36] Reid Curley, *Warehouse Dispatch: Pros and Cons of First In First Out (FIFO)*, Inventory Control, 2021, www.archon-interactive.com, [Online]

FIFO inventory management system. You can also reduce the number of incidents where customers received older, obsolete products that were not properly rotated.

- *Warranty issuance and control*: for those products for which the warranty is valid from the date of manufacture, FIFO ensures that the longest term for warranty.

On the other hand, it is worth to say that such a solution results to be tricky to be managed.

In fact, utilization of FIFO can lead to several drawbacks in management:

- *Better systems for compliance*: in most warehouses, the introduction of FIFO makes human management significantly difficult. The sheer volume of goods entering and leaving the space in any given time period, combined with the layout and accessibility of stock in your warehouse, usually require system upgrades to enforce FIFO. For FIFO to truly work, it needs to be consistently enforced, and some form of *automation and management system will be needed to make that possible*.
- *Difficult tracking at scale*: in case of large warehouse spaces, stock keeping units with thousands of pieces in stock in different locations, or high turnover on the stock requiring constant updates to the inventory level, it will be challenging to comply with FIFO. The larger the inventory, the harder the tracking.
- *Inflexibility*: the FIFO capabilities, combined to warehouse management systems, can be too rigid for companies manufacturing types of goods that becomes outdated in short time; but picks need to be steered based on criteria other than date of receipt.
- *Redeployment of space*: introducing FIFO, the designer needs to rearrange the storage space.

After considering pros and cons of adopting FIFO, it is worth to say that in case of Continental warehouse, the first aspect to be concerned about is related to the lack in complete control over the storage process, making difficult to assure high customer service level in case of delays or issues in delivery.

Another aspect is related to stacking heavy loading units (on average, each loading units weighs 600 kilograms) in indoor industrial areas, close to production lines / workshops.

Stacking poses a big effort to ensure the respect of safety standards on working environment: at first, a stacked piles of containers cannot reach tall heights without before assuring the respect of distances from common driveways or workstations, unless the presence of securing systems like grid walls or physical boundaries separating the warehousing area from the workshop floor.

As reported on a 2017 essay of PuntoSicuro.it, a reference site for safety on the workplace, storage activities are not exempted from risks. The main aspect to be concerned of are lifting, height of stacks, storage areas, aisles, and operator training.[37]

The reference considers the guidelines proposed from a Swiss institute for insurance and prevention from work injuries, correlated to local laws applied in the Italian industrial

[37] Vv. Aa, *Safe storage of stacked goods*, 2017, Luzern, https://www.puntosicuro.it/, [Online]

environment, that refer to the administrative order by the Italian government, number 81/2008.

To stack material, it is fundamental to consider:

- the storage area: floor conditions, presence of aisles, surroundings.
- Maximum height for stacks: concerning aspects related to types of loading units, instability due to wind or material handling equipment, presence of auxiliary systems (lighting and fire systems), maximum available height under the ceiling.
- Operator knowledge about stacking strategy and retrieval order.
- Presence in the surrounding of other people.

So, it is necessary to define a new solution, with the capability to improve productivity, safety, and rationality at the same time, relying also with the best practice in warehouse management (**Figure 4.4**).

Figure 4.4. Improvement of the finished good warehouse: from stacks to racks

In the figure, the implemented solution is shown (**Figure 4.7**).

The new system bases its concept on a block of movable pallet racks (as the one depicted in **Paragraph 2.3**), strictly designed for storage of Odette plastic containers, moving on motorized rails (**Figure 4.5**).

Figure 4.5. Movable pallet racking (source: Gonvarri Material Handling)

The system can store two different typologies of standard loading units for finished product: the largest container, with a base perimeter equal to 1000 x 1200 millimetres, and the second one (predominant typology), measuring 800 x 1200 millimetres.

The advantage of such a system is to exploit cubic and floor space of the rack at high levels, without wasting the available warehousing space.

The presence of rails on the floor allows the warehouse to be compacted in a block of racks, leaving just one aisle available for picking or loading the bins.

To enhance the utilization of the warehouse, the right tool for handling the loading units must be chosen: the requirement is to use the little amount of space but performing the same operation done by using a common counterbalanced forklift truck, so lifting considerable weight at notable heights.

A further aspect to be concerned is the need to put loading units at larger heights, respect to what is commonly done with traditional forklifts: this aspect is paramount due to the large number of bins that are concerned in this proposal of solution.

The most natural choice in this case could be a ***trilateral side-loader forklift truck***: this particular model of material handling equipment is also referred to as “narrow aisle turret truck”, because of its capability to move in very narrow aisles. The width of the aisle in case of adoption of a trilateral side-loader is 1700 millimetres, making the truck a natural option for highly saturated warehouses, where designer struggling for space utilization needs to save every inch possible to store as many loading units as possible.

The trilateral side-loader truck has a unique design: it is equipped with a *swinging mast*, able to rotate 180° around the centre of the truck, so that it can access unit loads on the left side of the truck or on the right side, as well as frontally placed. The operator cab is not at ground level, but it moves together with the telescopic part of the mast, reaching the storage bin together with the forks: this feature allows the turret truck to be used also for picking operations, not only for loading of pallets / containers on storage bin.

Figure 4.6. Trilateral turret truck (source: Jungheinrich AG)

Furthermore, the presence of movable shelves allows to only have one aisle at a time, differently from traditional rack systems, in which multiple aisles must be designed in order to access the storage bins.

The correct material handling equipment together with a compactable racking system: these two aspects allow the warehouse to allocate many loading units and at the same time, reducing the global footprint of the storage system: just 370 square meters of floor utilization, 54% less of previous area for both finished goods warehouses.

The presence of racks allows to store the containers on many layers, safely and without any height limits with respect to the stacking scenario.

By installing the movable shelves, it is possible for the plant to exploit the full cubic space underneath the facility storey ceiling. Each rack can rise up to 8 levels: considering an average height for each one equal to 1030 millimetres, the rack is extended for a max height of 8,24 metres.

Exploiting all the available cubic space allows to create 2128 storage bins for finished product (**Figure 4.7**).

Considering the final situation requirements at the end of the five-year planning, the sum of the capacity of the two warehouses was around 1760 storage bins; according to the exceptional features in capacity and floor/volume occupation, the proposed solution allows to gather the two previous arrangements in just one area: the devoted area is the one occupied in advance by the first warehouse, close to the shipping docks.

This choice is not random: concentrating the finished goods warehouse there allows to reduce distance from storage of the finished products from the shipment preparation area and, on the other side, the distance between the storage and the assembly lines, due to proximity to the majority of the assembly lines.

Another aspect considered in the analysis is the introduction of a collection run to feed the warehouse with containers.

According to the previous configuration considered the collection of the loading units by means of the storage forklift, to collect the loading units and consequently stack them in in the storage area. It has been decided to continue to adopt the system already present, because of the cumbersome features of the loading units, that are difficult to be loaded on a tug-and-trailer system, differently from what could be done for small components (that are break-bulked in smaller loading unit for utilization in workstations).

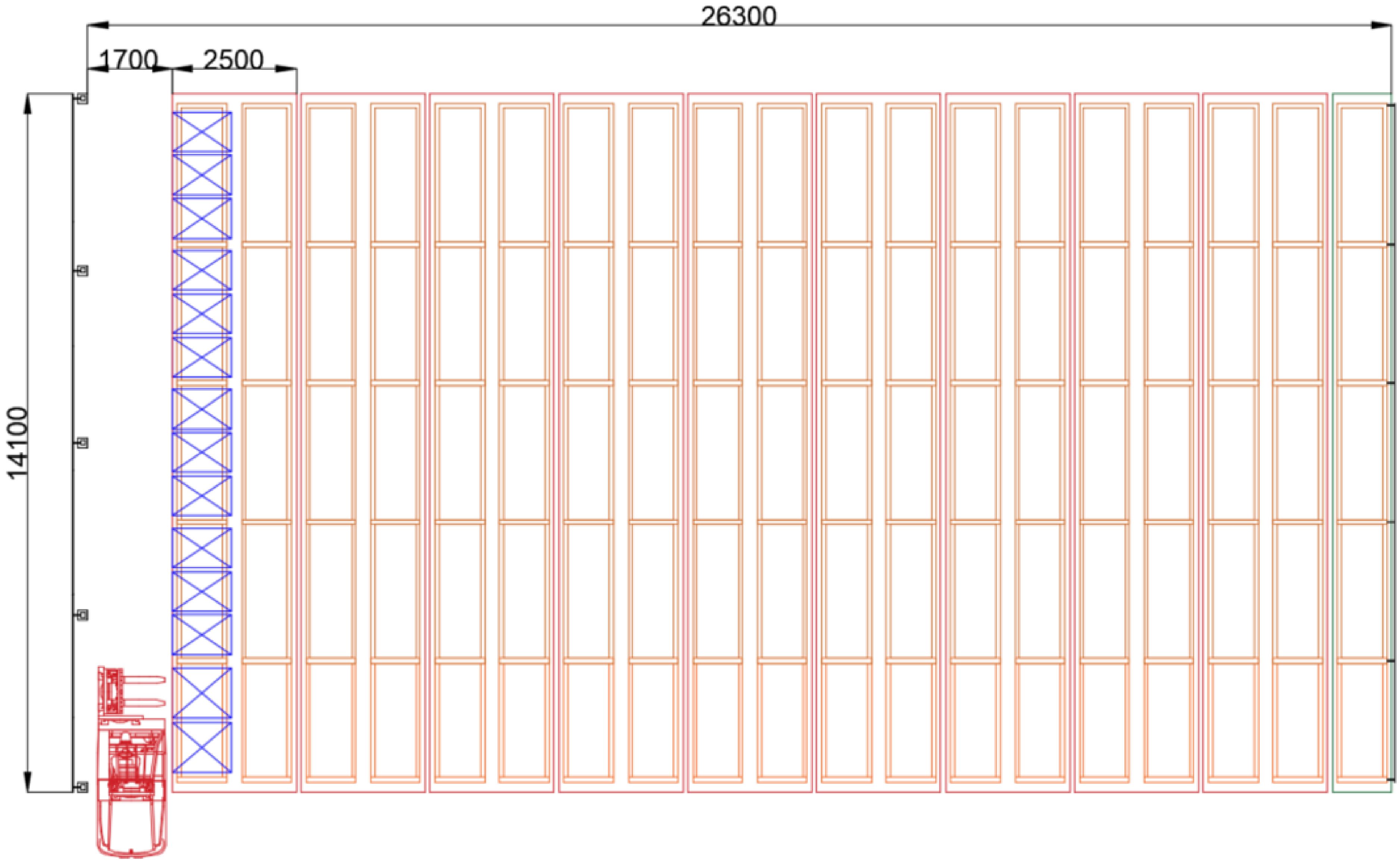

Figure 4.7. The proposed layout for the finished goods warehouse

4.3.2 Small components warehouse

The previous layout was based on a U-shaped warehouse area for storage of raw material components in central position with respect to the major assembly lines. Moreover, other components were stored in a separated warehouse area, placed in a more convenient place for replenishment of lines for manufacturing of large diameter models of drum brakes, on the opposite side of the plant.

The total amount of floor space occupied by the U-shaped warehouse was 294 square meters, for storage and supermarket operations; the second small components warehouse instead, developing along a straight line, occupied 52 square meters, with low storage bins occupation.

Thanks to the introduction of the new model of brake starting from 2019, the unchanged solution in a few months would start suffering a large stress on the raw material storage section, reaching the top value in 2022, with an average requirement of 180 bins in addition to the increasing volume of components due to other production lines.

In order to rationalise the available space for storage, the proposed layout is basically founded on a simple idea: due to similar characteristics of the stored parts (they are both belonging to the small component sub-group), the assumption was to increase the occupation of the storage facility by merging the two warehouses locations, to obtain a warehousing facility just dedicated to small components, with improved management of supplies.

The next aspect of the proposed solution is the placement of the warehouse: the purpose was the reutilisation of the area of the central warehouse for small components, changing the typology of storage system and dismantling the existing storage space of the second warehouse for small components. Furthermore, the position of the warehouse itself is strategic: the presence of unloading docks close to the system allows to reduce the distance of the storage from the incoming area, concentrating raw materials in a central position of the plant, allowing proficient replenishment of them.

Following the decisional stream that already impacted on the design of the finished goods warehouse, the strategy was to strive to better storage capacity and flexibility, by rethinking the storage area according to two drivers: the *optimization of rack system* and *the improvement in material handling equipment*.

The new layout, by reutilising the old position of the central warehouse, place the structure strictly close to the area occupied by the warehouse for finished goods.

The devoted storage system is a motorized block of compactable pallet-racks shelves, placed on steel linear rails, designed to store all equal loading units, composed by carton boxes stacked on wooden Europallets, characterized by standardised dimensions equal to 800 x 1200 millimetres.

Considering the need for restriction in space, the choice for optimal material handling equipment has been also in this case a narrow aisle trilateral side-loader turret truck, with extremely low requirements on aisles width, so further reducing the total impact on the plant floor space of this warehousing facility.

Plus, the presence of moving shelves allows to only have one aisle at a time, differently from traditional rack systems, in which multiple aisles are concerned. These two aspects allow this structure to set space for many loading units and at the same time having a small footprint: the new situation is just 163 square meters large, compared to 248 square meters area of the previous layout.

Nevertheless, the proposed layout can easily exploit the full height at its maximum, by extending for 8 levels under the ceiling of the plant facility.

The resulting storage dimensions, considering only Europallets as loading units, and the described storage systems characteristics, allows the warehouse to reach a storage capacity to an equal extent to 840 storage bins.

To perform proficiently the replenishment of the workstations with components, it has been decided to consider a *water spider system* (**Figure 4.8**) as a reasonable solution to move raw material from the warehouse to the assembly lines.

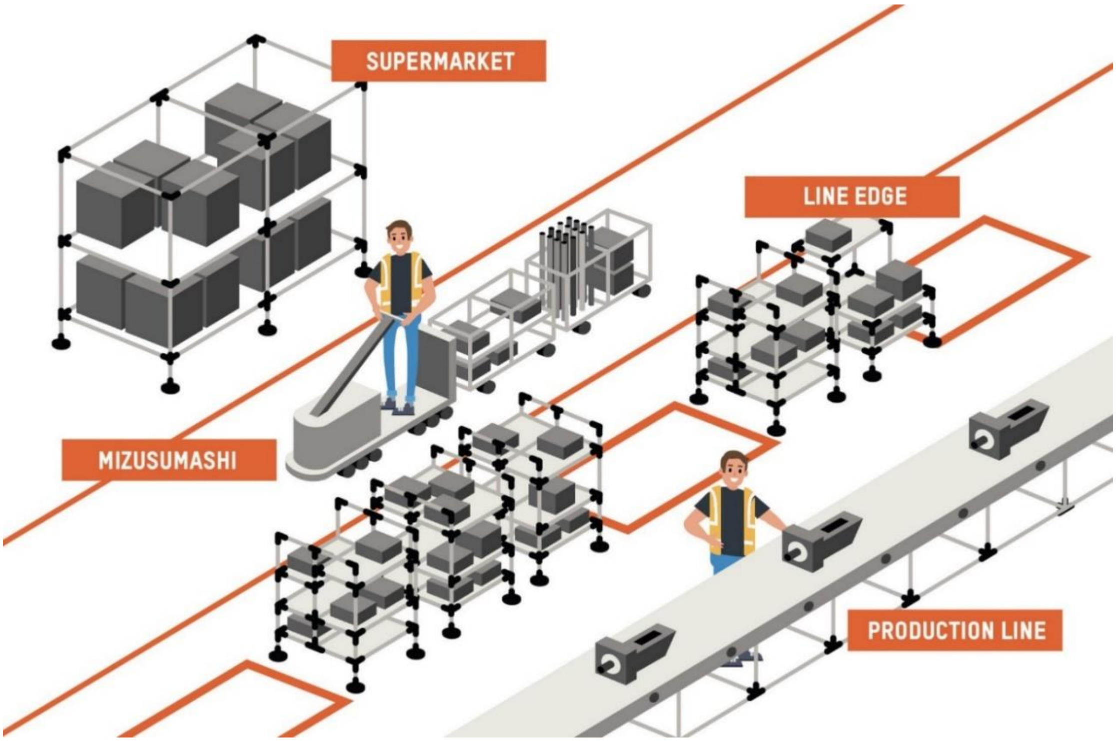

Figure 4.8. An example of *water spider* service (source: Flexipipe Inc.)

In lean manufacturing, supply chain managers define dedicated manpower, skilled about the production system and the warehouse management, to perform as *water spiders* (from Japanese *mizusumashi*), or integrated distributor of raw materials to workstations: knowing in advance when replenishment is necessary and refilling them with parts, they help maintaining a steady flow in production. This figure is strictly connected to kan-ban methodology, actuating just-in-time connection warehouse-production floor.

In the specific case under analysis, the water spider role is played by a warehouse operator running on an indoor tow tractor: a small traction unit, usually electrically powered, connected to a set of trailers, each one equipped according to the function to be exploited (e.g., hauling pallets, delivering boxes, tanks, etc.).

The small train runs across the assembly area, delivering raw material loaded at the warehouse, and supplied to the workstation after an "SOS call": the kan-ban card, a small tag system that it is exposed by the workstation to indicate that it needs replenishment of an exhausted component. The task of the water spider operator is to periodically run and collect kan-bans, to perform replenishment and avoid stops to the production flow.

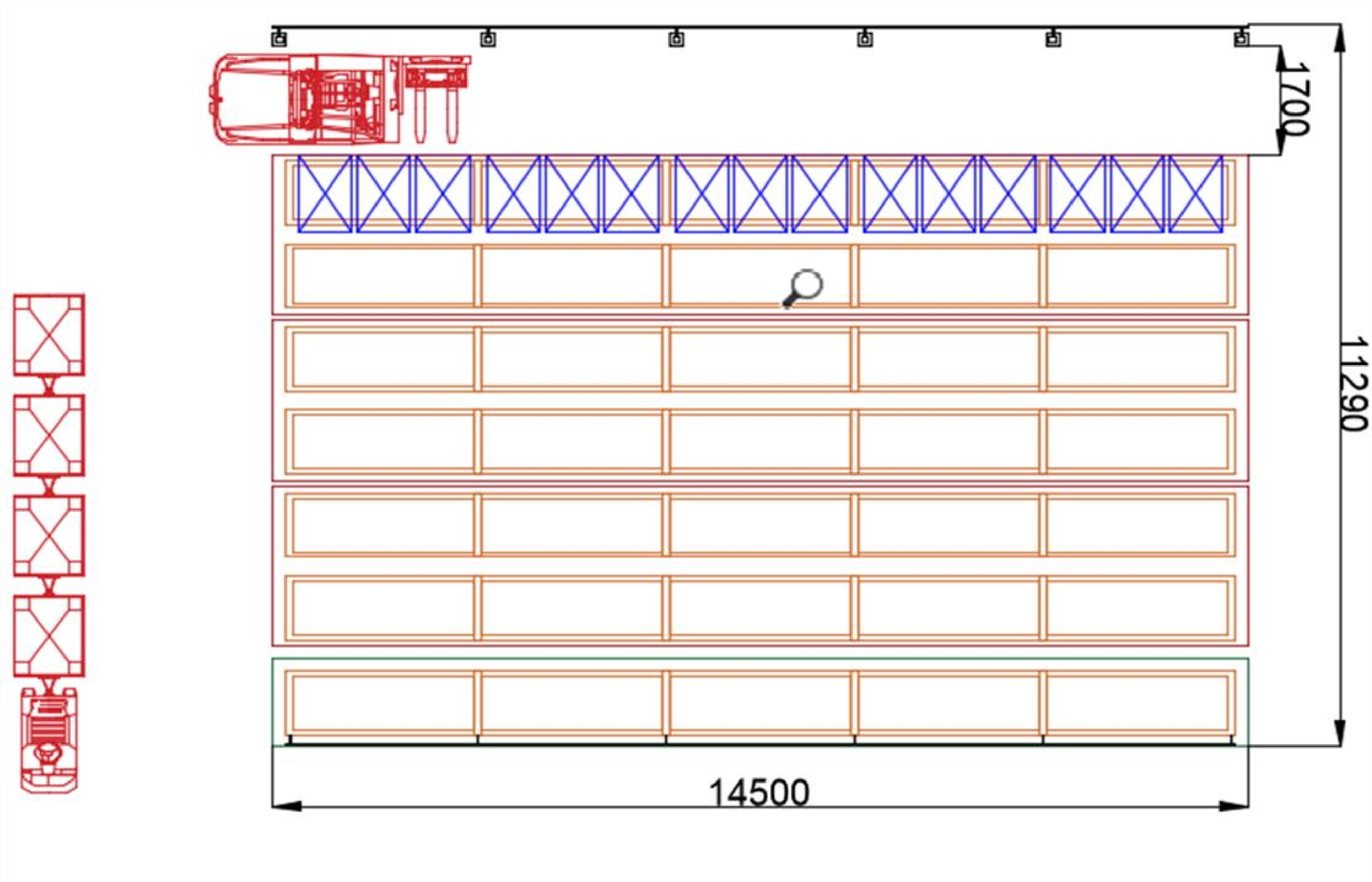

Figure 4.9. The proposed layout for the small components warehouse

4.3.3 Linings warehouse

The linings warehouse is a simple traditional storage system based on pallet racks, close to assembly lines, in central position.

The loading units are provided in pal-boxes, particular loading units made by a wooden pallet with cardboard sidewall, with a cardboard lid on the top. This unit allows great static strength to the packaging, ensuring the stackability of the pallets, during travel and storage.

For that reason, the occupation in the warehouse has been optimized by storing twice the available capacity in storing bins, going from 75 to 150 units.

The mid-term increment of volumes required to improve the capacity of the warehouse itself, without impacting too much on its layout.

To limit as much as possible the intervention, it has been decided to deploy some of the available space close to the warehouse, just to increase the number of bins to target values in order to avoid future saturation problems in case of further improvement of the production volumes or, on the contrary too many empty bins for diminishing volumes.

A simple solution has been implemented: by installing an ulterior set of conventional pallet racks (one with the bay capacity equal to three storage bins, the second of an extent equal to two storage bins), it has been possible to improve the capacity of the warehouse, adding 50 bins more to current layout. In the end, the storage capacity has been raised to a total number of 200 storage bins.

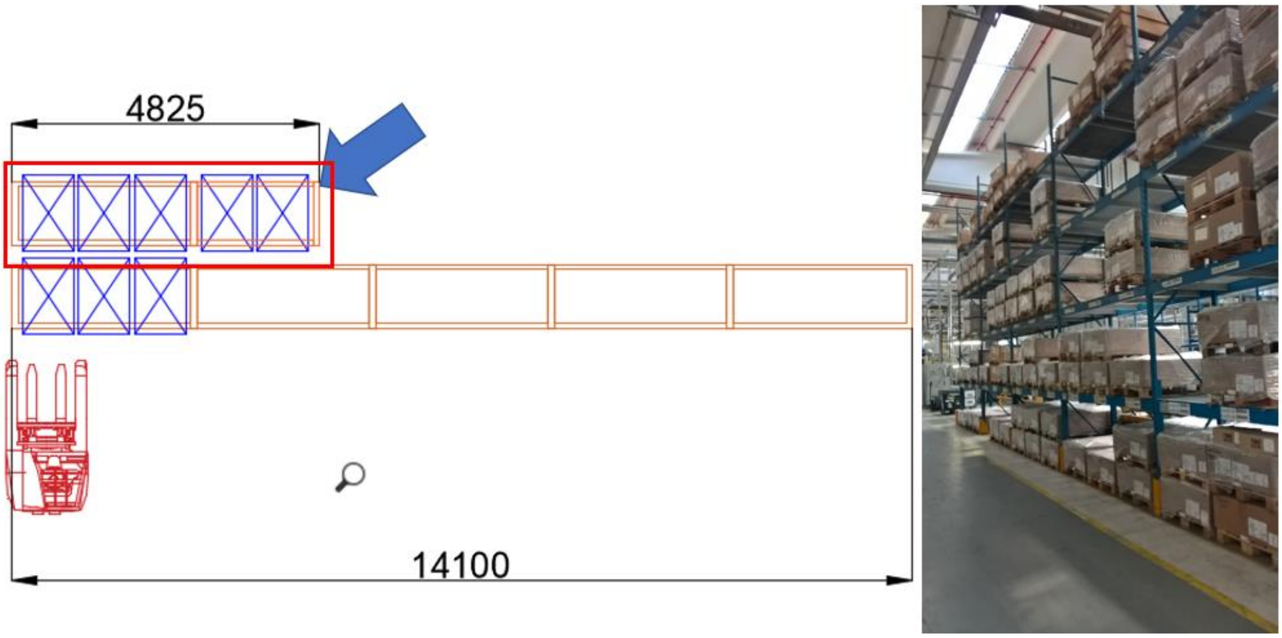

Figure 4.10. The proposed layout for the small components warehouse

The loading units are handled through reach trucks, according to the handling system already settled in the previous layout: the use of this forklift model allows to move in very narrow space without sacrificing flexibility in operations, conversely to turret trucks, that are strictly relegated to the warehousing utilization (due to particular infrastructure for guidance of the vehicle in aisles).

The pallets are distributed to the lining gluing workshop by means of the same reach truck.

4.3.4 Stamped parts warehouse (webs, tables and backplates)

In the stamped component group are included all the parts of the drum assembly that are manufactured via stamping procedures: all starts with a coil of metal sheet, that is used to feed the process. At the beginning, the sheet of metal is cut in several blanks of desired shape and dimensions; subsequently, the blanks are introduced in the stamping press, a machine made by a punch (an heavy duty piston that pushes on the blank, shaping the part) and a die (the constraint mould, on with it has been machined the desired geometry of the component), to be pressed and shaped in the desired configuration; at last, the parts are trimmed and stored, waiting for shipment to the customer.

In case of Continental, the process is performed by suppliers highly specialised in stamping processes. Every day, stamped parts (web, tables and backplates) are delivered to the assembly plant, and at the arrival they follow different ways: backplates are painted before being sent to assembly, while webs and tables are previously joined together and then painted, waiting to be glued to the lining.

Such a consistent flow of parts should be stored appropriately: the total available space for warehousing of parts consisted of around 470 square meters floor area, half for backplates, half for the remaining components, placed in two separated places of the facility.

The material is provided by metal containers for heavy duty applications. This kind of loading units has a unique feature, that essentially is the extreme resilience to intensive stresses due to high weight capacity, tough construction, and reutilization (containers can last for long periods before scrapping, some of them have faced a life cycle superior to twenty years, due to their robustness in application).

Parts are bulky loaded in the containers and shipped via full truckload to the plants.

At the plant, the containers are stored by counterbalanced forklift in a dedicated area in the middle of the factory: due to the lack in storage systems, the metal bins are stacked one on the other according to LIFO (Last-In First-Out) strategy (**Figure 4.11**): it means that the last stored part is the first one to be retrieved and sent to the workstations. The choice of that method is due to the low availability of space of the storage area, that does not allow neither to store goods in conventional ways nor to apply a FIFO method for retrieving, due to presence of constraints (wall boundaries) and intense passage of vehicles and operators nearby.

The first aspect concerning the poor efficiency of the system is that the warehouse layout has proved itself to limits the operability of the warehouse: in fact, stacks of loaded containers cannot reach elevated heights form the ground, due to safety issues concerning operators and risk of structural damages to the plant facility in case of fall; moreover, the capability of the space is not fully exploited, and the warehouse encounters an high risk of being stuck due to high saturation, especially during peak demand periods.

Figure 4.11. Example of stacked metal containers for heavy duty application

The second aspect is related to the chain of actions carried out between incoming and storage. The designer should think about the process to which parts undergo; once the loading units have been unloaded at the docks, they used to be stored in a waiting area, following the allocation in the storage. The main distance from the unloading dock to the storage is about 75 metres: the counterbalanced forklift transports two containers at a time, travelling on a driveway pretty close to assembly stations and walkways for operators (**Figure 4.12**).

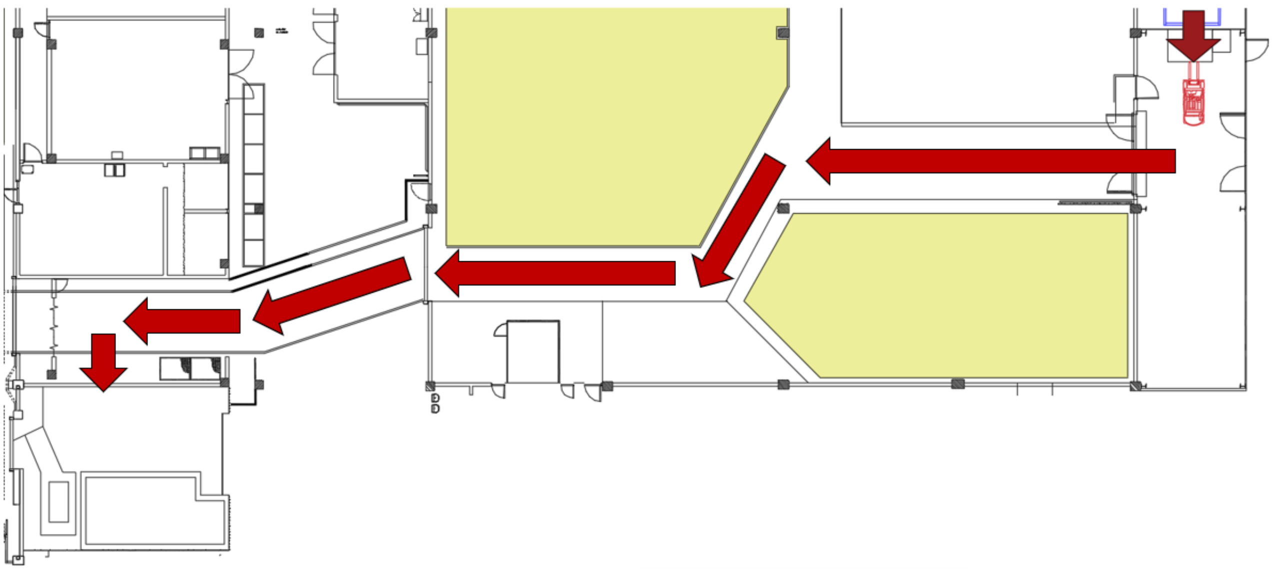

Figure 4.12. Total travelled distance from dock to warehouse in the old layout: 75 metres

To sum up, the system shows some drawbacks, that can be identified in:

- lack in proficiency for the LIFO system and the stacking.
- issues related to transportation of loading units from truck to storage area.
- long travelling distance by forklift.

The task of the designer is to think up a new strategy, able to proficiently dodge the setbacks that could occur from inadequate set up.

The solution built to overcome the distress is to think about a rearrangement of a disused area: the space occupied by the small components warehouse nr. 2. Because of its embedding in a general warehouse for small components, it left a large portion of floor area available for storage.

The purpose is to set in the area a system based on static conventional rack system with aisles, to store the containers instead of stacking. The advantages are multiple:

- increased proficiency in material handling with respect to LIFO system.
- each loading unit can be associated to a storage bin allocation, so the units can be easily loaded on WMS and tracked along the internal supply chain of the plant
- avoided risk of damages or injuries due to net separation from assembly lines, driveways, or common areas.

To save space, it has been decided to adopt a trilateral side-loader turret truck, that thanks to the excellent performance in narrow spaces, allows to reduce the total width of the aisles, with respect to a conventional warehouse managed through counterbalanced forklifts.

The trilateral truck helps at maintaining very low floor space encumbrance: the new warehouse occupies an area of extent equal to 432 square metres, with a storage bin capacity increased to 840 locations: 2 bins per bay, 5 bays per row, 6 levels for each row, for a total of 14 rows.

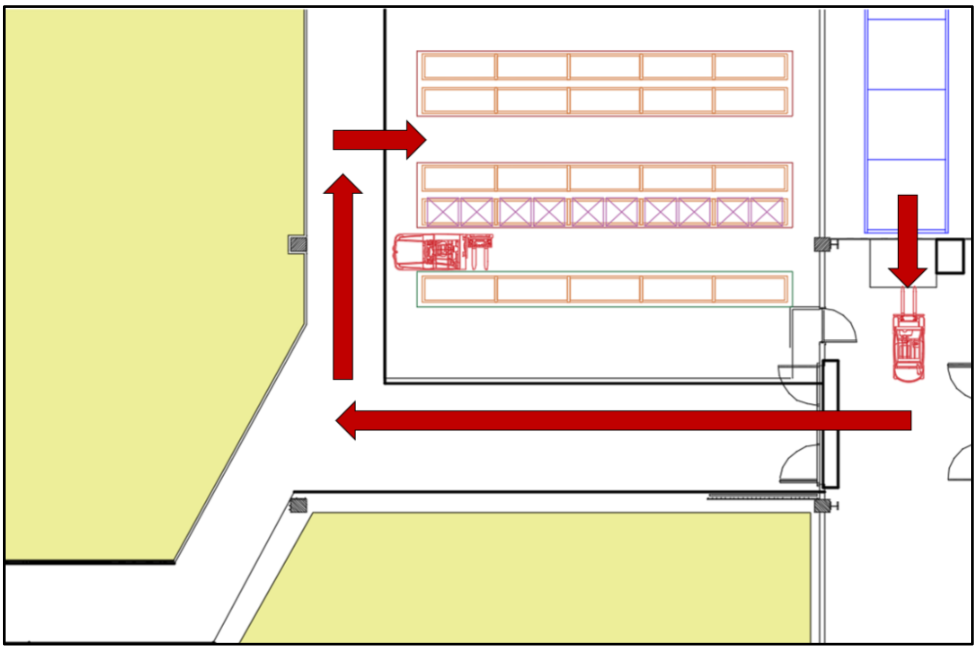

Figure 4.13. Total travelled distance from dock to warehouse in the new layout: 35 metres

The utilisation of the old components storage area is not random: an ulterior benefit comes from the reduced travelled distance performed by the forklift truck from the dock to the storage: 35 meters id the total path length to be travelled to bring loading units to the turret stacker, an improvement equivalent to half of the previously travelled distance (**Figure 4.13**).

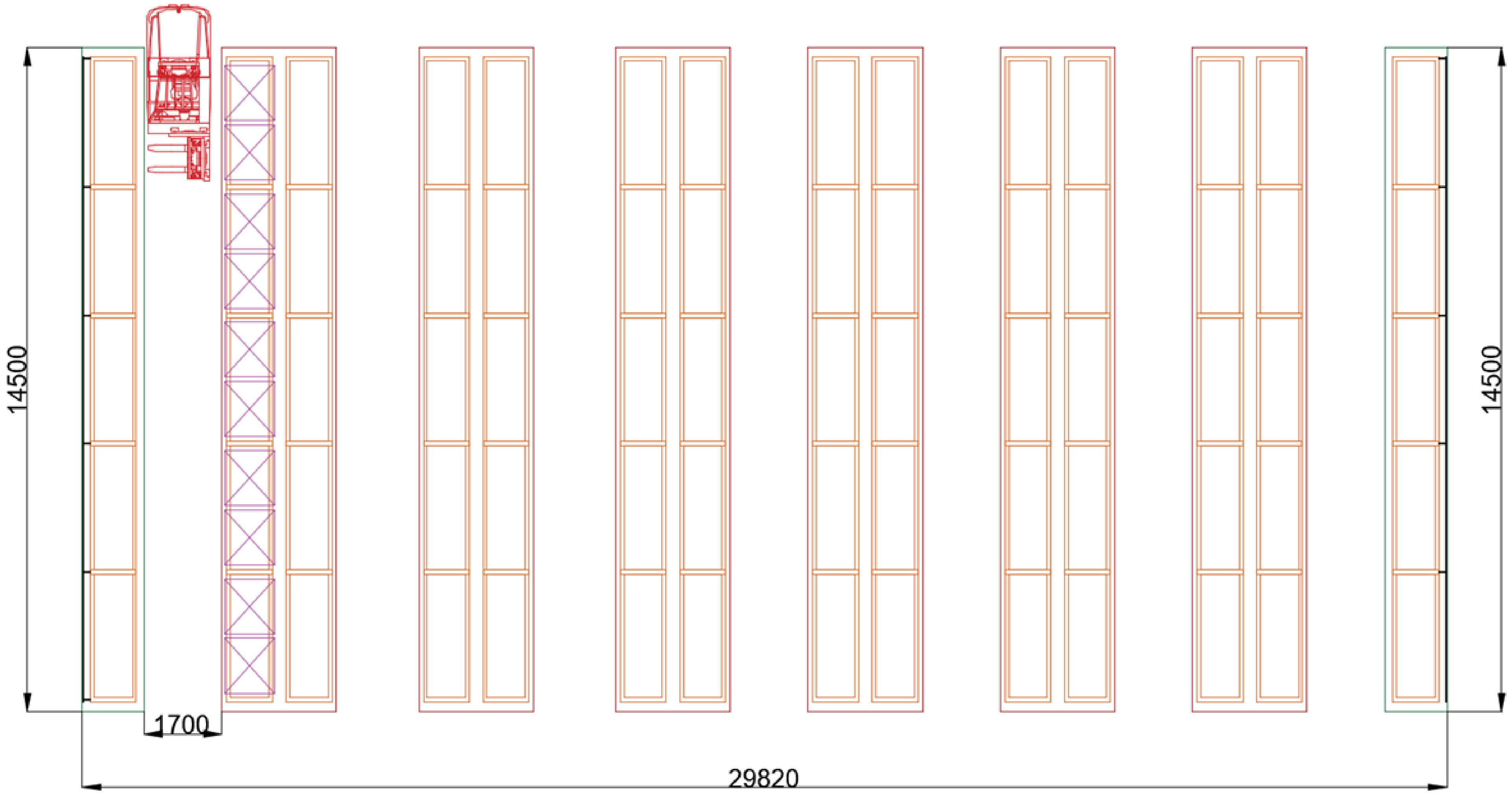

Figure 4.14 The proposed layout for the stamped components warehouse

4.3.5 Aluminium bars warehouse

The last warehouse needing for improvement: the storage area for aluminium bars, supplied to the plant to be machined in components for the assembly of the wheel cylinder.

The original warehouse was based on cantilever racks, situated in proximity to the area harbouring the machining equipment (*transfers*).

In the original layout, 6 cantilever racks are adopted, hosting 142 bins (**Figure 4.15**).

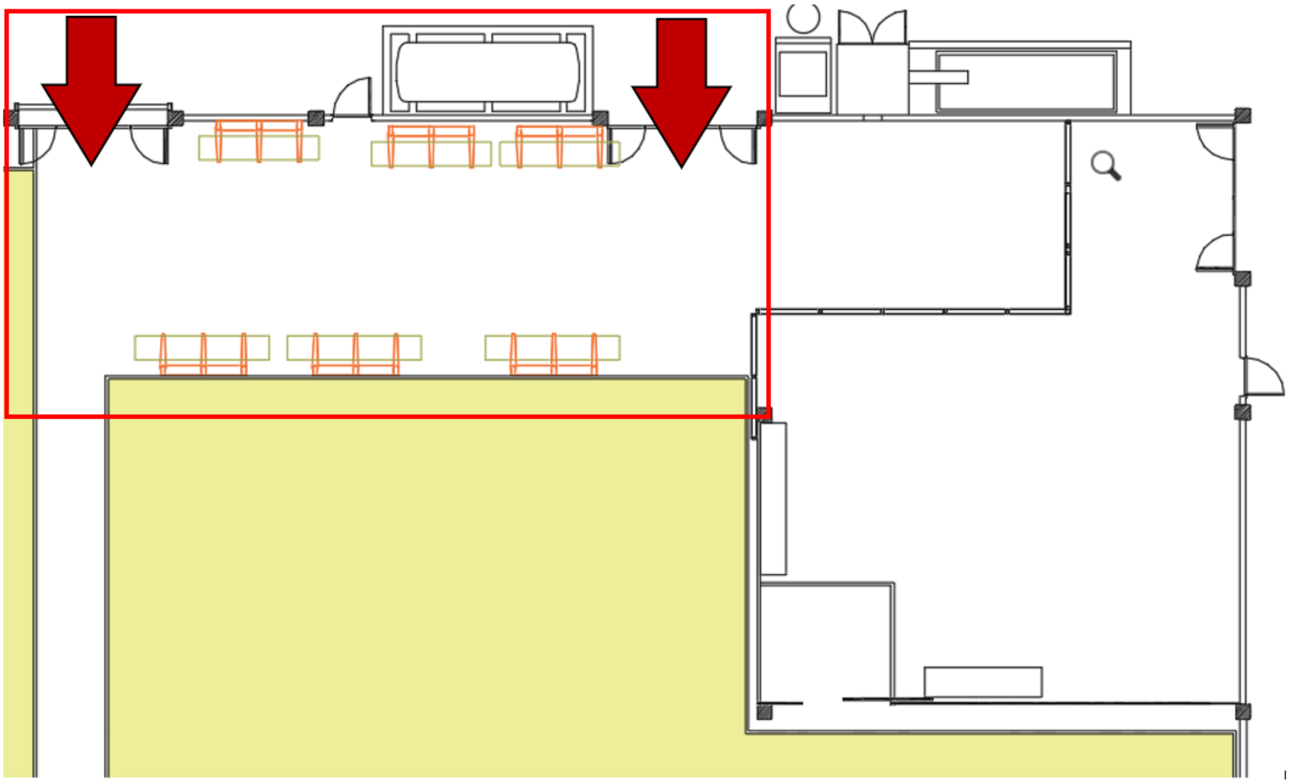

Figure 4.15. Original layout of aluminium extruded bars

The implemented solution is just based on a basic addition in the number of bins to the already existing ones. According to need exploited from the volume analysis, it has been decided to increase to 240 bins the available warehousing space.

Due to unavailability of space in the workshop, the extra cantilevers have been placed in an aisle close to the area, that allows to transport the loading units to the transfers without any hurdle (**Figure 4.16**).

Transportation is performed by standard reach trucks.

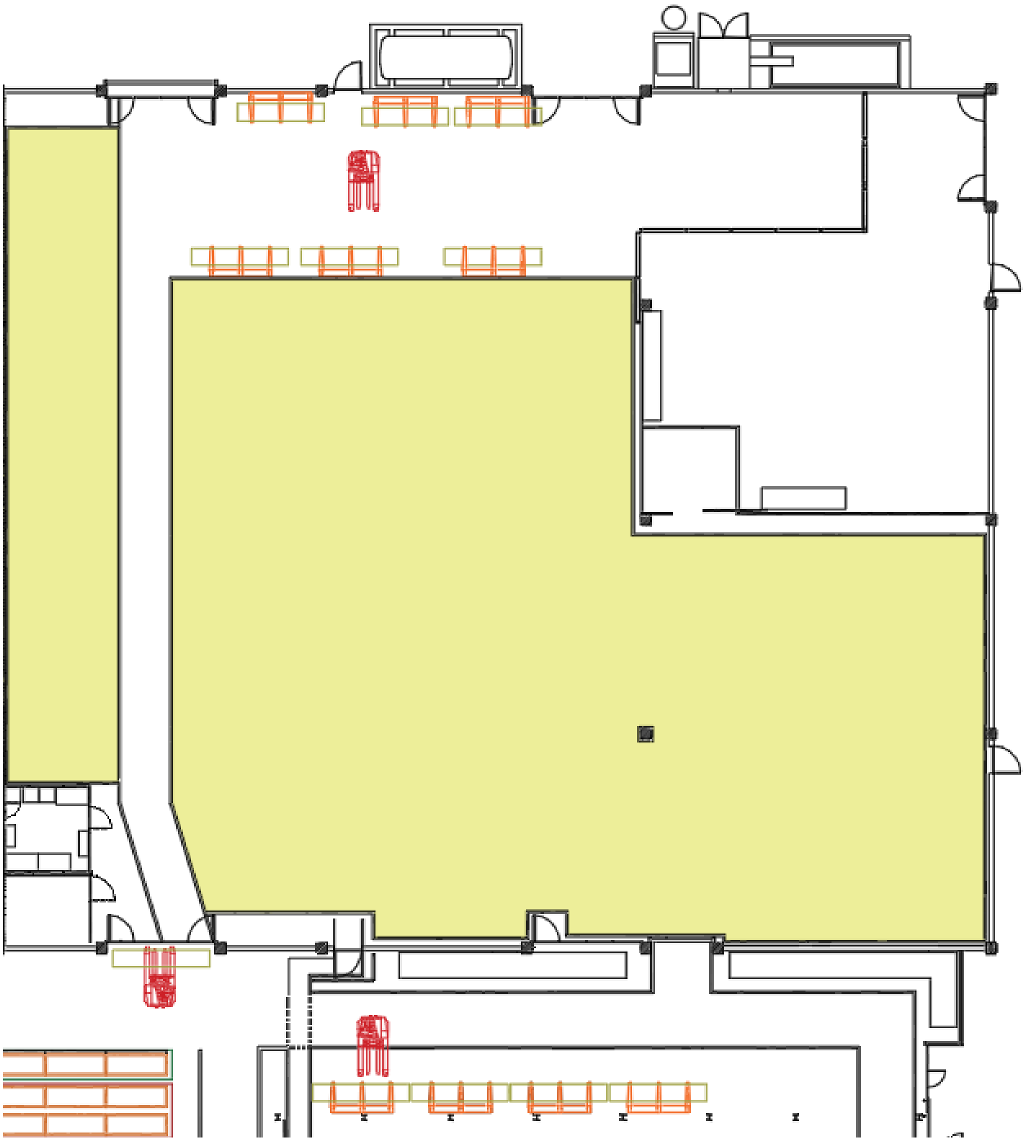

Figure 4.16. New layout: on the bottom the extra racks

5. Analysis of the result

5.1 Benefits of the improvement

The implementation of the new storage system represents a revolution with respect to the previous layouts analysed in the course of this paper.

Concerning benefits, several aspects that influence positively the process can be mined from the research, as a spark for further studies or application of the subject in other realities of supply chain.

The first aspect to be considered is the *improvement in the supply chain management of the plant*: the adoption of rationalised systems (inventory management systems, storage pallet racks, etc.) helps in management of the storage, compared to previous system based on stacking of loading units according to store-retrieve orders (FIFO and LIFO).

The second aspect is related to the *organization of the warehouses by logical types*, according to existing similarities between products: starting from a division of the products in subgroups (associating raw material according to common features), the designer can proficiently define a logical scheme for the structure of each warehouse, that in practice can be considered as a rough definition of the architecture standing at the case of the management of storage by means of WMS systems (as defined in **Paragraph 3.2**).

The third aspect concerns the *placement of the warehouses in strategical position* with respect to warehouse docks and workstation: the warehouse may be assumed as the focal point in the assembly plant, as source of material for the internal supply chain and drain for finished products. Just like the "heart" of the production system, it must be placed in a convenient place, to serve at its best even the most peripheral area of the plant; the target for the designer is to choose a median position, in order to reduce the itinerary of the goods during replenishment, reduce cycle time and reduce costs for distribution.

As a fourth aspect, distribution: by the introduction of a water spider in the supply chain, it is possible to introduce an improved integration between the warehouse and the production area: the service provided by the operator, owning skills and knowledge about inventory and production process, is a core aspect for the enforcement of lean manufacturing practice in the real working environment. The water spider system is an investment, to save resources in long term by creating a seamless stream of value along the whole supply chain.

The indicated aspects can be strengthened beyond, by referring to specific *key performance indicators* (KPIs) for warehousing.

By means of the KPIs variables the company can compare the practical improvement with numbers, measuring, tracking, and analysing performances related to production. They allow the comparison of observed results and planned targets, due to the importance of measurement of the performances to set the improvement processes.

Concerning the case under analysis, the choice felt over some elements to be considered when performing a numerical analysis of the warehouse performance:

1. *Reduction of "Dock-to-Stock"*: by this expression we refer to the process of in-bounding / out-bounding loading units, from the docks to the racks and vice versa.

It is an important aspect to monitor and improve; according to the American Productivity & Quality Centre (APQC), warehouse managed by smart systems can reduce the process of inbound by 90%, compared to traditional storage methods. [38]

Process improvement can be performed essentially by redesign of the warehouse and introducing better systems, setting a capable WMS, introducing automation when possible and reducing wastes in material handling.

2. *Efficiency in put-away*: put-away is the process of placing each item at a designated location (as anticipated in **Paragraph 3.2**), effective process guaranteed a reduction in lead time of the operation, ensuring a smooth dynamic of picking. The most effective KPIs related to put-away are:

- ***Labour and Equipment Utilization***, that corresponds to the percentage of manpower or equipment used in the warehouse to perform put-away, allowing to compute the costs related to management of the warehouse. Depreciation of storage system, equipment and costs of manpower are fundamental to be compared to operations.
- ***Put-away Cycle Time***: the time required to perform the whole put-away operation, impacting on the lead time of warehouse. Concerning this aspect, a valuable calculation must consider time for unloading the truck, time for completing the incoming operations, time for put-away.

  Concerning the layout of the case study, time for put-away is dependent on the kind of storage system applied:

  - *For the small components warehouse and the finished goods warehouse*, the time for it must include the motion time required to move the racks in order to select the right storage location, and the cycle time that the turret truck takes to move from ground position up to the bin.
  - *For the stamped parts warehouse*, the only time necessary to esteem put-away CT is the cycle time of the turret truck.

3. *Storage efficiency*: a valuable aspect to be measured, impacting on automated or conventional warehouses. It is based on:

- ***Space Utilisation***: percentage of the space occupied by the inventory versus the total space available for storage.
- ***Inventory turnover***: an index aimed at measuring how many times a company regenerate the storage in a defined period of time, in order to measure competitiveness, to make forecasts about profits and to assess the level of quality of the operations.

  The mathematical definition of the Inventory turnover index is:

[38] Vv. Aa., *Dock to Stock Cycle Time for Supplier Deliveries*, 2021, Houston, American Productivity & Quality Centre, www.apqc.org, [Online]

$$Inventory\ Turnover = \frac{Finished\ Goods\ costs}{mean\ value\ of\ Inventory}$$

5.2 Sensitivity analysis of the warehouse performances

In the analysis of the warehouse, an important aspect is to understand the robustness of the solution to the impact of the external environment.

The warehouse of a manufacturing facility is constantly exposed to stressful situations, having roots from different drivers, more often represented by market fluctuations, increase / decrease in volumes, need for flexibility of the storage system.

The core aspect in the definition of a proposal is that the solution must show a degree of resilience to changes in times; apart from the degree of innovation brought to the past situation, must not only be efficient in the operation, but the system needs to be tested in stressed operating conditions.

The analysis of sensitivity of the proposed layout starts by developing an assumption: the improvement in the system, as a result of an investment, should be able to withstand strain due fluctuations in the demand for products, either in best or in worst cases conditions.

As the demand increased of around 10% in the time span 2018-2022, the new target is to give in to a provocation, by observing what is going to happen if the demand, starting from 2023:

- *increases* in five years of 10% (*best-case analysis*).
- Conversely, *decreases* in five years of 10% (*worst-case analysis*).

To start the analysis, the proposal is to focus as a first step on the economic impact of implementing the warehouses.

For each warehouse unit, an approximated cost analysis has been performed, considering as a key aspect for the definition of an economic value of the storage (**Table 3.1**):

- Cost of the storage system: the cost of purchasing the storage system, including the elements composing the structure (e.g., pillars, beams, protection grids, accessories, etc.), the installation, and testing procedures.
- Cost for safety obligations: separated from the net storage system purchasing costs, they are the costs to be paid to cover safety insurance costs during the installation of the storage.
- Cost for construction: including expenses for performing construction work to install the storage system (e.g., masonry, plumbing, connection to power network grid, etc.).
- Cost of renting of material handling equipment: considered as a long-term rent (average duration equal to 60 months), it is the cost for the stacking equipment.
- Cost of labour: the cost for the operator, consider equivalent to the cost of one operator on 2 eight-hours shift, 5 days / week, for 220 working days / year.

	FEATURES								COST OF EACH WAREHOUSE SYSTEM					
WH VERSION	BINS	BINS PER LEVEL	COLUMNS	ROW	AISLES	AREA [sqm]	STORAGE TYPE	MHE MODEL	RACK	SAFETY COSTS	CONSTRUCT. WORK	FORKLIFT RENT	OPERATOR	TOTAL COST
FINISHED GOODS	2.128	14	19	8	1	370	Movable rack	Trilateral Turret Truck	198.500 €	3.300 €	11.800 €	50.000 €	123.200 €	386.800 €
RAW MATERIAL	840	15	7	8	1	163	Movable rack	Trilateral Turret Truck	79.800 €	1.300 €	3.600 €	50.000 €	123.200 €	257.900 €
LININGS	200	40	1	5	2	60	Static rack	Reach truck	2.300 €	138 €	184 €	15.000 €	123.200 €	140.822 €
STAMPED PARTS	840	10	14	6	7	175	Static Rack	Trilateral Turret Truck	81.500 €	4.890 €	6.520 €	50.000 €	123.200 €	261.110 €
ALUMINUM EXTR.	240	-	-	-	-	-	Cantilever Rack	Reach truck	18.000 €	1.080 €	1.440 €	15.000 €	123.200 €	158.720 €

Table 5.1. Average depreciation costs of the warehouse

By comparing the value to the inventory value to be store in the warehouse it is possible to look for a break-even point (to know when the investment is recovered) and then compute a depreciation rate to understand the residual value of the system during its life cycle.

It is important to distinguish between investment and running costs: the first is only concerned to the calculation of the investment for purchasing the structure (Cost of the storage system + Cost for safety obligations + Cost for construction), while the second is related to the cost for maintaining the warehouse (Cost of renting of material handling equipment + Cost of labour).

To evaluate the profitability of the investment, is necessary to evaluate the Return of Investment (ROI):

$$ROI = \frac{Net\ Profit}{Cost\ of\ the\ investment} * 100$$

Going back on sensitivity, the computation of the best- and worst-case help to understand how the warehouse can be resistant to swings in demand or, on the contrary, burden by demand variation.

The first aspect to validate is to choose a suitable increment value: 10% has been considered in the analysis because of the linearity with the increase trend of the case study.

By decreasing the volume by 10%, the system does not show any sufferance, by dealing with all values of warehouse capacity levelling around 75% (**Table 5.2**).

By increasing volume of 10%, the situation shows a goods resilience of the system, that can stand variation in volume without excessive sufferance and with good values in term of warehouse saturation (**Table 5.3**).

In details:

- Finished goods warehouse: by increasing the demand, the volume expressed as number of bins passed from 83% to 91%, indicating that the warehouse can store 190 pallets yet.
- Raw material warehouse: the increased situation had a consistent impact on the warehouse, that in five years reduced its saturation safety threshold of 9%, on the other hand indicating the availability of 55 vacant bins.
- Linings warehouse: the increase by 10% hit the spot in the warehouse, going from 84% saturation to 92%, allowing 15 units more to be stored in the warehouse.
- Webs and tables warehouse: in the best-case situation, the warehouse is showing a relevant amount of crisis, indicating that by augmenting the demand the saturation increases as well, requiring to think up different solution to avoid collapsing of the storage system.
- Backplates warehouse: best-in-class in terms of saturation, it is the warehouse that better reacted to the stress test, with a final 86% saturation value at the end of the increment period.
- Aluminium extruded bars warehouse: completely aligned with the other warehouses, it ended the test by a 92% of occupation, leaving free space per 20 extra loading units on the racks.

WORST CASE (DECREASE OF 10% IN VOLUME)					
WH VERSION	REQUIRED BINS	NEW CONFIG BINS	OCCUPATION	with 10% increment	FUTURE OCCUPATION
FINISHED GOODS	1.763	2.128	83%	1.587	75%
RAW MATERIAL	714	840	85%	643	77%
LININGS	168	200	84%	151	76%
WEBS&TABLES	376	420	90%	338	81%
BACKPLATES	330	420	79%	297	71%
ALUM. EXTRUSIONS	200	240	83%	180	75%

Table 5.2. Sensitivity analysis: worst case situation

BEST CASE (INCREASE OF 10% IN VOLUME)					
WH VERSION	REQUIRED BINS	NEW CONFIG BINS	OCCUPATION	with 10% increment	FUTURE OCCUPATION
FINISHED GOODS	1.763	2.128	83%	1.939	91%
RAW MATERIAL	714	840	85%	785	94%
LININGS	168	200	84%	185	92%
WEBS&TABLES	376	420	90%	414	98%
BACKPLATES	330	420	79%	363	86%
ALUM. EXTRUSIONS	200	240	83%	220	92%

Table 5.3. Sensitivity analysis: best case situation

5.3 Validation of results

According to the analysis of the sensitivity and the results in term of saturation and flexibility of the warehouses, it is possible to state that the solution is actually pretty stable and reliable, including state of the art solutions for warehousing that are in line with actual trend in literature.

This type of layout also leaves a certain degree for improvement, allowing the supply chain manager and the designer free to implement also more advanced information system for real time management of kan-ban, or goods receipt by RFID scanning systems, as shown in the latest studies about implementation of Lean Manufacturing related to Industry 4.0.

Furthermore, the purpose of the analysis is to set the path to an improvement model: the system can be a suggestion for those who wants to improve their knowledge about warehouse design and take notes on how the redesign procedure really works in industrial environment, which are the relevant data to be considered for analysis and which are the best practices to set the design.

The final layout shows better concentration of the warehouse, without scattering around the facility or utilization of inadequate areas for storage tasks (**Figure 5.1**); the increased utilization of space, the definition of new handling equipment and the fixation of the distribution network for raw material have been a renewal aspect for the logistics of the plant, that could benefit from this humble paper to get a spark for implementing a new warehousing solution whenever needed, in case of future improvement of the production process or redesign of the supply chain.

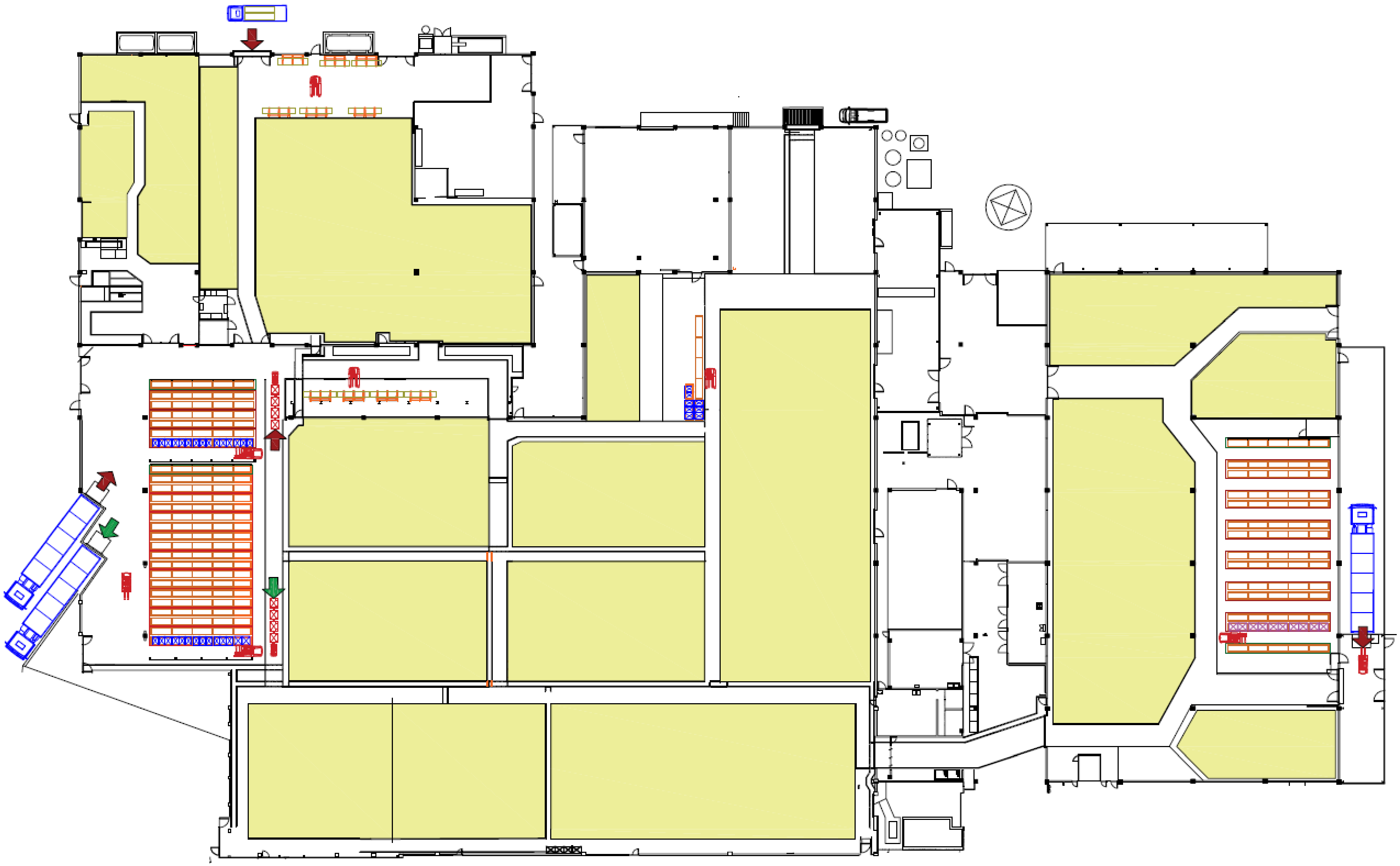

Figure 5.1. The final layout of the warehouses

6. Final Considerations

The final purpose of this paper it has been to focus the attention of the research on the aspect concerning the reaction of a supply chain to causes of distress or issues that could impact on it during the development of routine activities in non-perturbed situations.

The relevance of the case study is that it has roots in a real example, extrapolated from a former experience in the industrial tissue of the writer's area: so, all the results are proved to be consistent in the reality of supply chain management, at the same time resulting applicable not only to the automotive manufacturing scenario but also to other fields related to distribution and management of loading units.

The study began by introducing the cause of distress in the supply chain of an automotive components manufacturer.

Stress in the supply chain was due to the introduction in the production system of an increase in the customer demand: apart from positive consequence on plant profitability, the situation led also the drawback related to an increment in the production volumes for different categories of drum brakes, during the five-years period spanning between 2018 and 2022.

The main effects of the demand increase were:

- Increase in production volumes of standard assemblies.
- Introduction of a new family of product based on electronic functioning.

Whether the increase in the production volumes for standard parts could be manageable, in case of the brand-new component the same principle resulted to not to be applicable, due to steep increase in volume that needed to look for new solution at warehousing level and re-thinking of management of the internal supply chain for Continental Brakes Italy plant.

To get to consistent values on which base the design of the inventory, the first step is the analysis of the production planning based on forecast of the customer demand in the following years.

The data extrapolated from the Strategic planning file are of paramount interest because they offer a vast scenario of the future behaviour of the company in the next years; furthermore, the plan shows the order of magnitude of the production volumes, for dimensioning the production system.

The results are then collected and turned into requirements for stock: the quantity of raw material for each finished product is deducted from the finished product volume forecast; knowing the dimensions of each stock keeping unit, strategists can work out the amount of bins necessary to store the raw material, necessary to assemble the part. Then it is just a matter of grouping the different raw material according to macro-families to obtain reasonable values for dimensioning of each warehouse.

Next step, the definition of the main drivers on which establish the improvement: in case of this paper, the chosen elements have been the essentially the typology of storage system, the material handling equipment, and the distribution network around the plant.

So, for the different scenarios, different solutions for improvement have been chosen; movable pallet racking systems to improve proficiency of previous storage system (stack on floor and traditional static racks), trilateral side-loader turret trucks to perform material handling and picking operations (this solution allowed to dismiss previous system based on *warehousing supermarkets*), water-spider networking based on kan-ban system and utilization of tug train to move raw materials and finished goods from-to assembly lines and storage.

Then, the improvement needs numerical consolidation: after providing an economical assessment of the situation, the next aspect was to establish sensitivity of the new layout to further distress in the supply chain. Setting an extra 10% of volume increase over an extra five-year time interval, in line according to the exposed increment in production, the system was tested to prove its resilience to changes, obtaining as a result a percentage threshold expressing the tolerability of the warehouse and its saturation level.

The principle at the base of this paper was to prove the link between state-of-the-art techniques in warehousing (such as RFID based material handling equipment, dynamic storages, and warehouse management systems) and a real case study, that is interesting from the point of view of connecting the theory about supply chain and what is really performed in industry.

Nevertheless, the purpose is to report to the audience some tips related to the strategic thinking that stays behind the evaluation and design of supply chains and warehouses: how to proceed in the analysis, which tools can be fitted and used to mine data and extrapolate valuable information, which are the solution for management of material offered by the warehousing specialists.

The first step to be considered is to define *drivers* for the analysis.

They are the guidelines on which the warehouse designer should set its path to the resolution of the problematic. The drivers are useful to understand which aspects are to be emphasized by the user in order to get to valuable solution of the problem, and they can be of different nature: economical, physical (also referred to as *constraints*), safety drivers, etc.

Once the drivers have been defined, the definition of a new layout or management system can be performed without struggling, because they make clear which aspects should be examined in depth and which one can be overlooked.

According to this particular case, the suggestion to the audience is to establish as a starting point to think about if the solution needs to be designed starting from zero (*greenfield warehousing system*) or the system needs to be renewed (*brownfield solution*, just like the one shown in the essay).

Then, once the trail has been set, it is possible to establish the drivers for the analysis: in this case, the suggestion is to split them in two typologies, according to the degree of relevance that the designer attributes to them:

- *Must-Be*: they are compulsory to develop a consistent analysis and provided valuable results.
- *Nice-To-Have*: optional drivers, their absence does not compromise the well behaviour of the system, while on the other hand they act as *delighters* elements, enriching the analysis as a fine addition to make the system proficient.

The *must-be* drivers, that emerged to be useful when dealing with warehousing design, are essentially four:

- **Safety in operations**: the core aspect in the decisional process for design of the warehouse, safety is the starting point of every design process involved in industry, due to the fact that in industrial operation the presence of man is a constant reminder, and the main purpose is production at zero risk of injuries.

Safety aspects in warehouses concerns definition of storage area, their separation from other working spaces through physical boundaries (e.g., walls, protection grids, etc.) or marking tapes on the ground, presence of fall arresting systems, adequate protection systems for the operator manoeuvring the material handling equipment, correct stacking of loading units, adequate spacing for loading preparation, preventing dangerous interactions with walkways or common driveways, installation of warning lights and

- **Typologies of storage systems**: to look for the best solution for guaranteeing that the loading units are stored in safe conditions, without any risks for operators and for the value of the goods themselves.

  The search for the best storage systems should be done according to the following constraints:

  - *Physical layout of the warehouse*: maximum distance ground floor to ceiling, presence of fire extinguishing water grid, distribution grid modes, maximum capable payload of the floor
  - *Features of the loading units*: weight, stackability, type of container, fast/slow mover.
  - *Material handling equipment*: in case it would not be possible to rent or buy new stackers for economical or contractual reasons, it is important to set the warehouse storage features according to the material handling equipment already installed in the plant

  Once the storage system has been identified and installed, the next move is to set new storage locations and bins in the Warehouse Management System, to rationalize the storage and picking by attribution of a storage keeping unit to a container, allowing traceability of the load in the warehouse, and counting the movement from-to the storage system.

- **Typologies of material handling equipment**: the proper choice of a stacking system is fundamental for correct operation of the warehouse. As a core aspect in the design of the facility, the material handling equipment is defined according to different constraints:

  - *Characteristics of the loading unit*: weight, physical dimension, shape
  - Warehouse layout: amount of space for manoeuvring of the equipment
  - *Dimensions of aisles*: according to the nut utilization of the warehouse, the presence of multiple aisles and they width can invalidate the usage of certain material handling equipment: in case of high utilization of floor area, narrow stackers are preferred to counterbalanced ones.
  - *Maximum height of the storage system*: according to the height of the racks, different options for stacking maximum height are available
  - *Need for operators*: according to the performed activity and the goods management model, it is possible to adopt traditional vehicles or automated ones. AGVs can be used to automate the warehouse, especially when high picking operations are performed and warehouses are highly submitted to freight motion,
  - *Picking activities or pure stacking operations*.

- **Internal distribution network**: the way by which material is moved around the plant, linking the warehouse facilities to the assembly lines.

Different methods can be considered to exploit the task: counterbalanced forklifts, pallet jacks or water-spider systems.

In addition to that, the way in which the warehouse is alerted of the need for replenishment is a core aspect to be considered: the use of kan-ban techniques or integrated information systems by is the most adopted system on the industrial environment, allowing a just-in-time replenishment of the assembly workstation and a seamless flow in management of the warehouses.

On the other hand, the *nice-to-have* driver is represented by the **optimization of unused warehousing space**, meaning to improve profitability of the logistic area by redesign warehousing area to exploit them at their best. When possible, areas that have been cleared from previous warehousing activities can be exploited to improve implemented warehousing: e.g., in case the design of the warehouse made necessary to merge a warehouse into another, resulting that some space has been freed, that could be utilized to improve other warehousing systems.

After this short last consideration, the hope by the writer is that the audience enjoyed the paper, finding relief in the chapters for the solution of their similar logistic problems, or just as an inspiration to improve the described solutions and apply it with success in real life distress situations, in the scope of continuous improvement and lean organization, for a more integrated industrial companies and a proficient supply chain of future.

Final thanks

During the development of this thesis, some people gave me an invaluable help for the deployment of the paper itself, in terms of suggestions, critiques and observations. To them my gratefulness is direct, although I reserve to me every possible mistake or misunderstanding present in the paper, even if I tried to reduce them at the lowest possible extent.

Nevertheless, some final thanks are incumbent on me.

At first, I would like to offer thanks to Prof. Eng. Eugenio Morello, Massimo Simone, and Alessandro Francesco Leverano, tutors: without their support and their deep knowledge in supply chain management, any paper about the topic would not exist.

Then a special thank is reserved to friends and university mates for their precious understanding, cooperation and support into reading and analysing together the drafts and suggesting according to their previous experiences: thank you so much.

My special thanks go to the staff at Supply Chain Management department in Continental Brakes Italy S.p.A., for giving me the opportunity to understand the fine mechanism inside real supply chains and inspiring the definition of the core topic for the paper, making the double effort to turn a work opportunity into a learning chance, for my culture and my academic career.

Last, but not the least, I would like to address a devoted thanks to my loved ones: first, my family, for giving me the chance to undertake the Master of Science, to enrich my personal knowledges; next, my girlfriend Giada, for inspiring me every day and pushing me to the limit, especially during exam sessions. Then my brother Carlo, personal motivator, and dearest friend of mine.

The last, particular thanks go to my oldest sibling Eng. Giusemaria Goso, for her experience applied in the writing of the paper, and my four-years-old nephew Leonardo, my greatest joy.

To each one of them I am dedicating my work.

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