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Procedia Manufacturing 38 (2019) 1801–1832

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

Intralogistics and industry 4.0: designing a novel shuttle with picking system

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Abstract

Intralogistics is increasingly a matter of research and development as a form of optimization, automation, integration and management of the flow of materials and information that circulate within a business unit. With a strong connection to material handling equipment and automation solutions, intralogistics has proved to be one of the main factors responsible for something that is already happening: a fourth industrial revolution where it is possible to convert warehouses and manufacturing units into smart environments where the entire process can be controlled and supervised through a single system.

It became necessary to develop more innovative and efficient solutions to the constant diversity of challenges proposed by the market. In this sense, it was proposed to develop something innovative within the area of Automated Storage and Retrieval Systems (AS/RS), a technology increasingly sought after by today's manufacturing plants. As such, the goal was to improve the most emergent AS/RS in recent years: the Pallet/Box Shuttle AS/RS.

In order to achieve the proposed objective, it was necessary to analyze all the existing solutions in the market and, mainly, to find the main systems to be improved and the direction to follow in order to create a novel solution based on the existing advanced solutions. Moreover, regarding the recent needs required by the smart factories and Industry 4.0, it was intended that the new system would be able to make an optimized selection of products, forming sets or sub-sets of different products picking them from different places of the rack, a situation that is quite frequent in companies that produce and assemble equipment. The solution obtained shows that it is possible to increase the automation of the operations in the storage systems and improve the responsiveness of the system, taking this solution to a new level. Different products can be picked-up and put in a same box, providing a set of products/components able to be used in a production line or to be provided to a customer.

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Keywords: Indistry 4.0, ;Automated storage and retrieval systm;shuttle vehicle;Automatic Picking;Automatic Storage;Computer Integrated Manufacturing; Intralogistics

10.1016/j.promfg.2020.01.078

1. Introduction

Today, intralogistics has played an increasingly important role in the industrial world as a vehicle for optimizing processes, automating operations, and facilitate the flow of information and materials within business units. It is a process that seeks to design specific and highly complex technological solutions for the integration and management of the flow of information and materials from warehouses, manufacturing units or distribution centers [1,2].

Covering diverse areas of knowledge, such as project management, mechanical engineering, electrical engineering or software engineering, intralogistics enables to increase resource productivity and reduce operational costs by properly controlling and processing the flow of information, and efficiently move materials and warehouse products through sophisticated material handling equipment [1,2].

Through material handling equipment, intralogistics serves the warehouses in diverse operations from the receiving of the product until it is properly ready to be delivered to the customer. However, it is in the storage operation that intralogistics produces a special impact on warehouses through Automated Storage and Retrieval Systems (AS/RS), a solution increasingly developed in warehouses around the world.

AS/RS are storage systems that perform the storage and retrieval operations of the products, usually pallets or boxes in rack structures, automatically through machines specifically developed for this purpose. These machines are called storage/retrieval machines and can be stacker cranes, mini loads or shuttle vehicles, depending on the type of AS/RS [3]. The Pallet/Box Shuttle AS/RS is one of the newly developed AS/RS types, and the most emergent in the past few years. It is an innovative solution that has as principle of operation the storage of boxes or pallets through several vehicles that move inside the rack structure, carrying out the whole operation automatically.

The present work was based on the principle of operation of the Box Shuttle AS/RS, i.e., its storage/retrieval machine: the shuttle vehicle. The main objective was to innovate this system, creating a solution capable of collecting different products with small or medium weight from different locations in the same warehouse line, completing an order emitted by an internal or external customer, a task that was performed manually by the warehouse operators and which can now be performed completely automated and integrated inside the rack, saving time and cost of operation. This system fulfils the Industry 4.0 concept, collecting automatically parts to complete the assembly process of a mechanical device, amongst many other market demands.

2. Literature Review

The work presented in this paper focuses on four major areas: Industry 4.0, Automation, Robotics and Intralogistics. In each of these areas, growth and innovation have been evident over the last decade, so they will play a decisive role in the business units of the future, especially in the industrial world that is already undergoing its fourth revolution. As such, several works have been developed in this direction over the last few years. In the following paragraphs some of these works are highlighted.

In the area of Industry 4.0, which addresses topics such as digitization, smart factories or the Internet of Things, four works stand out. The first one is a framework developed by Qin et al. [4] to help organizations and their manufacturing systems achieve the requirements of Industry 4.0. The second, developed by Pereira et al. [5], clarifies the concept of Industry 4.0, and how it will influence the industry, the economy and the products and services. In this sense, Tjahjono et al. [6] studied the impact of Industry 4.0 across the supply chain. Lastly, Vaidya et al. [7] provided an overview on the nine pillars that are at the core of Industry 4.0.

In the area of Automation, the area with the greatest evolution in recent years, mainly in the automotive industry as a key to increase productivity and efficiency of the manufacturing systems, five works for the automotive industry are highlighted. Within the innovation of machines and equipment, Araújo et al. [8] increased the productivity and reliability of a manufacturing process by developing a full-automated cell for manufacturing cushions and suspension mats for vehicle seats, Costa et al. [9] developed a novel machine to agile the assembly operations of small sets applied in the automotive industry, decreasing significantly the setup time and the cycle time, ensuring as well the segregation of OK and NOK sets at the final of the assembly operation. Costa et al. [10] developed a fully automated system to solve quality problems on the assembly process of transmission system for automotive windshield wipers, detecting the dimensional deviations before the assembly process. On the other hand, Moreira et al. [11] showed that integrating some automated tasks can reduce production costs and times, while improving product quality and reducing drastically the intermediate stocks and the work in progress. Santos et al. [12] improved the performance of an APEX machine and, consequently, the quality in the preparation activity of a tire production process, increasing the level of automation and implementing the 5S methodology. Finally, Magalhães et al. [13] developed a novel automatic sorting system for bent wires used in suspension mats and cushions for car seats, preparing the bent wires to the next operation: plastic over-injection. This manufacturing system allowed to overcome the random position acquired by the bent wires after the robotized bending operation and corresponding cutting operation.

Robotics can be found in all types of industrial operations such as manufacturing processes, assembly processes or logistics processes. Within this area, some works about handling robots and collaborative robots are highlighted. Within the handling robots, one of the most popular types of robots, Briglen et al. [14] made a statistical review of the characteristics of robotic grippers (used for handling operations) from several companies, proposing a discussion on the future evolution of these devices, Moghaddam et al. [15] developed a framework for improvement of the Parallel Pick-and-Place operations using multi-gripper robotic arms, and Gultekin et al. [16] studied the best pure cycle to maximize the throughput rate of a dual-gripper robot loading/unloading two CNC machines. Within the collaborative robots, that have the advantage of working side by side with human operators, Schou et al. [17] developed a task programming software tool to help program industrial tasks on a collaborative robot through skill-based instructions, proving that it is applicable in industrial environments, and Realyvásquez-Vargas et al. [18] developed a project of a collaborative robot to perform an assembly task in order to reduce occupational risks and improve the manufacturing process efficiency. Castro et al. [19] developed a robotic cell able to weld bus structures in a sustainable way, recovering a robot out of use and improving the quality and productivity of the process.

Intralogistics, dedicated to optimizing the flow of materials and information in warehouses, distribution centers and manufacturing units, is the area where the work presented in this paper fits most. As such, five works developed in this area stand out. Within the warehouse simulation models, Gagliardi et al. [20] carried out a literature review about the dynamic and steady-state models for evaluation of the AS/RS performance in order to facilitate the resolution of specific problems related to the modeling of warehousing systems, Güller et al. [21] developed a simulation model to evaluate the performance of miniload multishuttle order picking systems, and Martina et al. [22] proposed a simulation model to calculate the number of Rail Guided Vehicles (RGV) required to serve an automated parts-to-picker system at a certain picking throughput, proving that one does not increase linearly with the other. Within the optimization of logistics systems and warehouses, Jaiganesh et al. [23] proposed an innovative Automated Guided Vehicle (AGV) with a robotic arm on top to perform special material handling tasks, and Caridade et al. [24] optimized the warehouse of a company in the automotive industry, proposing a new layout, installing a new warehouse management system and defining a new bin management solution.

3. Problem statement and Methodology

4. *3.1. Problem description*

The main challenge of this work was creating a solution capable of collect different products with small or medium weight from different locations in the same warehouse line, completing an order emitted by an internal or external customer. The proposed system fulfils the Industry 4.0 concept, collecting automatically different products of a warehouse, for example parts to complete the assembly process of mechanical devices, amongst many other applications. The shuttle vehicle is like a cart that has four or more wheels and moves along two rails that are part of the rack structure (Figure 1). When applied on a box shuttle AS/RS, it is capable of transferring packages (cartons, totes or trays) in and out of the layered stacked racks and transport them in a package carrying area [25]. Its main characteristic is the ability of running along the rack structure at high speeds, increasing system cadences and warehouse productivity. However, there are some differences between all the shuttle vehicles existing in the market. The major differences are in the mechanism that is used to store and retrieve packages, and in the power source that feeds the system. Those differences were described and analyzed in the next section.

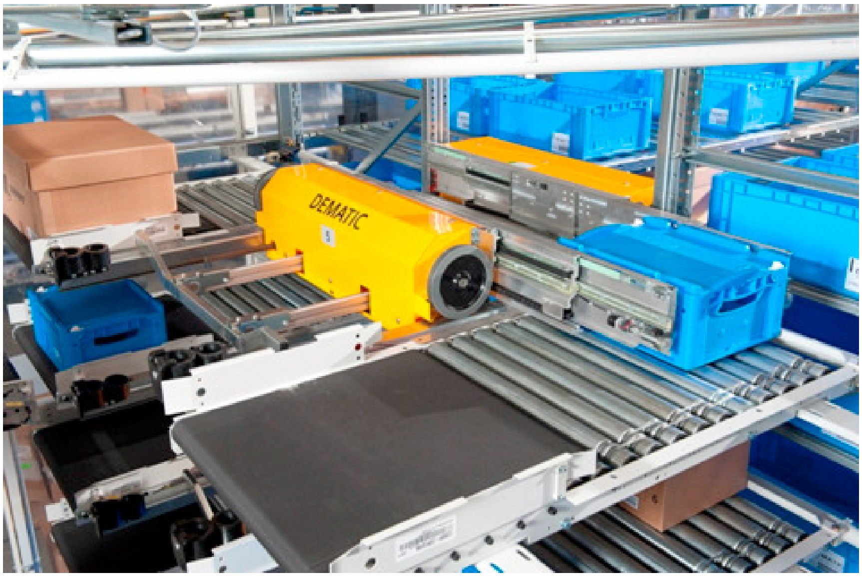

Figure 1 - Example of a shuttle vehicle for cartons, totes or trays (from Dematic) [25].

4.1. Benchmarking: analysing existing solutions

Having defined the problem to solve, it was necessary to make a complete analysis of the existing solutions in the market and, from there, to study the advantages and disadvantages of each one. Although there were many other similar types of shuttle vehicles from other manufacturers, only the main versions existing in the current market were studied.

The first solution encountered is a shuttle vehicle equipped with a telescopic load extractor that expands and contracts to adjust the carrying area for varied sizes of boxes. The power comes from a conductor rail and the vehicle is only capable of moving in one direction. The Dematic Multishuttle® is an example of this solution (Figure 2 - a) [25].

The second solution is quite different from the first one. It is a shuttle vehicle that comes with a load deck plate that moves over a belt conveyor, however the carrying area has a fixed length, width and height. On the other hand, it is capable of rotating 360°, thanks to its pivoting wheels, which allows the vehicle to move crosswise and longitudinally, something that is only possible with the use of batteries to feed the system. This solution belongs to KNAPP AG with his YLOG-shuttle (Figure 2 - b) [26].

The next solution is very much like the previous one. It also works with batteries and the vehicle can move crosswise and longitudinally. The difference is in the extraction mechanism and the carrying area. In this case, it is composed by a belt conveyor and the carrying area has an open base with fixed dimensions. The ADAPTO from Vanderlande is an example of this solution (Figure 2 - c) [27].

The last solution is the Perfect Pick® from OPEX Corporation, an innovative method to make the operations of goods-to-person faster. It is a shuttle system that has the picking stations directly connected to the racking system (composed with only one aisle), in other words, the shuttle vehicles provide the operators without resorting the packages to conveyor systems, working as a single module that encompasses all these components. The shuttle vehicle in this system walks around a rack structure, going down to the various levels by means of a mechanism actuated by rack and pinion. It is powered by ultracapacitors that capture regenerated energy from a conductor rail, runs along one direction, and the extraction device is a chain conveyor that picks and stores totes and trays on both sides of the aisle (Figure 2 - d) [28].

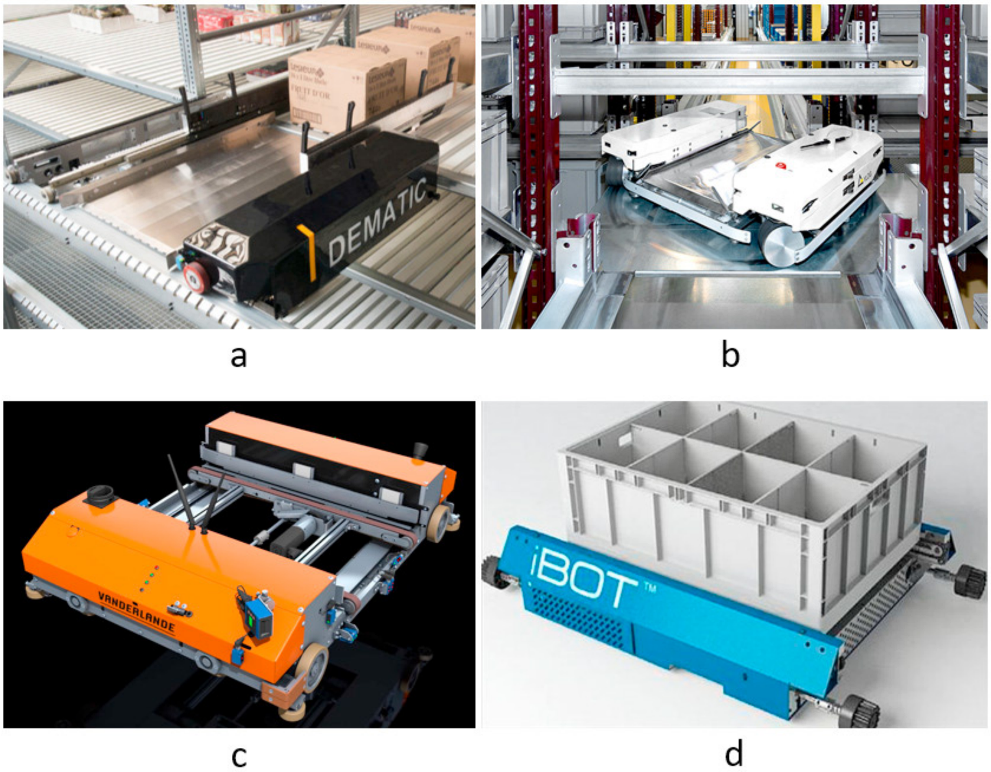

Figure 2 - (a) Multishuttle® from Dematic [25]; (b) YLOG-shuttle-system from KNAPP AG [26]; (c) ADAPTO from Vanderlande [27]; (d) Perfect Pick® solution from OPEX Corporation [28].

4.2. Problems found and how to improve

After the benchmarking phase, it was necessary to identify the problems of the existing solutions in the market, find ways to improve them and create an idea to innovate the shuttle vehicle in the desired way.

The idea to increase the cadences of the vehicle was proposed, in other words, by causing the shuttle vehicle to give the system even more products per minute. The solution found for this problem follows a product introduced by KNAPP AG, the Pick-it-Easy Robot (Figure 3). It is a fully automatic robotic arm capable of performing picking operations for the order fulfillment process, the process of fulfilling customer orders (something like a list with specific items and quantities) and one of the most costly operations for warehouses. This is a task that is normally performed manually and outside of the rack structure, a limitation for the AS/RS. This robotic arm handles small products transporting them from a full box to an empty box that is intended to meet the quantities of a customer order [29].

The idea would be to incorporate a similar solution to the Pick-it-Easy Robot directly in the shuttle vehicle, so that it was able to carry out the picking operations directly on the rack structure, through a material handling device like a robotic arm of four axes or a system of gantry and gripper. In this way, the shuttle vehicle will increase its cadences because it moves in shorter distances inside the rack structure, and it will create an innovative solution.

Figure 3 - Pick-it-Easy Robot from KNAPP AG [29].

4.3. Main requirements and selected solutions

The developed shuttle vehicle is intended for a target market made up of distribution centers and warehouses for lightweight products with small dimensions and well-defined geometries such as the consumer goods industry, machines manufacturers, retailers, and so on, where the products are stored in boxes and order fulfillment operations are a constant. For the purpose of this work, and as case study, it was defined that the shuttle vehicle would be inserted in a warehouse with three different products: blue, green and red bottles stored in dark grey boxes that stay in the rack. The system then receives customer orders where the number of bottles of each color is indicated. Fully automatically, the shuttle vehicle must satisfy each order by placing the respective bottles in light grey boxes (the customer boxes), directly in the rack, avoiding the need to travel long distances. Figure 4 represents the type of boxes and the bottles of each color.

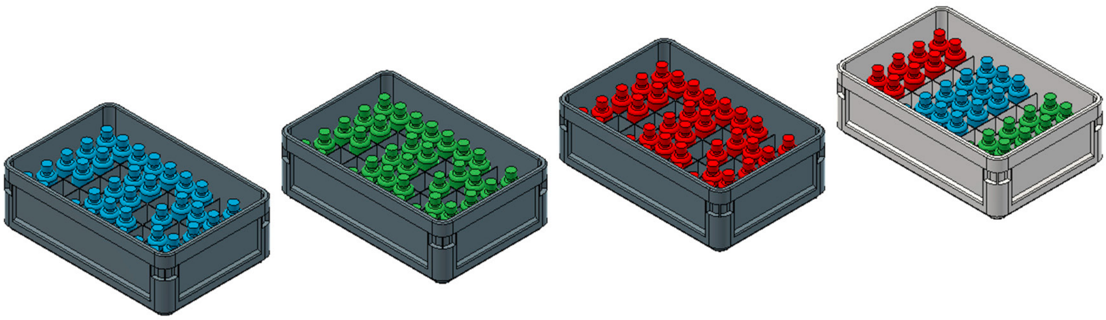

Figure 4 - Plastic boxes with three different products: blue, green and red bottles in dark grey boxes and a light grey box with the desired mix of products resulting from the picking operation into the other boxes.

In a stage of pre-definition of the shuttle vehicle, the main requirements were drawn and the respective solutions were found. This definition, although still without any detailed technical specification, allowed to trace the way to go during the phase of the mechanical design and to facilitate the decision making. All decisions were made considering the benchmarking phase and the solutions of the various material handling equipment already developed.

Table 1 lists the solutions selected for each of the main requirements of the shuttle vehicle.

4.4. Preliminary technical specifications

Following the main requirements of the shuttle vehicle, it was also necessary to define some preliminary technical specifications for the design and dimensioning of the various components that make up the shuttle vehicle. During the design of the equipment, other technical specifications were defined, such as the power of the gearmotors, which are not listed in this section. Some of these values were changed during the mechanical design process, so section 4.2 shows the final technical specifications of the shuttle vehicle.

Table 2 represents the detailed technical specifications at a stage prior to the mechanical design. All values were selected considering the technical specifications collected during the benchmarking phase and some standard values existing in the market.

Table 1. Solutions selected for each of the main requirements of the shuttle vehicle.

Main Requirement	Selected Solution
Store and Retrieve Boxes	Fixed Stroke Load Extractor
Fixed Size Transport Platform	Load Extractor Non-Expandable
Vehicle Movement in Straight Line	Non-Pivoting Wheels
Perform Picking Operations Automatically	Four-Axis Robot
Vehicle Guided on the Route	Side Rollers
Accurate Positioning in Box Storage Positions	Bar Code Positioning Device
Electric Actuators	AC Gearmotors
Electric Power Supply for Movable Equipment	Conductor Bar
Lightweight, Fast and Inexpensive Equipment	Optimized Steel Structure and AC Gearmotors
Ensure all Environment, Health and Safety Protection Requirements	Covers and Safety Devices
Good Accessibility for Maintenance Tasks	Transport Points and Easy Removal of Components

Table 2. Preliminary technical specifications for the shuttle vehicle.

Technical Specification	SI Unit	Value/Description
Load Type	-	Plastic Tote Box
Load Dimensions	mm	600 x 400 x 200
Maximum Payload	kg	100 (50 kg/box)
Robot Maximum Payload	kg	1
Load Extraction System	-	Fixed Stroke Load Extractor
Maximum Vehicle Speed Loaded (Unloaded)	m/s	3,0 (3,0)
Maximum Vehicle Acceleration Loaded (Unloaded)	m/s^2	1,5 (1,5)
Extraction System Speed Loaded (Unloaded)	m/s	0,25 (0,5)
Extraction System Acceleration Loaded (Unloaded)	m/s^2	1,0 (2,0)
Number of Wheels	u	4
Expandable Transport Platform (Yes/No)	-	No
Pivoting Wheels (Yes/No)	-	No
Temperature Range	ºC	0 – 40
Position Control	-	Bar Code Positioning Device
Power Supply	-	Conductor Rail
Power Supply Voltage	V	230

Having defined the main problem to be solved, analyzed similar solutions in the market, and established the main requirements and technical specifications, the starting point for the design of the shuttle vehicle was given.

5. **Results**

4.1. Final concept

One thing that helped to sequence the mechanical design was the Work Breakdown Structure (WBS) of the shuttle vehicle (Figure 5). This tool allowed dividing the main system into sub-systems and, in this way, directing the efforts to each of the subsystems in isolation. Since these are dependent on each other, the design process had to be often iterative so that in the end the vehicle would be compact and without interferences between the different subsystems. The final version of the equipment is shown in Figure 6, where it is possible to analyze which are the subsystems of the vehicle.

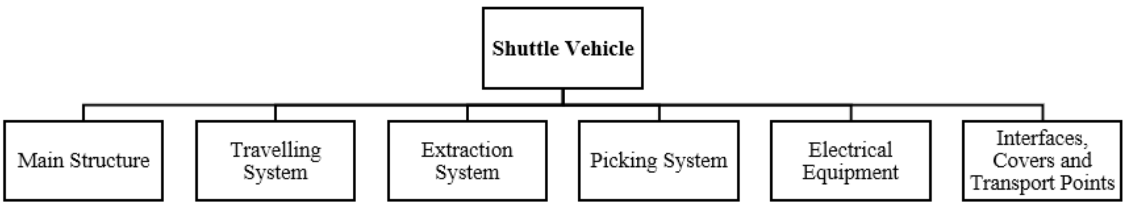

Figure 5 - WBS of the shuttle vehicle.

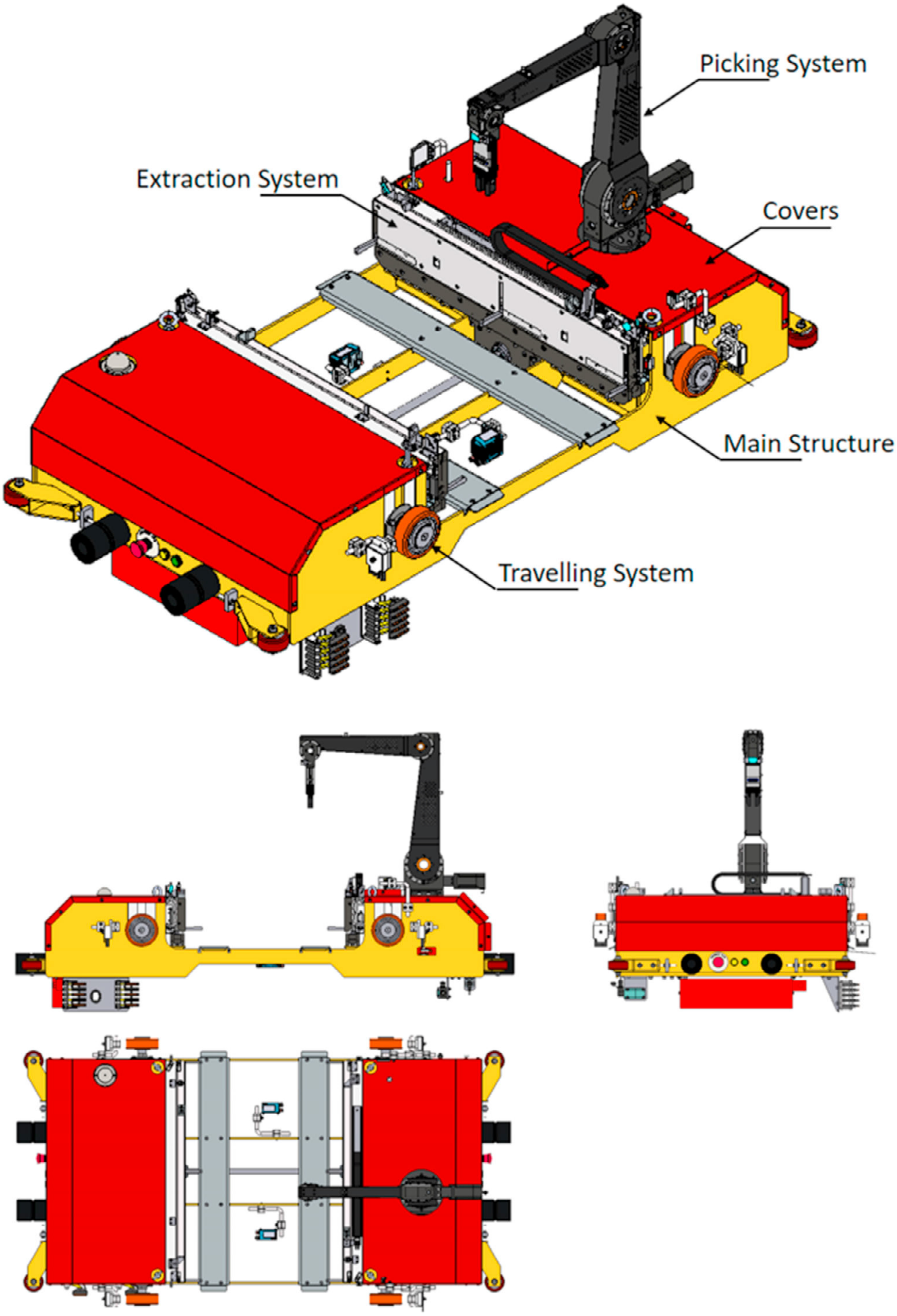

Figure 6 - Final version of the shuttle vehicle with identification of the main systems and components.

In order to better understand the purpose of each of the subsystems of the shuttle, it is necessary to analyze the principle of operation and the different tasks that it is able to perform when inserted in an AS/RS. In Figure 7 it is possible to observe the shuttle vehicle in operation, being inserted in a rack structure that supports it through rails and that has one shuttle for each level. This rack also has the purpose of storing products that are handled by the shuttle vehicle systems.

It is important to note that the purpose of this work was only the shuttle vehicle, so only the vehicle was part of the mechanical design scope, but there are other essential equipment for the shuttle operation within an AS/RS, such as the rack or conveyor lines, that were not the subject of study for this work. The rack used in this work is merely representative and serves only to help understand the operating principle of the shuttle vehicle. On the other hand, it is not shown here how the vehicle is placed inside the rack and interfaces with the outside of the rack so that it can send/receive the boxes of products that are being handled throughout the AS/RS. The shuttle vehicle can be placed on the rack by lift trucks or vertical conveyors placed on the top of the rack and allow interface with conveyor lines that move the boxes throughout the AS/RS.

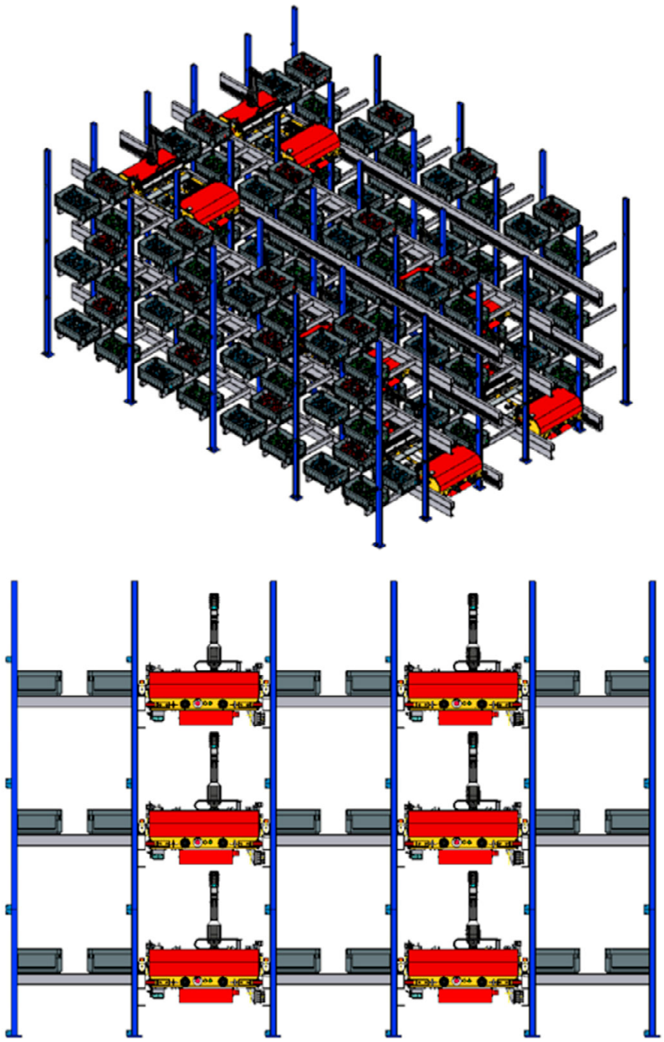

Figure 7 - Shuttle vehicle in operation.

As already mentioned, the shuttle vehicle is inserted in a warehouse with three different products: blue, green and red bottles stored in the boxes that stay in the rack. All the boxes handled by the system have the dimensions initially considered in the technical specifications (600 mm x 400 mm x 200 mm), storing a maximum of fifty bottles positioned in the wells of a matrix sized for this type of product.

The shuttle vehicle can carry two boxes at the same time (each 50 kg maximum) that may be dark grey boxes or light grey boxes. The light grey boxes are never stored in the rack since they are the boxes to send to the customer.

The vehicle has three fundamental systems for the operations it can perform. These three systems, connected by the main structure, are as follows: the travelling system, the extraction system and the picking system. It is important to note that each of the systems works independently of the others, it means that when one of the systems is in motion, the other two remain locked.

The travelling system, as the name implies, is responsible for the travelling movement of the vehicle along the rack structure rails (Figure 8), ensuring straight line movement and correct positioning of the vehicle in relation to the boxes it is loading or removing from the rack.

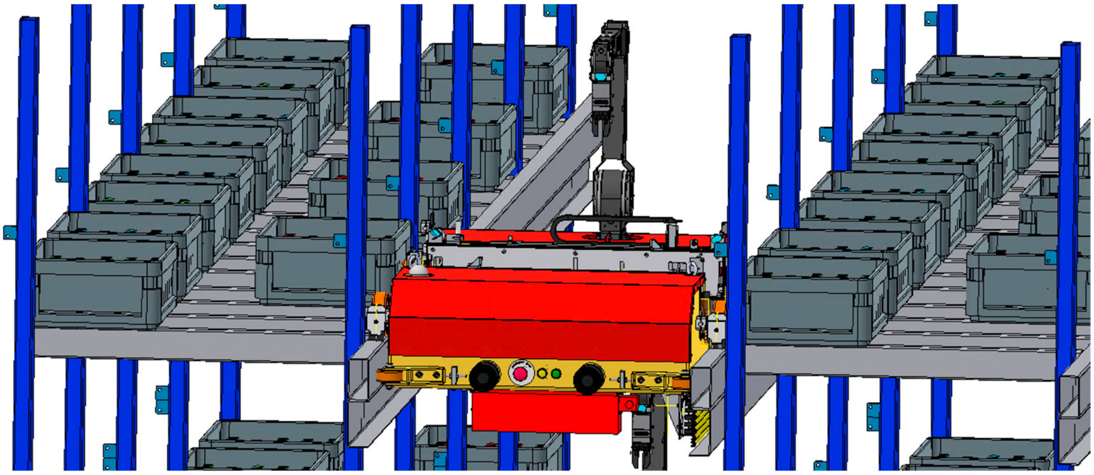

Figure 8 - The shuttle vehicle travels along the rack structure rails through the travelling system.

The extraction system is responsible for extracting or storing the boxes on the rack through two retractable arms that cause the box to move in or out of the vehicle (Figure 9). The shuttle vehicle can extract or store boxes on both sides of the rails, keeping them properly positioned both on the rack and inside the vehicle when they are being handled.

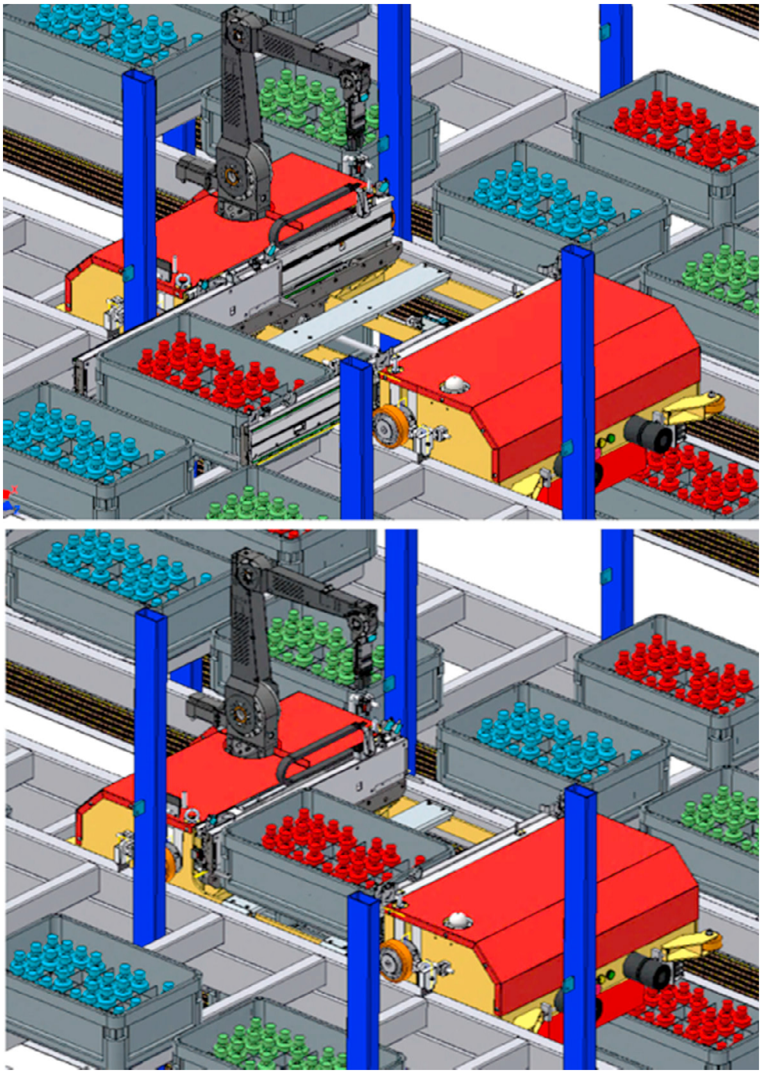

Figure 9 - The shuttle vehicle extracts/sores the boxes on the rack through the extraction system.

The picking system is the system that allows the picking operations to be performed directly in the rack in a completely automatic way, this being the great innovation of the shuttle vehicle when compared to what exists in the market. It is a robot with four axes that transfers the bottles of each color between the dark grey boxes and the light grey box (Figure 10), satisfying the customer's order.

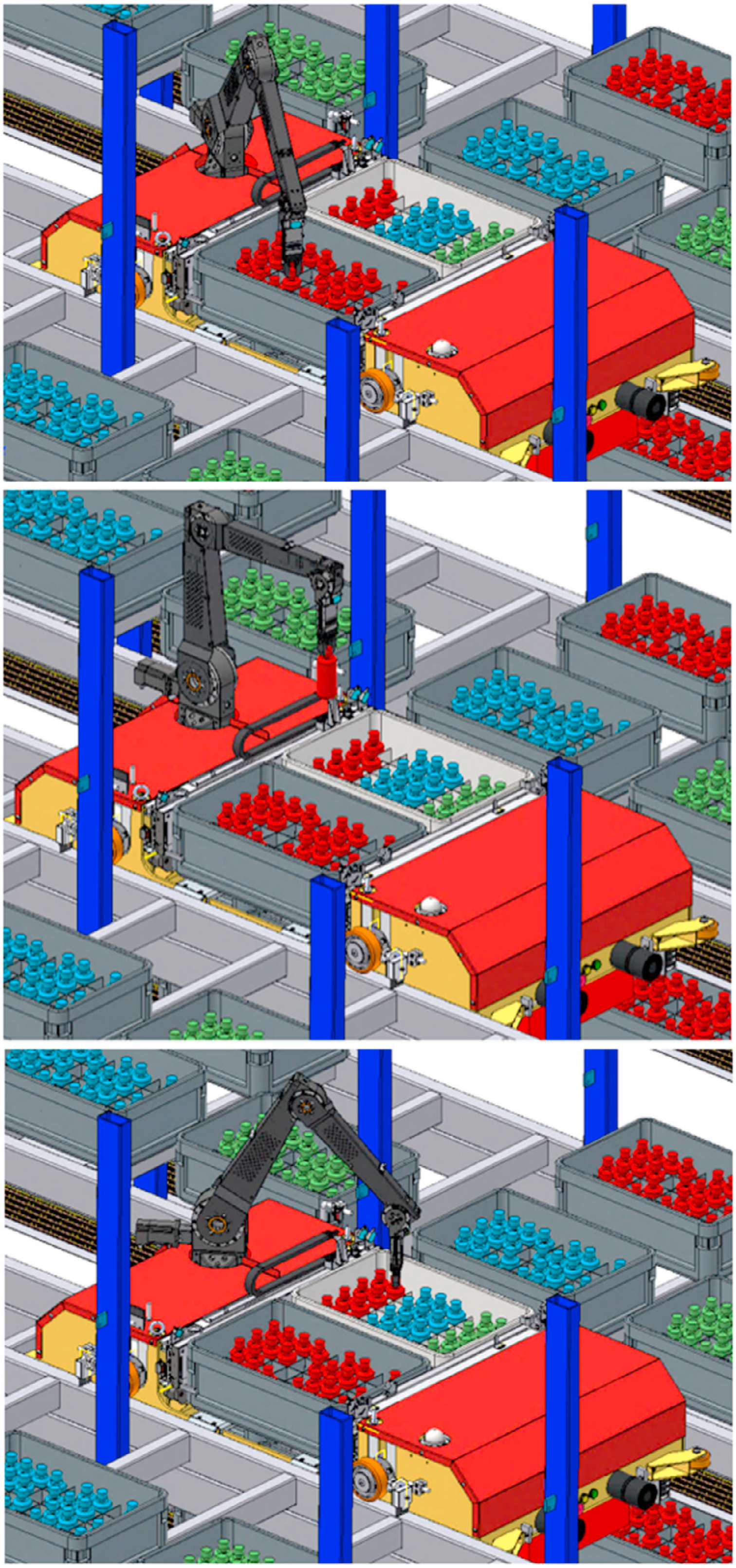

Figure 10 - The shuttle vehicle performs the picking operations directly in the rack.

4.2. Mechanical design

4.2.1. Design of the main structure

The mechanical design started with the main structure, although it is a component that depends on all the other systems of the machine. Being one of the main parts of the vehicle, it was necessary to have some care in the design of it, trying to simplify its manufacture to try to reduce the production costs of the machine. Given its complexity, it is natural that there are many alternatives to what is presented in this work, so it is important to note that the solution presented here is only a possible solution and may not even be the optimal solution.

This structure has evolved over time, as different systems of the shuttle vehicle have been developed, so to understand the purpose of each of the elements that constitute this part, it is necessary to read the sections for each of these systems (sections 4.2.2 to 4.2.5). In Figure 11 it is possible to notice the evolution of the structure from the first version to the final version, proving to be an iterative work.

As the main features, the structure is visually symmetrical and consists of two longitudinal plates which are transversely separated by two other U-shaped bent plates (Figure 12). It then has small bars, bent sheets and reinforcing plates which support the different vehicle systems (see sections 4.2.2 to 4.2.5).

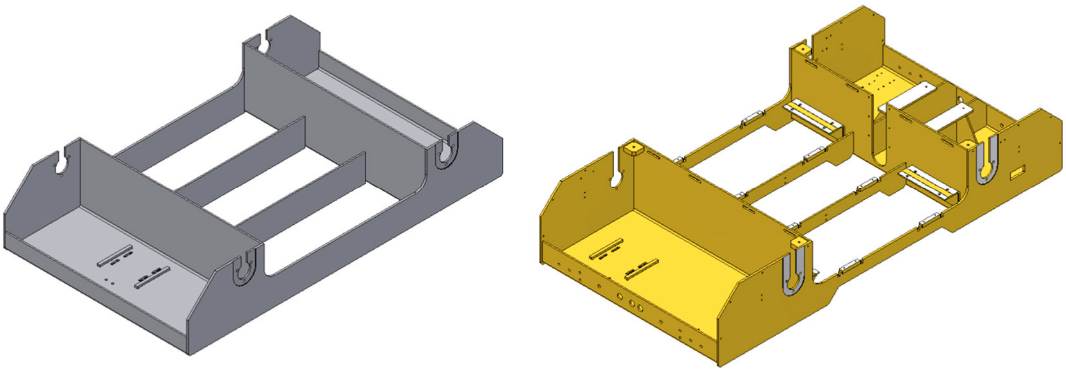

Figure 11 – First and last versions of the main structure.

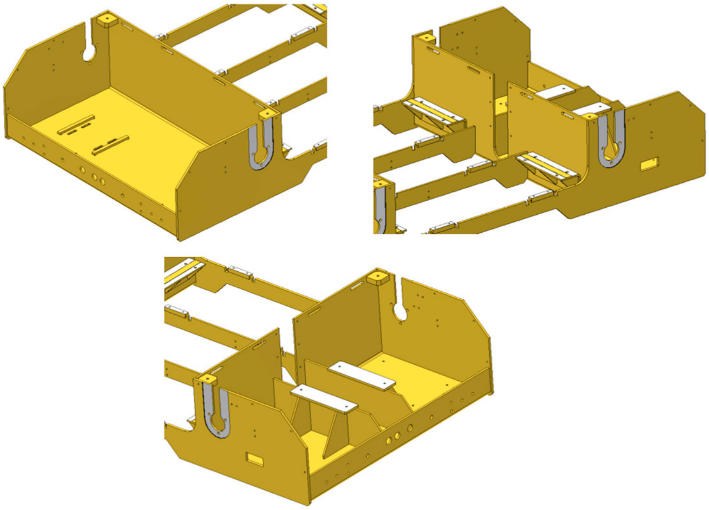

Figure 12 – Some details of the main structure.

4.2.2. Design of the travelling system

The travelling system (Figure 13) was the first system to be developed for the shuttle vehicle. It is a system with the main purpose of moving the vehicle along the aisle of the rack automatically at a defined speed and acceleration, stopping accurately in the storage positions of the boxes.

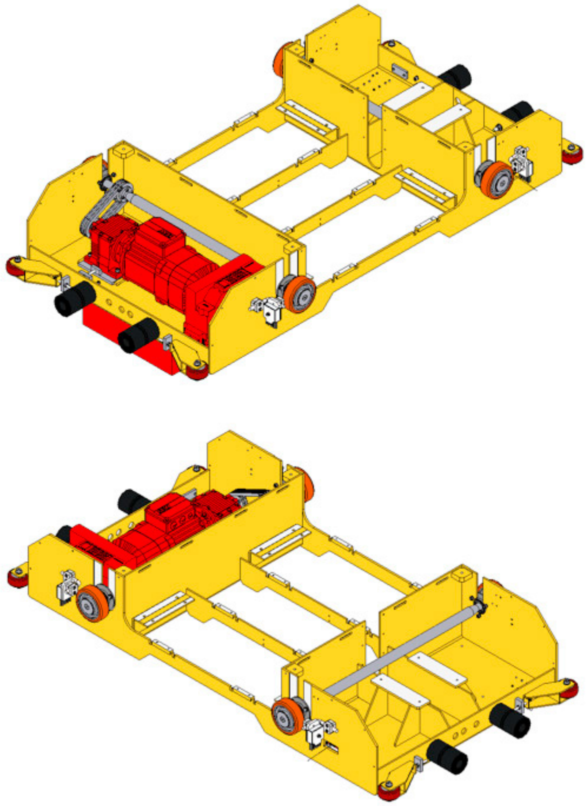

Figure 13 - Travelling system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

- It shall be possible to assemble the travelling system in the main structure of the shuttle vehicle based on the geometry pre-designed for it, trying to put most of the components inside so there is no component visible;
- The movement of the vehicle is only rectilinear along the aisle, and must remain guided transversely on the rails;
- The vehicle must be composed of four wheels, two driving and two driven;
- The gearmotor must be of alternating current and type helical gearmotor;
- There should be a waste removal system along the rail to extend wheel life;
- The travelling system shall have shock absorbers at the ends to absorb the impact of the vehicle on the aisle end stoppers in the event of any failure of the controls;
- The travelling system must have the necessary sensors and controllers to operate automatically and accurately.
- The different components that constitute the travelling system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 14 it is possible to observe the WBS of the travelling system and to see how these components are organized.

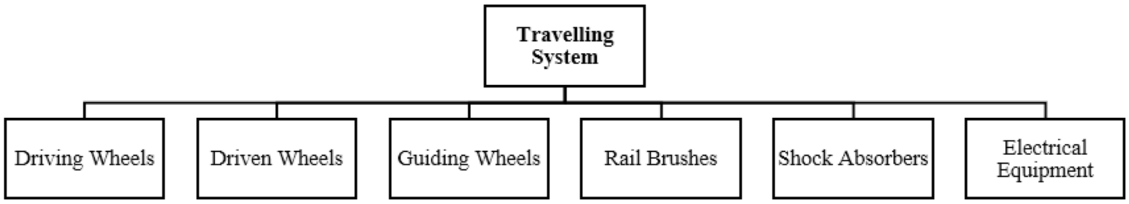

Figure 14 – WBS of the travelling system.

For the driving wheels assembly (Figure 15), the following components were selected:

- A driving shaft that rotates supported by two bearings and where the two driving wheels are assembled;
- A gearmotor that transmits the motion to the driving shaft by means of a pair of sprockets and chain;
- Locking assemblies that transmit motion to the wheels and sprockets.

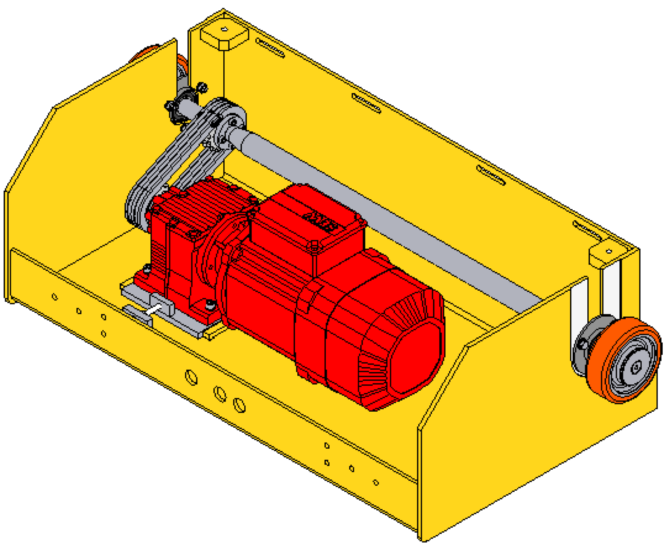

Figure 15 – Driving wheels assembly for the travelling system.

For the driven wheels assembly (Figure 16), the following components were selected:

- A driven shaft that rotates supported by two bearings and where the two driven wheels are assembled;
- Locking assemblies that transmit motion between the driven shaft and the wheels.

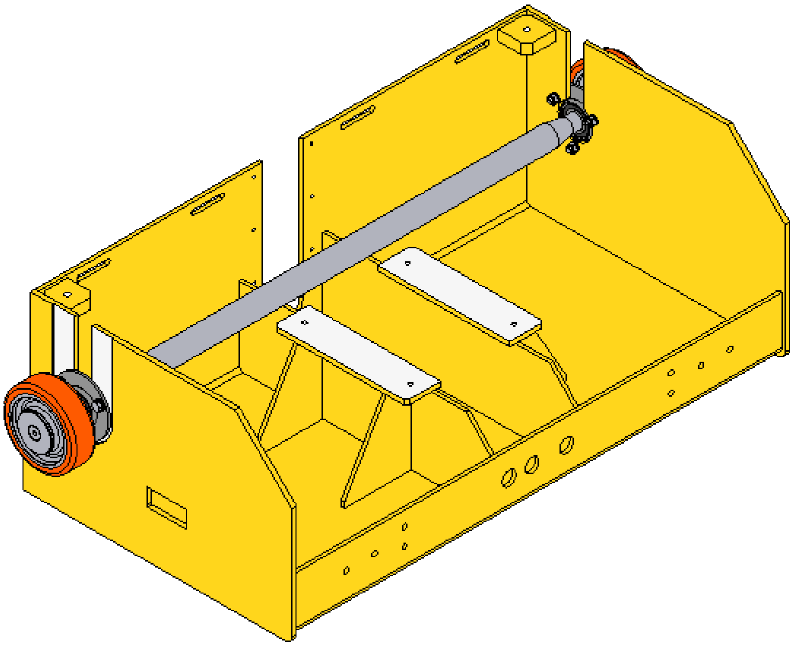

Figure 16 – Driven wheels assembly for the travelling system.

For the guiding wheels assembly (Figure 17), the following components were selected:

- Fork-shaped supports, each with an axle where the guiding wheel is assembled;
- Small bars with a threaded rod to adjust the position of the guiding wheels.

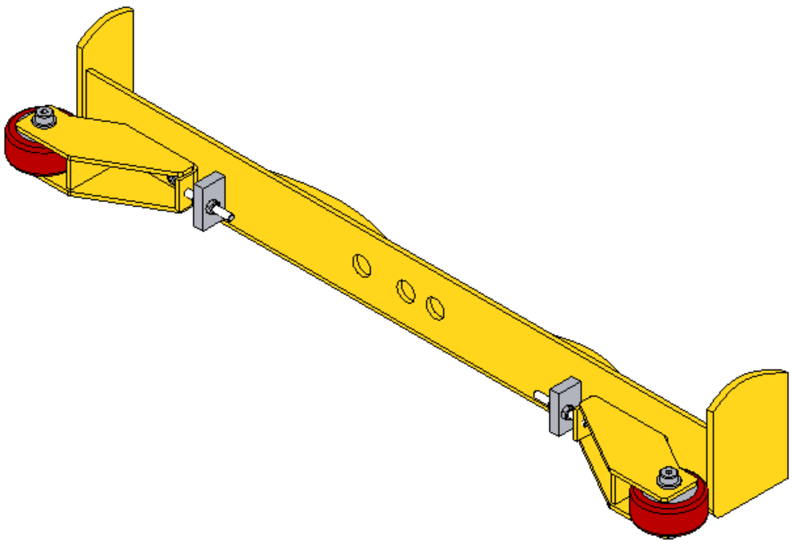

Figure 17 – Guiding wheels for the travelling system.

The rail brushes (Figure 18), used to remove the waste along the rail, have the following components: Brushes and the supports to assemble the set.

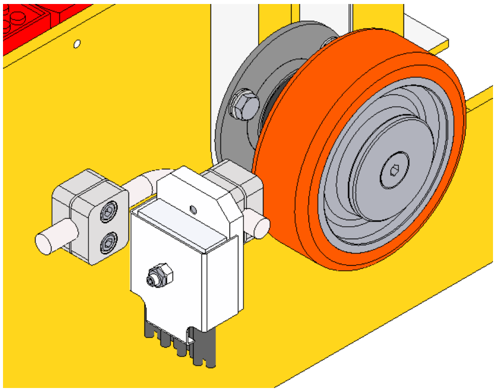

Figure 18 – Rail brush for the travelling system.

The shock absorbers (Figure 19), used to absorb the impact of the vehicle on the aisle end stoppers, have the following components:

1. Polyurethane buffers.

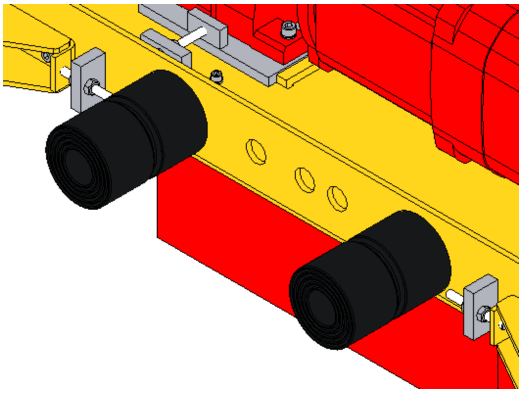

Figure 19 – Shock absorbers for the travelling system.

4.2.3. Design of the extraction system

The extraction system (Figure 20) was the second system to be developed for the shuttle vehicle. It is a system with the main purpose of extracting and storing the boxes on the rack at a defined speed and acceleration, ensuring alignment in the final positioning. The entire operation must be performed automatically, accurately and smoothly.

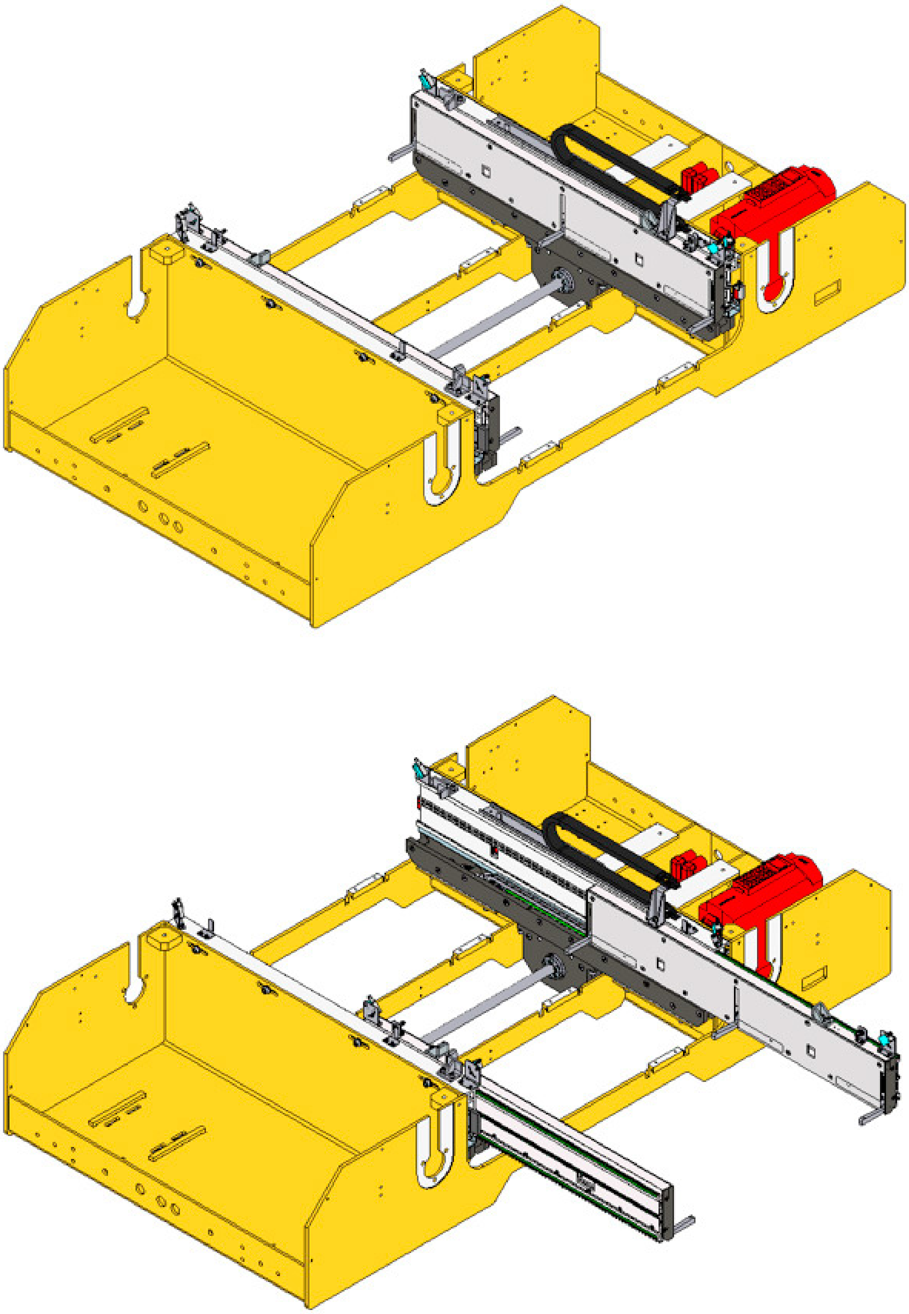

Figure 20 – Extraction system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

- It shall be possible to assemble the extraction system in the main structure of the shuttle vehicle based on the geometry pre-designed for it;
- Only one box at a time should be removed or stored, even if the vehicle can carry two boxes;

- The extraction mechanism shall be a retractable mechanism composed of two fixed arms and two movable arms;
- The extraction or storage movement of the boxes must be linear in the direction of pulling or pushing the boxes;
- The boxes must be guided along the movement to ensure correct alignment in the final positioning both on the vehicle and on the rack;
- The boxes must remain locked on all faces when the vehicle is in motion;
- The fixed and movable arms shall be manufactured from extruded profiles;
- The parts that make up the system should be made of aluminum, preferably, to reduce the weight of the vehicle;
- The system must be driven by an electric servo gearmotor to increase the positioning accuracy;
- The linear movement of the arms must be carried out by means of chain and rack;
- There shall be mechanical end stoppers for the movable arms;
- The extraction system must have the necessary sensors and controllers to operate automatically and accurately.
- The different components that constitute the extraction system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 21 it is possible to observe the WBS of the extraction system and to see how these components are organized.

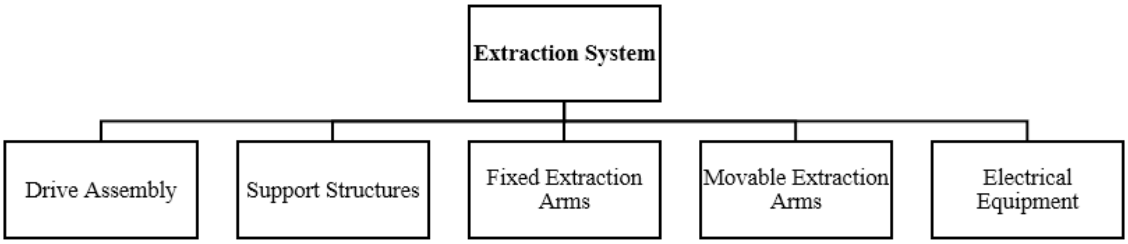

Figure 21 – WBS of the extraction system.

The drive assembly (Figure 22), used to operate the system, consists of the following components:

2. Two pairs of support plates to secure the drive assembly and connect it to the support structures of the extraction system;
3. A servo gearmotor that drives a shaft that rotates supported on two bearings, the first mounted on the fixing flange of the servo gearmotor and the second mounted on a customized bearing housing;
4. Two sprockets, that are used to drive the roller chains, coupled to the driving shaft through locking assemblies;
5. Chain deviation rollers, so that the chain contacts more than half of the sprocket teeth.

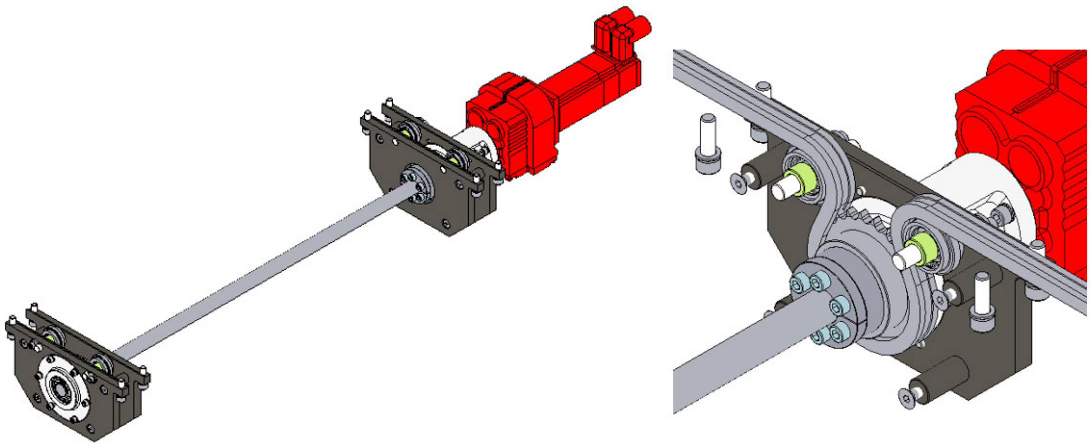

Figure 22 – Drive assembly for the extraction system.

Each of the two support structures (Figure 23), used to support the entire extraction system and to fix it to the main structure of the shuttle vehicle, consists of the following components:

- Two longitudinal bars and a structural tube to support the fixed and movable extraction arms and to connect the extraction system to the main structure of the vehicle;
- An intermediate block with a plastic profile on top for supporting and sliding the chain;
- Tensioning systems actuated by spring washers to tension the roller chains.

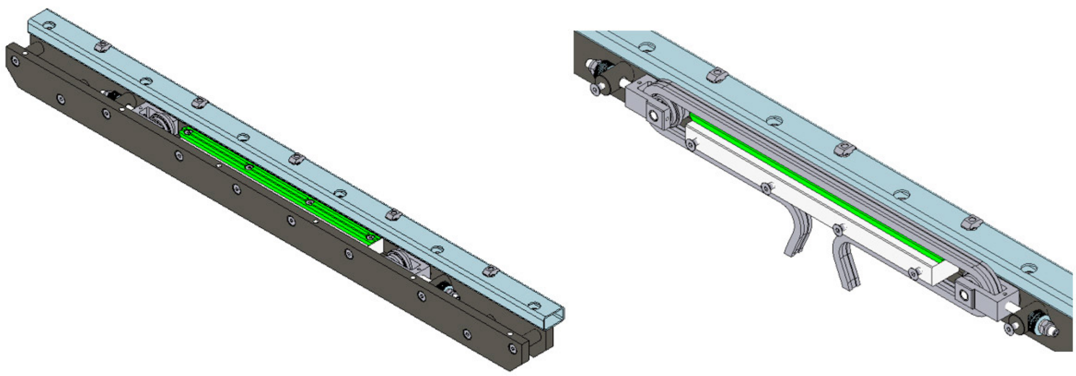

Figure 23 – Support structures for the extraction system.

Each of the fixed extraction arms (Figure 24), used to support and guide the movable extraction arms, consists of the following components:

- A stringer made by an extruded aluminum profile to support all the components and work as the main structure of the fixed extraction arm;
- A mechanical end stopper used to limit the stroke of the retractable mechanism, preventing the movable arm from projecting from the extraction system in the event of a failure of the controls.

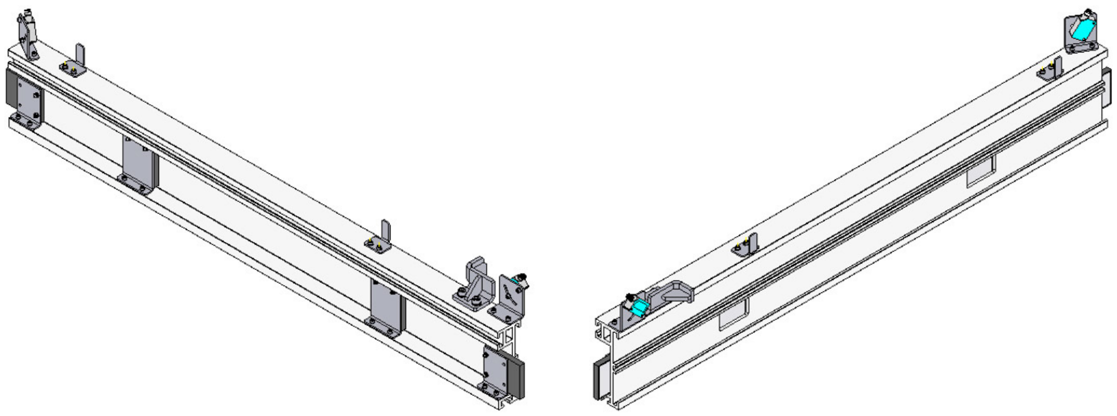

Figure 24 – Fixed extraction arm for the extraction system.

Each of the movable extraction arms (Figure 25), used to create the retractable mechanism and perform the linear movement, consists of the following components:

- A stringer, made from an extruded aluminum profile, with the purpose of fixing all the remaining components of the assembly and increasing the strength. Between the contact surfaces of the movable and fixed extraction arms, the stringer has sliders, made from extruded plastic profiles, that facilitate the sliding between the two parts;
- A rack that is driven by the roller chain so that the arm can move;
- Three retractable fingers, driven by direct current drives, that perform the operations of pushing or pulling the boxes, besides serving to keep them locked inside the vehicle;
- A mechanical end stopper used to limit the stroke of the retractable mechanism, preventing the movable arm from projecting from the extraction system in the event of a failure of the controls;
- A longitudinal cover for guiding and locking the boxes inside the vehicle, and two top covers so that the components inside the stringer are not visible.

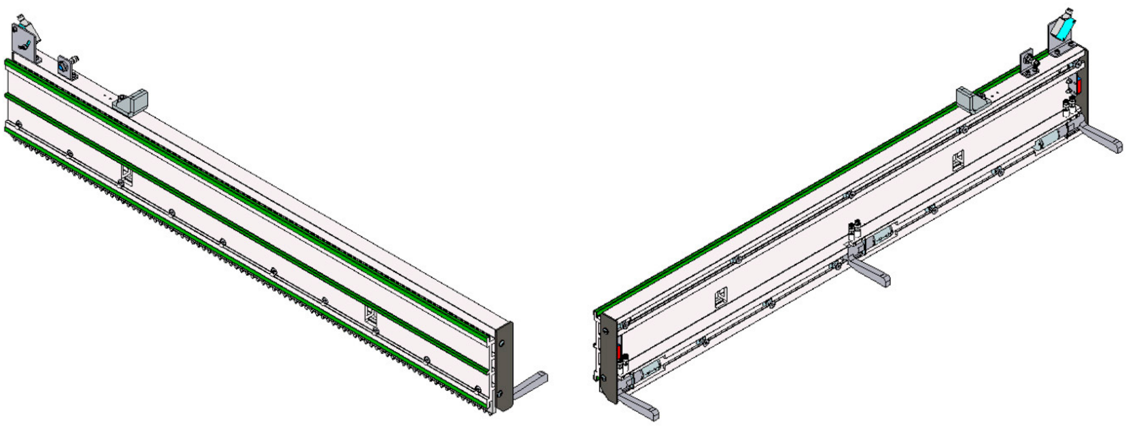

Figure 25 – Movable extraction arm for the extraction system.

4.2.4. Design of the picking system

The picking system (Figure 26) was the third system to be developed for the shuttle vehicle. It is a system with the main purpose of performing the picking operations automatically directly on the rack, in other words, transferring the products between the warehouse boxes and the boxes where customer orders are met. In this case, the products must be handled with high precision and flexibility.

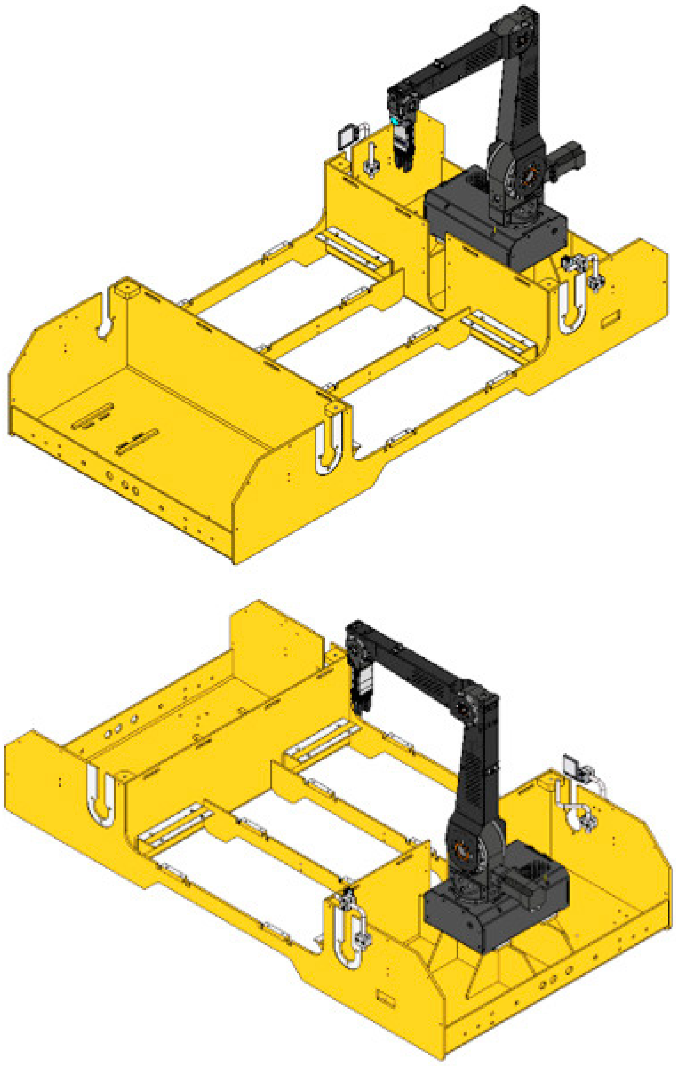

Figure 26 – Picking system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

- It shall be possible to assemble the picking system in the main structure of the shuttle vehicle based on the geometry pre-designed for it;
- Only one product at a time should be transferred between the two boxes, with high precision and flexibility;
- The pick and place operations shall be carried out by a robotic arm with an electromechanical gripper at the end to grab the products;
- The robot must be able to reach the entire occupying area of the two boxes inside the vehicle;
- The system must have a resting point, in the form of a rod or a block, for the robot to grasp when it is not in operation;
- The picking system must have the necessary sensors and controllers to operate automatically and accurately.

The different components that constitute the picking system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 27 it is possible to observe the WBS of the picking system and to see how these components are organized.

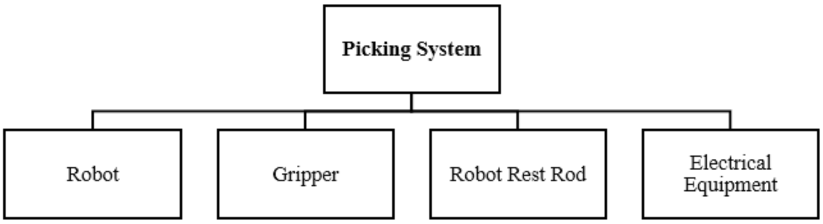

Figure 27 – WBS of the picking system.

The robot (Figure 28), used to transfer products between boxes, consists of the following components:

- A four-axis robot responsible for moving the products between boxes in a flexible way

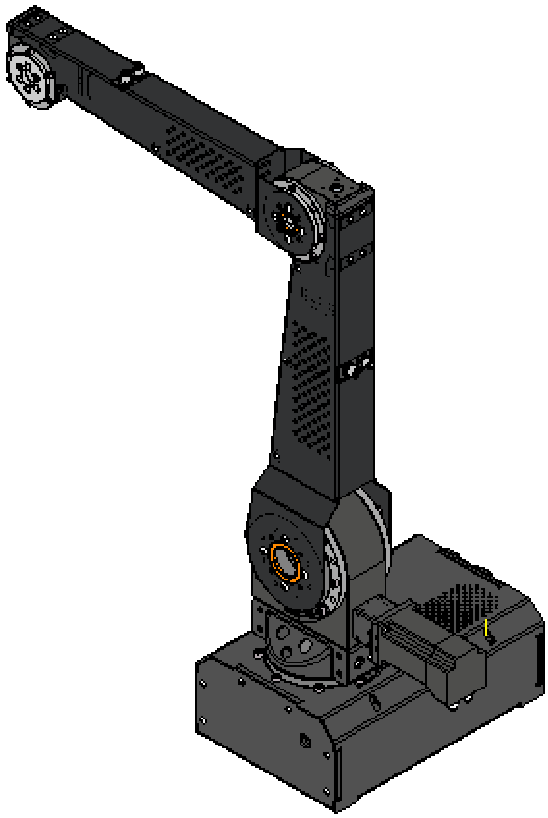

Figure 28 – Robot for the picking system.

The gripper (Figure 29), used to grab the products inside the boxes, consists of the following components:

- An electromechanical gripper with two jaws to grab the products.

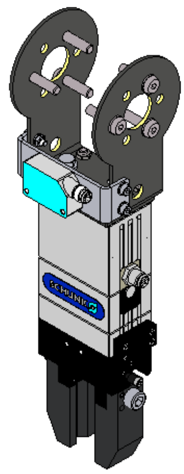

Figure 29 - Gripper for the picking system.

- The robot resting rod (Figure 30) is used so that the robotic arm remains in charge when grabbing the rod, preventing it from being loose whenever it is not in operation, namely during the travelling movement of the vehicle. It consists of the following components:
- A rod that is gripped by the robotic arm, keeping it loaded and locked.

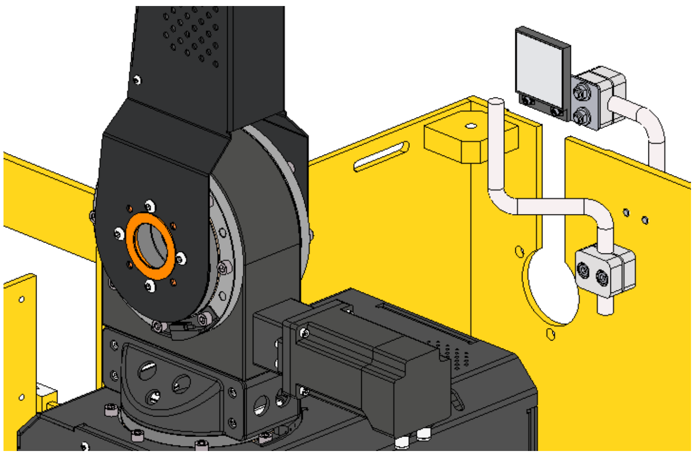

Figure 30 – Robot resting rod for the extraction system.

4.2.5. Interfaces, covers and transport points

The interface of the shuttle vehicle with the rack structure is related to the passage of the boxes to the interior of the vehicle because there is a natural gap caused by the separation of the two surfaces. As such, two flat steel plates were developed to support the boxes inside the vehicle, between the extraction arms (Figure 31). The plates have four bends all around, two at 90 degrees for reinforcement and two at 20 degrees to smooth the passage of the boxes between the rack structure and the interior of the vehicle.

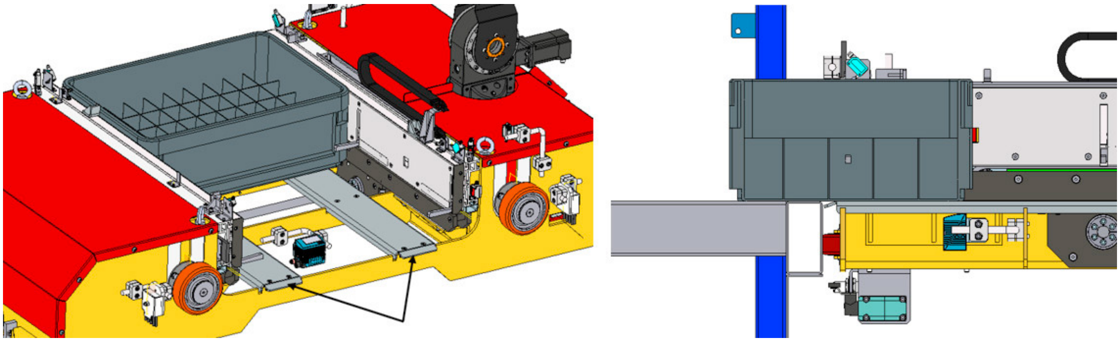

Figure 31 - Plates to support the boxes and smooth the passage of the boxes between the shuttle vehicle and the rack.

The transport and handling of the shuttle vehicle during the assembly, installation or maintenance process is carried out by means of four lifting eyes placed at the top of the main structure (Figure 32), allowing the vehicle to be lifted with the use of industrial cranes.

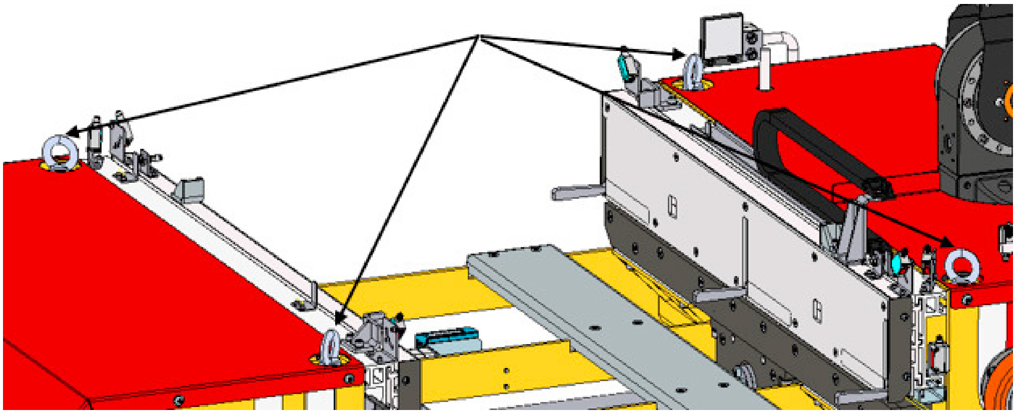

Figure 32 - Four lifting eye bolts on top of the main structure.

The covers are used to close the two cavities that exist in the main structure of the shuttle vehicle where the travelling and extraction gearmotors are housed. They were developed to protect the components from external waste, to prevent the risk of manually accessing the components during the testing phases of the equipment off the rack, and to aesthetically improve all equipment (Figure 33).

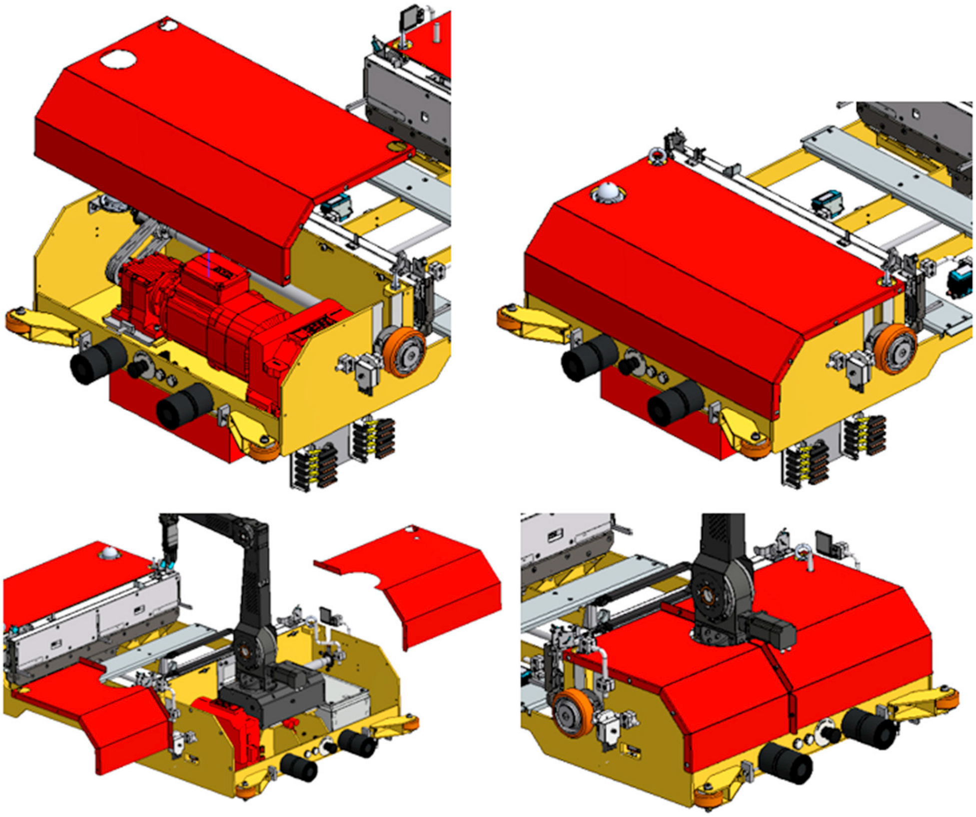

Figure 33 - Covers assembly on the shuttle vehicle.

Although not mentioned in detail throughout the text, the developed equipment has all the sensors and controllers necessary for the operation to be precise and automatic.

4.3. Final technical specifications

Table 3 represents the final technical specifications after the mechanical design of the shuttle vehicle, where all technical specifications were defined and updated in relation to the preliminary ones. As such, some technical specifications that were not defined previously were added, such as the powers of the gearmotors or the mass of the shuttle vehicle, and some values that were adjusted during the calculations of the equipment were updated, such as the travelling acceleration or the extraction acceleration. This is due to the fact that many of these values are related to the mass of the shuttle vehicle, a value that was only known after the complete design of the equipment.

Table 3. Final technical specifications for the shuttle vehicle.

Technical Specification	SI Unit	Value/Description
Shuttle Vehicle Mass	kg	300
Load Type	-	Plastic Tote Box
Load Dimensions	mm	600 x 400 x 200
Maximum Payload	kg	100 (50 kg/box)
Robot Maximum Payload	kg	1
Maximum Vehicle Speed Loaded (Unloaded)	m/s	3,0 (3,0)
Maximum Vehicle Acceleration Loaded (Unloaded)	m/s^2	1,5 (1,5)
Number of Wheels	un	4
Pivoting Wheels (Yes/No)	-	No
Travelling Gearmotor	-	Standard AC Helical Gearmotor
Travelling Gearmotor Power	kW	1,1
Load Extraction System	-	Fixed Stroke Load Extractor
Extraction System Maximum Stroke	mm	575
Extraction System Speed Loaded (Unloaded)	m/s	0,45 (0,45)
Extraction System Acceleration Loaded (Unloaded)	m/s^2	0,9 (0,9)
Extraction System Gearmotor	-	Standard AC Helical Servo Gearmotor
Expandable Transport Platform (Yes/No)	-	No
Picking System	-	Four-Axis Robot with Electromechanical Gripper
Temperature Range	ºC	0 – 40
Position Control	-	Bar Code Positioning Device
Power Supply	-	Conductor Rail
Power Supply Voltage	V	230

Discussion

The result of the developed shuttle vehicle meets the main requirements previously set, being functional and capable of handling boxes with mass and dimensions well defined, through the contribution of the following main subsystems that make up the equipment:

- The travelling system allows to move the vehicle automatically along the rack structure;
- The extraction system allows to extract and store the boxes of the rack structure automatically and accurately;
- The picking system allows to perform the picking operations automatically and directly in the rack structure.

These three main subsystems, together with the defined sensors and control components, guarantee the main operations of the shuttle vehicle and thus the operation of the AS/RS with the appropriate interfaces between the rack structure and the vehicle.

The shuttle vehicle developed with the built-in picking system is a truly innovative and disruptive solution to what already exists in the market, not only in the box shuttle AS/RS, but also in the other types of AS/RS, because it allows to combine the advantages of traditional AS/RS (performing the same storage and retrieval operations) with the advantages of automating picking operations (often done manually), all directly inside the rack structure, which makes order fulfillment processes much faster.

When compared to other Intralogistics works (see section 2), the work developed in this paper presents more advantages and greater impact in optimizing the flow of materials and information in warehouses, distribution centers and manufacturing units. On the one hand, when compared with the simulation models proposed by Gagliardi et al. [20], Güller et al. [21] and Martina et al. [22], although they are important tools in evaluating the performance of storage systems, do not present an innovation aspect as evident as the shuttle vehicle with a picking system that introduces something different from the existing solutions. On the other hand, when compared to the optimization solutions of logistics systems and warehouses proposed by Jaiganesh et al. [23] and Caridade et al. [24], both with very innovative products, the developed shuttle vehicle has a much more advanced development state and a much wider degree of applicability at the level of the warehouses in which it can be installed.

The novel shuttle vehicle now developed presents a picking system that induces that the space of occupancy of the rack structure is poorly used, since it is necessary to have enough gap between the levels. As such, implementing such system implies having enough space available in the warehouse, being necessary to study and realize if the investment in the shuttle vehicle with the picking system incorporated is viable. It will always depend on the type of warehouse and the type of products stored, this solution is more adequate to warehouses with high storage height and great diversity of products stored. However, it would be possible to develop an alternative picking system, possibly a gantry system of three axes to reduce the space occupied by the shuttle vehicle inside the rack structure.

1. Conclusoins

It is possible to conclude that the main objective of innovating the shuttle vehicle for the shuttle box AS/RS has been completed. The idea of incorporating in the shuttle vehicle a picking system able to carry out the picking operations automatically and directly in the rack structure is, in fact, something innovative when compared with the solutions existing in the market. The developed shuttle vehicle with picking system is a major contribution not only for Intralogistics, for introducing a completely novel solution within the AS/RS and for creating the possibility to automate and accelerate even more the operations of a warehouse, but also for Industry 4.0, for being another step in the creation of smart factories with fully automated systems and a constant communication between machines and products. As a proposal for future challenges, the possibility of developing an alternative picking system, such as a gantry system that is more compact than the robotic arm, remains open.

Acknowledgements

João Fernandes thanks Consoveyo, S.A., in particular Mr. Luís Alexandre and Mr. Jorge Amaral, for allowing this work to be carried out at the company.

References

[1] J. Moris, What is Intralogistics?, Invata Intralogistics Website, 2013. [Online] Available at: http://www.invata.com/what-is-intralogistics/. Retrieved on 5th of January 2019.

[2] M. Barbosa, F. J. G. Silva, C. Pimentel, R. M. Gouveia, A novel concept of CNC machining center automatic feeder, Procedia Manufacturing, 17 (2018) 952-959.

[3] K. J. Roodbergen, I. F.A. Vis, A survey of literature on automated storage and retrieval systems, European Journal of Operational Research, 194 (2009) 343–362.

[4] J. Qin, Y. Liu, R. Grosvenor, A Categorical Framework of Manufacturing for Industry 4.0 and Beyond, Procedia CIRP, 52 (2016) 173–178.

[5] A. C. Pereira, F. Romero, A review of the meanings and the implications of the Industry 4.0 concept, Procedia Manufacturing, 13 (2017) 1206–1214.

[6] B. Tjahjono, C. Esplugues, E. Ares, G. Pelaez, What does Industry 4.0 mean to Supply Chain?, Procedia Manufacturing 13 (2017) 1175–1182.

[7] S. Vaidya, P. Ambad, S. Bhosle, Industry 4.0 – A Glimpse, Procedia Manufacturing, 20 (2018) 233–238.

[8] W. F. S. Araújo, F. J. G. Silva, R. D. S. G. Campilho, J. A. Matos, Manufacturing cushions and suspension mats for vehicle seats: a novel cell concept, The International Journal of Advanced Manufacturing Technology, 90 (2017) 1539–1545.

[9] R. J. S. Costa, F. J. G. Silva, R. D. S. G. Campilho, A novel concept of agile assembly machine for sets applied in the automotive industry, The International Journal of Advanced Manufacturing Technology, 91 (2017) 4043–4054.

[10] M. J. R. Costa, R. M. Gouveia, F. J. G. Silva, R. D. S. G. Campilho, How to solve quality problems by advanced fully-automated manufacturing systems, The International Journal of Advanced Manufacturing Technology, 94 (2017) 3041–3063.

[11] B. M. D. N. Moreira, R. M. Gouveia, F. J. G. Silva, R. D. S. G. Campilho, A Novel Concept Of Production And Assembly Processes Integration, Procedia Manufacturing, 11 (2017) 1385–1395.

[12] R. F. L. Santos, F. J. G. Silva, R. M. Gouveia, R. D. S. G. Campilho, M. T. Pereira, L. P. Ferreira, The Improvement of an APEX Machine involved in the Tire Manufacturing Process, Procedia Manufacturing, 17 (2018) 571–578.

[13] A. J. A. Magalhães, F. J. G. Silva, R. D. S. G. Campilho, A novel concept of bent wires sorting operation between workstations in the production of automotive parts, International Journal of Advanced Manufacturing Technology, 2019, in Press. https://doi.org/10.1007/s40430-018-1522-9.

[14] L. Birglen, T. Schlicht, A statistical review of industrial robotic grippers, Robotics and Computer-Integrated Manufacturing, 49 (2018) 88–97.

[15] M. Moghaddam, S. Y. Nof, Parallelism of Pick-and-Place operations by multi-gripper robotic arms, Robotics and Computer-Integrated Manufacturing, 42 (2016) 135–146.

[16] H. Gultekin, Ö. O. Dalg, M. S. Akturk, Pure cycles in two-machine dual-gripper robotic cells, Robotics and Computer-Integrated Manufacturing, 48 (2017) 121–131.

[17] C. Schou, R. S. Andersen, D. Chrysostomou, S. Bøgh, O. Madsen, Skill-based instruction of collaborative robots in industrial settings, Robotics and Computer-Integrated Manufacturing, 53 (2018) 72–80.

[18] A. Realyvásquez-Vargas, K. C. Arredondo-Soto, J. L. García-Alcaraz, B. Y. Márquez-Lobato, J. Cruz-García, Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company, Robotics and Computer-Integrated Manufacturing, 57 (2019) 315–328.

[19] A. F. Castro, M. F. Silva, F. J. G. Silva, Designing a robotic welding cell for bus body frame using a sustainable way, Procedia Manufacturing 11 (2017) 207-214.

[20] J. Gagliardi, J. Renaud, A. Ruiz, Models for automated storage and retrieval systems: a literature review, International Journal of Production Research, 50 (2012) 7110-7125.

[21] M. Güller, T. Hegmanns, Simulation-based performance analysis of a miniload multishuttle order picking system, Procedia CIRP, 17 (2014) 475–480.

[22] C. Martina, P. Alessandro, S. Fabio, Modelling of Rail Guided Vehicles serving an automated parts-to-picker system, IFAC-PapersOnLine, 51 (2018) 1476-1481.

[23] V. Jaiganesh, J. D. Kumar, J. Girijadevi, AGV with Robotic Logistics System, Procedia Engineering, 97 (2014) 2011–2021.

[24] R. Caridade, T. Pereira, L. P. Ferreira, F. J. G. Silva, Analysis and optimisation of a logistic warehouse in the automotive industry, Procedia Manufacturing, 13 (2017) 1096–1103.

[25] Dematic Multishuttle® 2 – An In-depth and Independent Review from a Supply Chain Consultant”, Dematic Global Website, 2013. [Online] Available at: https://www.dematic.com/en-us/products/products-overview/storage-systems/dematic-multishuttle/. Retrieved on 6th of January 2019.

[26] Rotating shuttles from YLOG add agility, Handling & Storage Solutions Website, 2015. [Online] Available at: https://www.hsssearch.co.uk/page_567539.asp. Retrieved on 6th of January 2019.

[27] ADAPTO, Vanderlande Industries B.V. Website. [Online] Available at: https://www.vanderlande.com/warehousing/innovative-systems/storage-asrs/adapto/. Retrieved on 6th of January 2019.

[28] OPEX Perfect Pick a Revolutionary Picking Solution Based on Proven iBOT Technology, Supply Chain 247 Website, 2013. [Online] Available at: https://www.supplychain247.com/article/opex_perfect_pick_a_revolutionary_picking_solution. Retrieved on 6th of January 2019.

[29] Picking, KNAPP AG Website. [Online] Available at: https://www.knapp.com/en/solutions/technologies/picking/. Retrieved on 7th of January 2019.