Preliminary Design of an Automatic Guided Vehicle (AGV) System

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Aerospace Engineering

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Gracias a mi familia que siempre me ha apoyado.

Abstract

Nowadays it is normal for all industries to introduce robots or automatic systems in order to increase performance.There are many types of automated systems depending on what activity is going to be done. For the case of this project that activity is material handling, and the automatic system is called AGV, Automated Guided Vehicle.

This project aims to collect as much information as possible about AGV systems that currently exist and the subsequent preliminary design of an AGV system for a workshop of TAP Air Portugal Company. For this design, it was necessary to collect all possible information on this subject, to choose the best possible model for our case that will be built from zero, trying to take advantage of the materials that the company already has. It is important to say that the design of this system is only the first step, since the company plans to devote some more master theses that will involve the detailed study and development of each part of this system.

Finally the preliminary detailed design was achieved by carrying out different market studies of the different components and a 3D model of the vehicle was designed. Later the work done was analyzed as conclusion of the project with a section with future work to further develop this system.

Keywords: AGV, vehicle, workshop, material handling, automatic system

Resumo

Hoje em dia é normal que todas as indústrias apresentem robôs ou sistemas automáticos para aumentar o desempenho. Existem muitos tipos de sistemas automatizados dependendo de qual atividade será executada. Para o caso deste projeto em que a actividade é o manuseio de materiais, o sistema automático é chamado AGV, do inglês Automated Guided Vehicle.

Este projecto visa recolher o máximo de informação possível sobre os sistemas AGV que existem actualmente e o subsequente desenho preliminar de um sistema AGV para uma oficina da TAP Air Portugal Company. Para este projeto, foi necessário recolher todas as informações possíveis sobre o assunto, para escolher o melhor modelo possível para o nosso caso que será construído a partir do zero, tentando aproveitar os materiais que a empresa já possui. É importante dizer que o design deste sistema é apenas o primeiro passo, já que a empresa planeia dedicar mais algumas teses de mestrado que envolverão o estudo detalhado e o desenvolvimento de cada parte deste sistema.

Finalmente, o projeto preliminar foi realizado através da realização de diferentes estudos de mercado dos diferentes componentes e um modelo 3D do veículo foi projetado. Depois o trabalho realizado foi analisado como conclusão do projeto com uma secção com trabalhos futuros para desenvolver ainda mais este sistema.

Keywords: AGV, veículo, oficina, manuseio de material, sistema automático.

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Variables

h	Distance between the ”head” and the ”body” of the vehicle
F	Forces acting on the vehicle
M	Moments acting on the vehicle
Payload	Weight transported by the AGV

Acronyms

AGV Automated Guided Vehicle. 1

BMS Battery Management System. 31

GPS Global Positioning System. 46

HP Hydraulic and Pneumatic. 1

Li-ion Lithium-Ion. 17

MMH Manual Material Handling. 1

TAP TAP Air Portugal. 1, 22

Chapter 1

Introduction

Material handling is an invariable part of any manufacturing or service operation. Manual Material Handling (MMH) is the method more used by companies, and as it is manual, there is always a physical human effort in these operations, because there is an interaction between the worker and the material handling equipment [1]. Because of this interaction there could be problems such as: late delivery of the material, accidents that damage the load or injured the worker, or delivery of the wrong material.

Material handling systems play an important role in industrial environments, and to ensure that materials are delivered to production in the shortest possible time automated material handling system are used. These automated systems improves efficiency and accuracy of transportation, storage and retrieval of materials [2]. The most popular automated system in material handling is the Automated Guided Vehicle (AGV).

AGV is a term used to mention any transport system capable of functioning without human driver. These vehicles are sophisticated machines that represent a complete material handling solution that can increase efficiency and productivity as well as reduce product damage and labor cost; this is why they are becoming very popular worldwide, especially in repetitive actions over a distance. Common activities include loading/unloading of cargo or towing.

Nowadays the companies that are at the technological forefront, such as Amazon, Toyota or BMW are using this technology to improve their performance. For example, in 2012, Amazon introduced 15,000 AGVs across 10 of its warehouses with the aim to reduce delivery times [3].

TAP Air Portugal (TAP) wants to modernize its inner operations in order to not fall technologically behind and also to take advantage of the benefits of this system that will be further explained in a later section.

1.1 About the Company

TAP is the main airline of Portugal and it has its headquarter at Lisbon Airport. It operates an average of 2,500 flights a week to 87 destinations in 34 countries worldwide with a fleet of 84 airplanes [4].
In one of its workshops it is wanted to introduce an AGV system, namely in the Hydraulic and Pneumatic (HP) workshop, where about 300 people work in the maintenance to more than 2000 components from airplanes that belong to TAP or from other companies. In this workshop there are some wastes, mainly of transportation, movement and waiting. These wastes are identified by the department of *Melhoria Continua* which its mission is to look for wastes in the different activities inside the company. In order to

erase these wastes, this project is conducted.

1.2 AGV

1.2.1 AGV history

The history of AGVs began around sixty years ago, in 1953 when the first commercial automatic guide vehicle was used in a grocery warehouse in the Unites States. At this time AGVs had mechanical safety bumpers and were guided by a simple wire located in the floor (active inductive guidance) or using an optical sensor [5]. AGV came with many advantages (cost savings, increased efficiency, etc), so it had a great demand that drove the development of more advanced technology.

At the end of the 80's there was a severe recession that hit most of the industries, so the AGV development stopped because they were very expensive and money needed to be saved, not spent on expensive technology. Also about the same time the Japanese automobile manufacturing industry introduced the Lean Production, lowering operation costs and increasing quality.

At the end of the 90's active inductive guidance was no longer the only alternative, due to the introduction of new technologies such as laser navigation that started a new era where the AGVs were more flexible and reliable. This era continues to this day, and although the firsts AGV were expensive, difficult to install and maintain, inflexible and unreliable, modern AGV have improved until they have become a symbol of reliability and efficiency, and are used in a great variety of industries, however an AGV system represents a significant investment for a company, so this system is almost exclusively for large firms [5].

1.2.2 Benefits of the AGV

Factories, warehouses and hospitals are the mainly places where these systems are working nowadays, taking advantage of the benefits they have. The benefits can be divided in 6 categories:

- **Improve safety**. Safety of workers is guaranteed because of the presence of sirens and lights that alerts of the oncoming AGV and the contactless sensors which allows the vehicle to stop instantly. Moreover this vehicle travels on designated paths which have been prescribed by users so non-safe paths are avoided.

- **Reduce operational cost**. It can work 24/7 at a steady consistent speed. It doesn't need vacation, lunch break or sick leave.

- **Reduce labor cost**. It reduces man power (less money spent in wages, training, injuries...).

- **Total inventory control**. The position and status of the vehicles are constantly tracked and controlled by a computer system and the inventory can be identified by bar codes.

- **Decreases product and facility damage**. The contactless sensors stop the vehicles from running into other equipment, walls and inventory.

- **Allow flexibility**. Easily installed and modified and can be integrated with other equipment.

In conclusion, AGV give companies a competitive edge increasing productivity and time efficiency, as reducing costs.

1.3 Objectives

The main objective of this project is to study the introduction of an AGV system within the work environment in the components workshop of maintenance and engineering department of TAP Air Portugal Company. This study is a preliminary design of the system that will include the type of vehicle and its components, as well as the navigation system, best path design and the type of schedule. Finally a mock-up of the vehicle will be presented.

1.4 Thesis layout

There were several steps taken for the realization of this project, and they can be seen through the reading of the thesis. First of all, the search for the system requirements, in Chapter 2, where was conducted a bibliographical research on the subject, as well as the search for companies related to this kind of system. This research was made in order to have as much information as possible about current AGV systems.

In Chapter 3, a study of the activity was made within the workshop where this system will be implemented. With all the data and based on the bibliography found decisions were made about how should be the system configuration, guide-path design, type of vehicle and drive configuration. In addition to these decisions about the configuration of the system, some market studies had to be conducted to choose the best components to build the system. At the end, the vehicle was designed in 3D, the price of the system was estimated and the main benefits of the system for the company were explained.

And finally, in Chapter 4, the conclusions and future work were explained.

Chapter 2

System requirements

At the time to implement an AGV system in a new workplace, the following issues must be taken into account[6]: guide-path design, estimating the required number of vehicles, vehicle scheduling, idle-vehicle positioning, battery management and vehicle conflict resolution. During the design and later implementation of the entire system there may be interactions between these problems, for example, the type of guide path directly influences the complexity of the vehicle scheduling system and the number of vehicles required.

The design of an AGV system is a complex task that has many variables that impact on its operation [7]. The main aspects to take into account in a design of an AGV system are:

- Traffic management
- Battery management
- Number of loading and unloading areas
- Requirements of the vehicles
- The path design

Finally, the AGV system can be divided on 4 main parts: vehicle, host software, user interface and battery.

- The vehicle is the machine that provides movement, there can be as many as it is necessary in a system and depending of the type of job there are different types of AGVs vehicles available, such as Forklift vehicles, Underride, Towing vehicle or Custom. Each of these vehicles will be explained in more detail after.

- Host software is formed by on board microprocessors and a supervisory control system which monitories various tasks like distributing orders and controls the location of each vehicle.

- The user interface allows the employees to monitor and support the AGV system, through requesting a material movement to the vehicle and analyzing system alarms and vehicle utilization to improve overall operation.

- All automatic guided vehicles are typically powered by batteries (fuel cells, lithium-Ion, Ni-Cad...) with voltages ranging from 12 to 48V and usually sized to last at least 8 hours during normal use and there are two main ways to charge the battery. One of these ways is to change the dead battery for one fully charge, and the other consist in charging the battery while it is still inside the vehicle.

The sections included in this chapter are:

- Guide Path
- Navigation Systems
- Vehicle types
- Drive configuration
- Safety
- Batteries
- Control system
- Scheduling system

2.1 Guide Path

The guide-path design is an important part in the system design and is usually the first issue to be considered. The vehicle guide-path is usually represented as connections between pick-up and delivery locations and according with Tuan Le-Anh [6] the layout design can be classified as follows.

Table 2.1: Guide Path configurations

Flow topology	**Number of parallel lanes**	**Flow direction**
Conventional	Single lane	Unidirectional
Single-loop	Multiple lanes	Bidirectional
Tandem		

A conventional guide path connects all workstations and it may contain junctions, intersections, and shortcuts. This type of guide path can be unidirectional or bidirectional. The most popular system is the unidirectional guide-path, where the vehicles travel in only one direction. On the contrary, the bidirectional system, in which the vehicle can travel both ways, is not as used due to the fact that the control of the system becomes very complicated [6]. The problem with the bidirectional system can be resolve using multiple lanes, each lane has its own travel direction and vehicle movement in one lane is independent of the vehicle movement in another lane. Because of this, the separation between lanes has to be wide enough for two vehicles can be in parallel one in each lane. The negative aspect is that the guide-path covers more area and therefore needs more space and it is more expensive.

The single-loop layout differs only from conventional guide-path in which vehicles travel in a loop without any shortcut or alternative routes. Bidirectional traveling is also less used than unidirectional, because without alternative routes, vehicle interference is more likely to happen. To obtain the same performance as with the conventional system, the single-loop system needs more vehicles[6].

If a layout has multiple zones, it is called tandem guide-path. Only one vehicle serves each zone, so vehicle blocking and interference problems are totally eliminated. This layout configuration provides multiple transportation possibilities, and if the cargo needs to be moved from one loop to another to reach its destination, there are transfer areas where the loops interact between them.

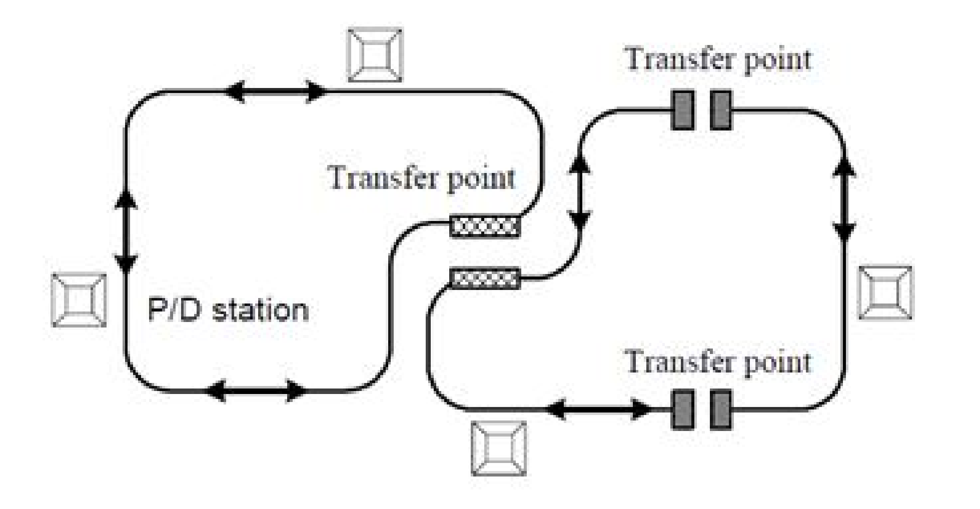

Figure 2.1: Tandem configuration [6]

2.2 Navigation Systems

Since the introduction of AGVs there have been two main classifications for the navigation system: close path and open path [8]. The selection of the type of navigation system is made based on the application, area size, cost, among others.

Close path. The path is indicated through physical guidelines such as points or lines buried or attached to the ground and the vehicle is able to follow it using a sensor pointing to the ground. There are five types of this system, two use points and the other three continuous lines. The ones that utilize points are inertial guidance and magnetic grid; on the other hand, magnetic tape guidance, wire guidance and optical guidance use lines. As the path is fixed to the ground, the modification of the layout is not very frequent, making the system not too flexible; however this type of path is cheap and easy to implement.

Open path. This kind of system has not physical paths for the AGV, though the paths are virtually pre-defined in the control unit. As this system has not physical paths, it is used to cover problems related to flexibility, due to that the vehicles which use this type of navigation system can change the path faster comparing with close path. There are two types of open path navigation systems: laser triangulation and natural frequent guidance. In these systems the probable deviation and the location of the AGV are controlled by the supervisory unit. Moreover, in this steering system the accuracy and flexibility are high, but it is much more expensive if it is compared to the close path method.

Next, each system mentioned above will be briefly explained:

Laser triangulation. Nowadays this is the most popular method of AGV navigation [9]; consists in mounting reflective targets through the facility at known positions and a laser scanner on the vehicle. The laser scanner search for reflective targets and then with the vehicle control algorithms calculate the exact vehicle triangulation (see Figure 2.2).

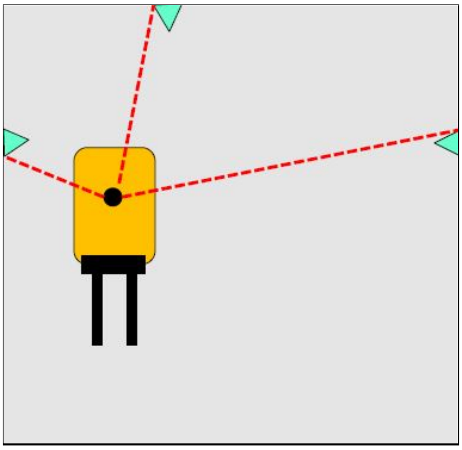

Figure 2.2: Laser triangulation [9]

Inertial navigation. This system uses the feedback from 3 different devices to determine location. These devices are: a gyroscope on the vehicle which measures vehicle's heading; a wheel encoder on the vehicle that calculates the distance traveled; and some reference points, usually magnets, which are embedded in the floor at certain coordinates in a map of the system which are detected by a sensor on the vehicle as it passes over the reference point (see Figure 2.3).

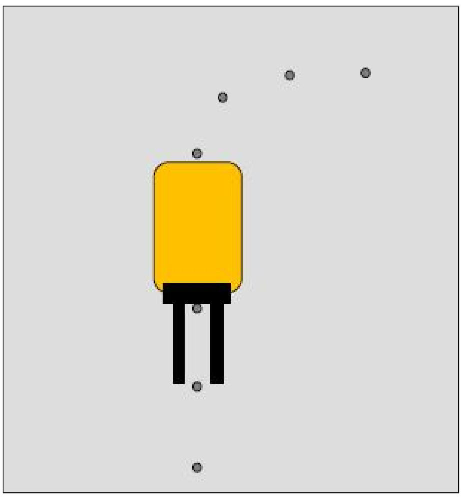

Figure 2.3: Inertial guidance [9]

Magnetic tape guidance. As its name suggest, a magnetic tape added to the floor is used and it is detected by a sensor mounted on the vehicle (see Figure 2.4).

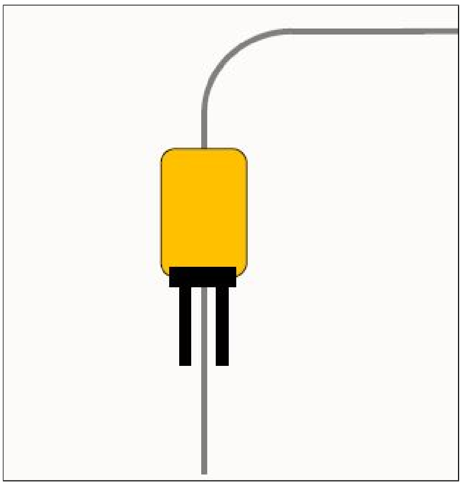

Figure 2.4: Magnetic tape guidance [9]

Magnetic grid guidance. This system is very similar to the inertial system, the main difference is that in the inertial system a path was design with the reference points and now the reference points design a grid (see Figure 2.5). Nevertheless the performance is the same.

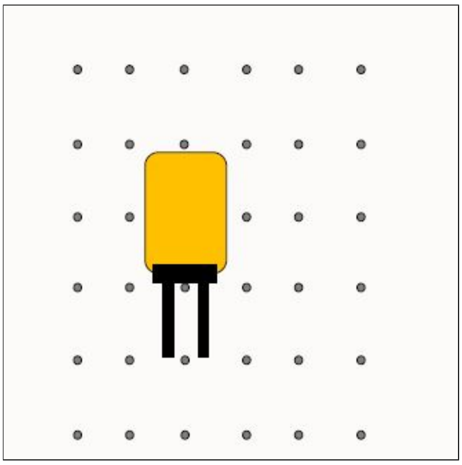

Figure 2.5: Magnetic grid guidance [9]

Natural feature navigation. The operating area is mapped and the reference images are stored in the vehicle's computer memory. The location of the vehicle is calculated based on its relative position compared to the natural features (see Figure 2.6).

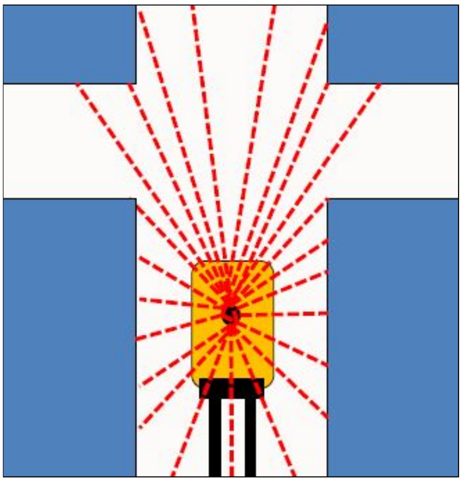

Figure 2.6: Natural feature guidance [9]

Wire guidance. This system is similar to magnetic tape. It uses a continuous wire embedded in the floor, and the antennas located in the vehicle detect the signal from it (see Figure 2.7).

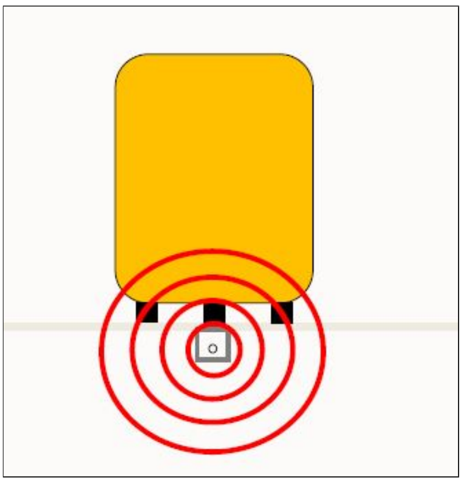

Figure 2.7: Wire guidance [9]

Optical guidance. For this system a chemical or a tape strip fixed or painted on the floor it is used, and it is detected by a sensor mounted in the vehicle (see Figure 2.8). This method could be the simplest to introduce on a industry but it is not typically used because the floor line needs to be cleaned or the tape reapplied periodically.

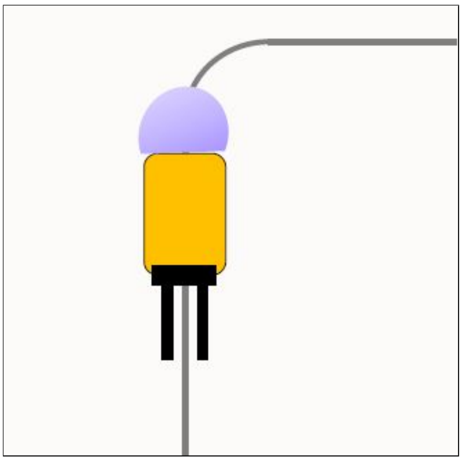

Figure 2.8: Optical guidance [9]

2.3 Vehicle types

Vehicles are the central elements of an AGV system as they perform the transportation tasks, and can have different characteristics depending on its application. The best way to categorize AGVs is by looking the loads they transport [5]. Next the main types of vehicles will be briefly explained.

Forklift vehicles. This vehicle's load unit are pallets or compatible containers, and it can be completely autonomous or it can have a seat to allow manual driving (illustrated in Figure 2.9 [10]). The advantage of a Forklift vehicle is that it is able to pick up or delivery load from the floor or various heights, making it the AGV most flexible.

Figure 2.9: Forklift AGV [10].

Underride vehicles. An underride AGV goes under a roller cart or wagon and lifts it slightly (illustrated in Figure 2.10 [11]). This vehicle is more compact and it can read a transponder at the bottom of the wagon to get instructions on what the specific cart contains and where it has to go. This vehicle has many advantages over the others, underride vehicles have a high maneuverability and occupy less space, and moreover it can be used as a towing vehicle.

Figure 2.10: Underride AGV [11].

Towing vehicles. As the name suggest it tows wheeled carts, and the load must be placed on and off manually or with another automated machinery (illustrated in Figure 2.11 [12]). The benefit of this vehicle is that it can carry several carts at the same time.

Figure 2.11: Towing AGV [12].

Custom. These vehicles are designed to move special loads so its size, shape and capacity can vary (illustrated in Figure 2.12 [13]).

Figure 2.12: Custom AGV [13].

2.4 Drive configuration

This configuration determines the maneuverability, complexity and cost of the vehicle depending on the number of wheels of the vehicle and by which wheels are driven and have steering. There are 4 main types:

Tricycle configuration. This is the most common configuration because provides precise tracking and the maneuverability is acceptable for most applications (see Figure 2.13).

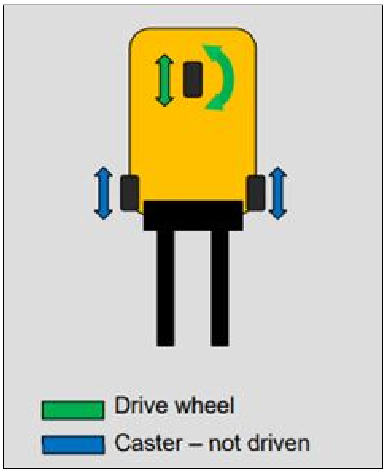

Figure 2.13: Tricycle configuration [9]

Differential wheel configuration. The steers wheels use the differential speed of drive wheels and for this, this configuration is very maneuverable due that the vehicle can rotate around its center (see Figure 2.14).

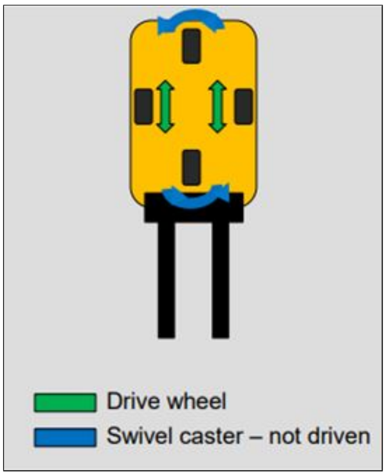

Figure 2.14: Differential configuration [9]

Quad. This configuration has two steer and drive wheels (see Figure 2.15), so it is more complex than the other drive configurations but it has the advantage of rotating around its center and move sideways.

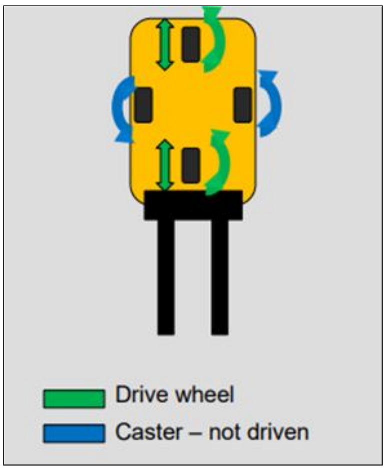

Figure 2.15: Quad configuration [9]

Omni-directional. The vehicle has 4 drive mecanum wheels that allow the movement in any direction (see Figure 2.16 [14]).

Figure 2.16: Omni-directional wheel configuration [14].

A mecanum wheel is a conventional wheel with a number of rollers attached to its circumference [15]. These rollers have their axis of rotation inclined, and are attached to the hub with rotating joints, so they can rotate freely around their axes [16] (see Figure 2.17).

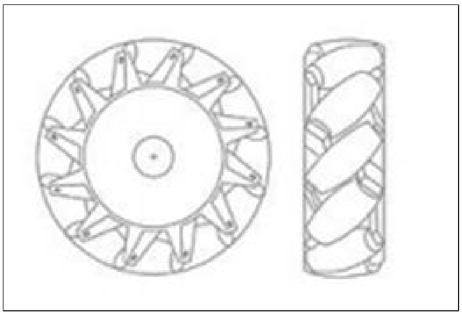

Figure 2.17: Mecanum wheel [16].

The omnidirectional motion is achieved by mounting four mechanum wheels on a four-sided base, controlling the angular velocities and the direction of rotation of each wheel without changing the direction of the wheels. Due to these reasons, each wheel has to be powered by a singular motor. The possibilities of the omnidirectional motion can be seen in Figure 2.18.

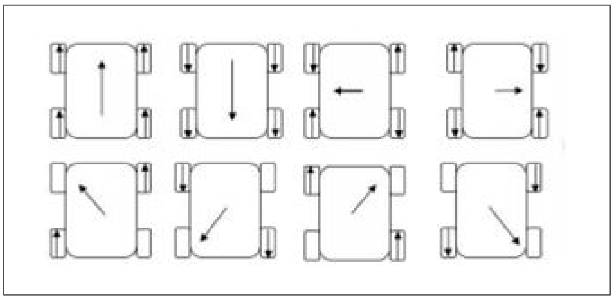

Figure 2.18: Omni-directional motion [16].

2.5 Safety

These vehicles are expensive and heavy, so they must implement safety systems to guarantee that both, vehicle and employees will not suffer any accident. Because of this, AGV vehicles are equipped with a collision avoidance system that has been improved through the years. All the AGVs should follow the central regulation UNE-EN 1525, despite this regulation is quite old (from 1997), it is still in use [5].

One of the most important elements of the regulation is the personnel protection system. It has to ensure that people or objects located in the drive path are recognized and the AGV would stop before hit them (see Figure 2.19 [17]), if the vehicle can not stop in time, the contact may not exceed 750 N and then the AGV must shut off instantly. This safety system consists basically in proximity sensors to prevent a collision and bumpers to avoid damage if a crash happens. Proximity sensor could be a laser scanner that moreover it can be used to help the navigation or infrared sensors. These sensors work with 2 delimited areas that vary with speed and direction, one is the warning field and the other is the stop field. The warning field is bigger than the other and when an obstacle is inside, the vehicle slows and sounds a horn, and if finally the obstacle enters to the stop zone, the vehicle must stop. However if the vehicle does not stop and the obstacle is hit, the bumpers would enter in action. This bumpers are usually made of plastic, foam or flexible metal that will compress when the crash happens activating a limit switch that would stop the vehicle.

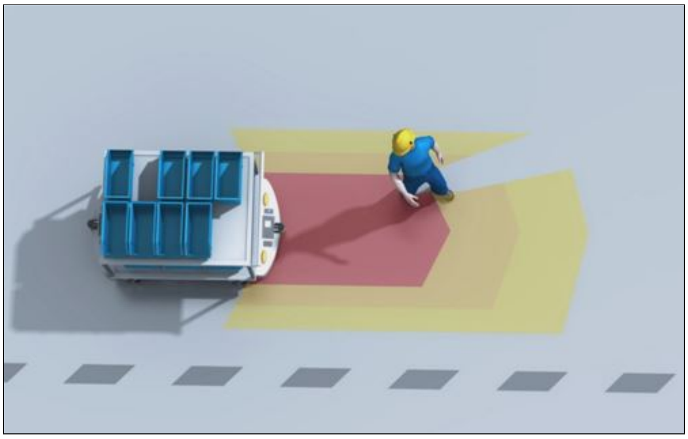

Figure 2.19: Safety areas [17].

Moreover it should have an emergency stop button accessible and easily recognizable, to allow anyone to turn it off on anytime and a combination of optical (rotating lights) and acoustic warning signals to warn that it is moving.

2.6 Batteries

Although some outdoor AGVs run on diesel engines, most of them run on electrical power, supplied by batteries that are rechargeable. The vehicle has to be supplied with electrical energy for the sensor system, navigation and movement of the mechanical parts.

Through a market study it can be seen that the most common batteries are lead-acid batteries and nickel cadmium batteries. According to Ullrich [5] there are modern batteries such as lithium-ion but for the moment they are not part of the technological standards for AGVs.

Lead-acid batteries [18] are the most widely used battery in the automotive industry, and the most common battery in AGVs. This widely use is because these batteries are the cheapest rechargeable battery and have more than 140 years of development that makes them a reliable technology. The disadvantage is that this battery is very heavy and it has a strong environmental impact.

Nickel-cadmium batteries were one of the main competitors of the lead-acid battery for use in electric vehicles [19]. They have a longer life cycle and nearly twice the specific energy of lead-acid batteries, but can cost three times as much and are equally harmful to the environment.

Lithium-Ion (Li-ion) batteries are the lightest batteries and they are becoming the most common batteries for electric vehicles [18]. These batteries generally have low weight and high energy density and according to some studies, in 2020 they will have ten times higher specific energy than lead-acid [18]. The only disadvantage is the price, however it is becoming lower each year. From 2010 to 2016 it had a drop of 73% [20].

Table 2.2: Batteries characteristics [21].

Batteries	Lead-Acid	Ni-Cd	Li-ion
Specific energy (Wh/kg)	30-50	45-80	100-265
Energy density (Wh/L)	60-110	70-90	250-290
Specific Power (W/kg)	285	220	Up to 1350
Cell voltage (V)	2.1	1.2	3.7
Capacity (mAh)	4000-7000	600	2000-6000
Number of charges (to 80 of initial capacity)	700	1500	500-2000
Self discharge rate (per month)	5-20	10-20	2-8
Theoretical life time (years)	3	2	6
Cost per kWh ($US)	100-200	300-600	300-1000
Recharge time (h)	8	1	2-3
Memory effect	No	Yes	No
Maintenance	No	Yes	No

Through this table it can seen that there are many characteristics that are clearly better on Li-ion batteries (specific energy, energy density, specific power, cell voltage, self discharge rate and theoretical life time) and although Li-ion batteries are more expensive than Lead acid, the cycle cost may be less, because the Li-ion battery has a longer life [21].

2.6.1 Charging Methods

Charging is an important operation because the AGV has to be charged at the right time to not affect the operation of the system. Charging at the wrong time can cost time and money. Nowadays there are three methods of battery charging used in AGV, charging traction batteries, non-contact energy transfer and hybrid systems [5].

Charging traction batteries is the classical method used almost in every electrical device. This charging consists basically in locating the vehicle at a charging station and putting it in contact with an energy source.

The next method is non-contacting energy transfer which is based in the induction phenomenon. Through this phenomenon the energy is transfer from a conductor coil attached on the floor along the path of the AGV, to a secondary circuit mounted on the bottom of the vehicle. This method is good enough for simple AGVs layouts but the coil need to be located everywhere where the vehicle is going to move.

The last method is the hybrid system. It consists on putting together the two methods mentioned above. Here the main charging method is the non-contact energy transfer, while the traction battery in reality is only auxiliary and fulfills only limited tasks, for example if the vehicle has to drive off the layout to avoid a collision or when it is not possible/necessary to put a conductor coil in the path.

2.6.2 Charging schemes

There are five different charging schemes for AGVs [22], manual battery swap, automatic battery swap, opportunity charge, automatic charge and combination charge.

The manual swap is the most basic of all the battery schemes, when the battery level is under a certain percentage, the vehicle is headed to the charging station where the battery is manually changed to a fully charged one. The automatic swap differs only with the manual in which the battery change is made by a machine instead of a human, and it usually takes less time to complete the exchange

Opportunity charge is made when the AGV has predictable stops and takes advantage of idle time to charge the batteries. Charging stations are located near the AGV stop location and the AGV is charge while waiting for its next task. If it is well defined this method has not affect the operation time. In the other hand, if we cannot predict the stops, the automatic charging can be used. In this scheme the vehicle will run until the battery level falls below a certain percentage, at this time it will be directed to a charging station where the vehicle will remain until the battery is full again. Finally, it can be use also a combination between automatic and opportunity charging.

2.7 Control System

AGV system is able to follow a determined path, detect and dodge obstacles, and carry out its task without constant human supervision. Some of these vehicles that have a superior processing capacity are able to communicate between them in order to calculate routes and taking decisions to not have an accident [23]; however it is better to have a central control system which gives orders to each vehicle. With this central system the AGV needs less processing capacity, so it is cheaper. Moreover the traffic can be managed from a global point of view and if something about the programming (for example any change in the path) has to be modified, it would be change faster because it would only have to be reprogrammed the central system, not each vehicle. Nevertheless, although it is used a central control system, vehicle controllers are needed. These controllers would be responsible for the low level drive system control, such as the electric motors or the lights.

Nowadays there are some companies that deal with traffic management software, but these softwares are not ready to use after their installation because they have to be customized to the needs of the company, they only facilitate the management and route calculations as well as the creation of an interface.

2.7.1 Conflict resolution

At the moment there is more than one vehicle in our AGV system it is necessary to impose traffic rules to maximize the movements of the vehicle eliminating potential traffic jams. Schedule and routing the vehicles without conflict is very important because a conflict may collapse the whole system [6]. The situations that can be seen as potential conflicts can be divided in two: when two or more vehicles are going to the same intersection from different lanes, or when they are traveling along the same guide-path but at different speeds. There are several ways to avoid these situations, for example, using a tandem configuration or a better router algorithm; moreover some researchers have propose some rules for resolving conflicts in different guide-paths layouts[24] [25], especially for unidirectional layouts.

Normally, before starting the movement to perform any tasks the path is selected and it is checked. If it is free the vehicle will leave right away. After the vehicle has started its way every time it passes a track point, the traffic situation is evaluated again in order to acting accordingly to the traffic state.

2.8 Scheduling system

The scheduling system decides when, where and how a vehicle should act to perform an order. Every order can be resumed to move one load from a pick-up- location A to a drop-off- location B, but it can be defined by one or several movements. When it is used in a pick up application, an order may contain several stops where items are added or left. The objective of the scheduling system is to minimize the total costs of processing all the tasks, such as cost of empty travel distance and delays.

There are two types of scheduling, offline and online [6]. In the offline case, all tasks are known in advance, so the routes can be constructed and optimized before the vehicle starts to move. Nevertheless, a small problem in this system (a failure of a vehicle, a collision, a delay in the arrival time, etc), may have a big impact or even destroy the whole schedule.

In reality, the tasks are often known at a very late instant, so this makes offline scheduling impossible and it is necessary to impose the online case, where the schedule is continuously adapting. In this case the schedule should be updated when is known a new order to perform. An approach is to schedule using a planning horizon in which the new tasks are updated after a predetermined time period. The quality of the online schedule depends on the length of the planning horizon.

Chapter 3

System Design

In this Chapter it will be used the information from the previous one, where it was conducted a research for the requirements of an AGV system, to make a preliminary design of the AGV system. Based on the bibliography found, decisions will be made about how should be the system configuration, guide-path design, type of vehicle and drive configuration. In addition to these decisions about the configuration of the system, some market studies will have to be conducted to choose the best components to build the system.

3.1 Work environment and activity performance

The work environment where the AGV system would perform its activities is an important factor to have in mind, because the design and selection of the guide-path, vehicle and navigation guidance depends strongly on it.

The place where the AGV system is wanted to be introduced is a workshop, which has four work groups inside, and the cargo expedition zone which is next to it. The mission of this workshop is to maintain and repair some components used in the airplanes of the company. To facilitate the pick-up and delivery of these elements, each work group has two zones, one for collecting material that need to be repaired and other to deliver the components already fixed.

About the physical environment these work groups are separated by a corridor which is 5 meters wide, two groups are on one side and the other two are in front of them. It is not a small workshop, but like most workshop, it is very crowded with people and material thus it must be taken into account when designing the AGV system to eliminate future problems.

Nowadays, to perform the tasks of pick-up and deliver material inside the workshop it is used a LEAN technique called MIZUSUMASHI. It consists in putting the cargo in small standardized boxes on a cart (forklift is not used in this system) with a high delivery frequency, and as the frequency is high, the cargo quantity is low. As there are four work groups inside the workshop, the boxes have four different colors, that indicate to which work group that box has to go.

These transport tasks are made entirely by three people and every half hour one of them is responsible to carry out the activity that the AGV will perform, with a “small” cart, while the other two do other activities.

As a summary, the activity that will realize our system AGV will be the transport of materials between the 4 work groups inside the workshop and the reception/expedition area in the entrance of the workshop. Remember that each work group has 2 zones for handling material, one is the reception zone and the other is the delivery zone.

3.1.1 Analysis of current activity

It was necessary to analyze the current activity in order to obtain useful data for the AGV system. This data was provided by TAP, and it was concerned about: the maximum weight of the carts, the frequency, if it is necessary more than one cart, if there are an important number of urgency deliveries, the dimensions of the pieces, the biggest piece transported and if any work group has more activity than the others.

The first question that was clarified was that more or less all the work groups have the same activity, so the AGV should go through every work group in each shift. Moreover, as it was said previously the tasks are performed each half hour, due to this fact, the frequency is enough for each work group, and the cart is not usually full, so it is not necessary more than one cart per task. Because of the same reason (good transportation frequency), the number of urgencies is low.

About the dimensions of the pieces, previously it was said that they are put inside standardized boxes and currently different sizes of boxes are used, however in a near future it is wanted to use only one size, 600x400 mm.

The cart that it is now used, see figure 3.1 would have capacity for 4 boxes with the measures to be implemented.

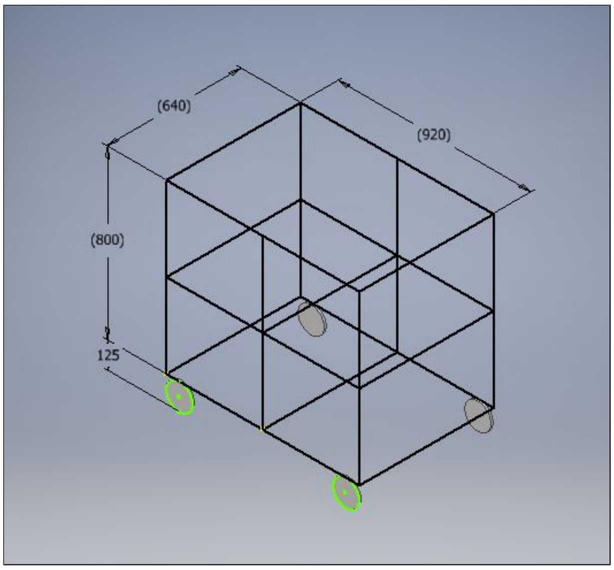

Figure 3.1: Cart measurements

Cargo weight is an important factor at the time to select the type of vehicle, and through this study the objective was to define the maximum load the AGV would carry. After talking with the manager of the workshop and checking the weight of some pieces, it was specified that the maximum load weight (cart weight with four boxes) would be about 150 kg (the majority of the similar AGV in the market are designed for much higher loads) and it is not often that it reaches this weight.

In addition to this information, the manager also provided the following estimated data about the daily operation of the current system:

- 16 rounds per day;

- 50 boxes per day;

- 15 minutes per round.

Using the above data it can be seen that an average of 3 boxes are transported in each round, so the cart is not usually filled, moreover it can be seen that a worker spends every day 240 minutes (4 hours) in this activity, just moving material from one place to another.

3.2 AGV system design scheme

For the design of the AGV system it will be followed the scheme recommended by Tuan Le-Ahn [6], showed in figure 3.2, in which the first thing to do is to define the guide path, then vehicle selection (at this stage, also is defined the navigation system), vehicle scheduling, vehicle parking, and finally battery management. This is the order this author give, however there are interactions between each stage so the order can change.

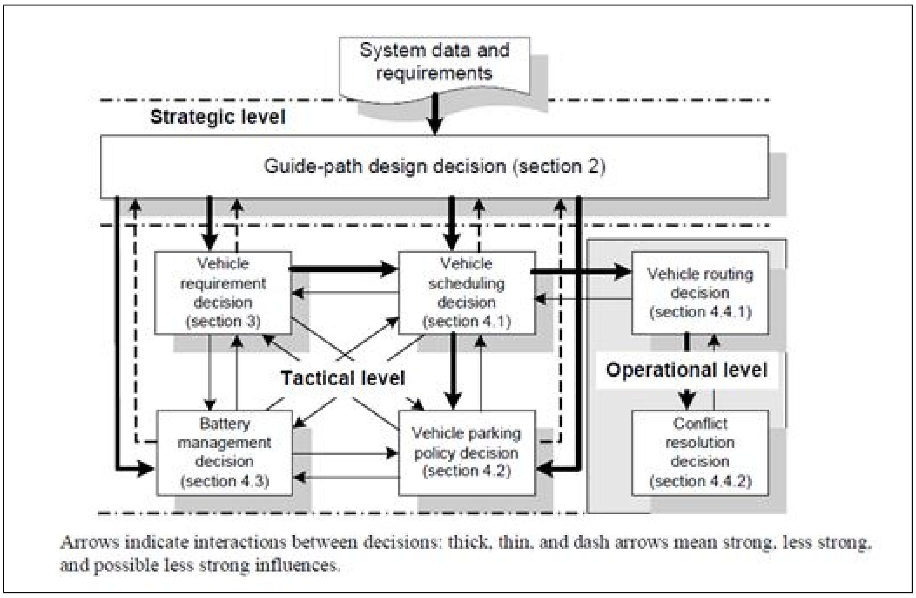

Figure 3.2: AGV design scheme [6].

3.3 Guide Path Design

There is not always only a perfect guide-path design and a perfect navigation system for one AGV system, most of the time more than one configuration can be considerate. In this case, in order to select one appropriate guide-path design it would be followed the next scheme:

1. Selection of the type of path (close or open);

2. Selection of the navigation system;

3. Selection of the design-path configuration.

3.3.1 Selection of the type of path: close or open

The type of path will be chosen from the following decision table, where the columns are the two type of paths, the rows are factors that influence the performance and each entry has a number between 0 and 5. If the factor is very positive, it will have a value of 5 and if it is negative it will have a value of 0. Adding all numbers in a column will give the score for a system. The system with the biggest score is selected.

Table 3.1: Path decision.

Characteristic	Close path	Open path
Flexibility	3	5
Cost	5	2
Implementation	5	2
Total	13	9

The type of path selected to this system is the close path because it is cheaper than the open path and although it is not as flexible, it is not needed too much flexibility since the locations where the AGV have to go are already known. There are only 8 destinations (each work group has 2 zones for handling material) and the system is not expected to be modified in a short period of time. In addition, the implementation of any close path is easier because it does not need too much programming.

3.3.2 Selection of the navigation system

Now that it is selected the type of path, a navigation system must be chosen from the ones that fit in the close path. These systems are: inertial guidance, magnetic grid, magnetic tape guidance, wire guidance and optical guidance.

For this selection is also used a decision table such as the one used previously. The evaluated factors are: control simplicity of the system, flexibility, introduction of the navigation system inside workshop the and maintenance. Cost here is not a factor because their price is similar, also the reliability is not a factor either because they are very reliable.

Table 3.2: Navigation system decision.

Factor	Optical guidance	Wire guidance	Magnetic grid	Magnetic tape	Inertial guidance
Simplicity	5	5	2	5	3
Flexibility	3	0	5	3	3
Introduction	5	1	3	5	4
Maintenance	0	2	4	4	4
Total	13	8	14	17	14

Through the above decision table it is chosen the magnetic tape guidance as navigation system for the AGV. With this navigation system the AGV would be simply to control (it is only needed a magnetic sensor and magnetic tape and the programming is not complex), easy to introduce inside the workshop and easy to maintain because it is very robust.

Finally, as it was decided to use the magnetic tape guidance, a market study was conducted to find a magnetic sensor and the magnetic tape. Both elements are from the company Roboteq [26]; the magnetic sensor is the MGS1600GY 3.3, and the magnetic tape is the MTAPE25NR ($141/45.7 m).

Figure 3.3: Magnetic sensor [26].

3.3.3 Selection of the design-path configuration

For this section, three paths were designed with different configurations following the different categories mentioned previously in 2.1, one is a conventional path with single bidirectional lane, other is a single loop with a single unidirectional lane and the last is the tandem configuration with a single unidirectional lane each circuit.

All these designs have in common the circuit of the reception zone where the AGV would pick up the cart with the materials that must be repaired and deliver the devices already repaired that the AGV would have previously collected. The vehicle parking would be in this circuit just in the position O, and also in this place the AGV will be charged. Moreover every layout has 8 stops, since every work group has one zone for collecting material and another to deliver it.

Now the different guide-paths will be introduced with their correspondent design (illustrated in Figures 3.4 to 3.6), some information about distances and expected times (see Tables 3.3 to 3.5) and the main advantages and disadvantages. To get the expected time it will be used a mean velocity of 2 m/s that is a normal velocity for current AGV.

Conventional path with single bidirectional lane

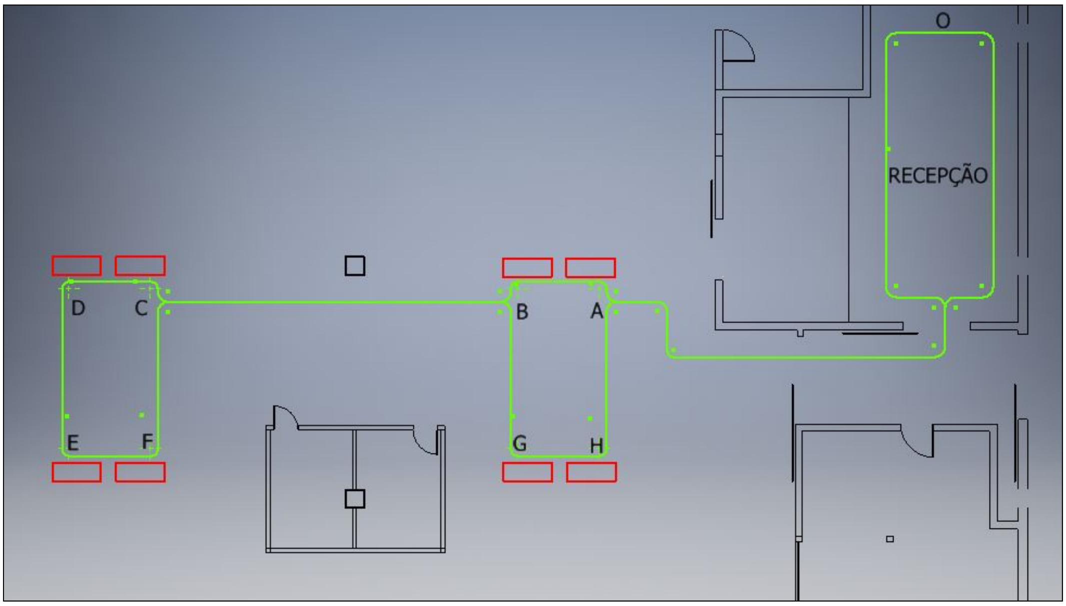

Figure 3.4: Conventional path with single bidirectional lane.

Table 3.3: Conventional path characteristics.

Range	Distance (m)	time (s)
O - A	27.08	13.54
A - B	3.4	1.7
B - C	13.07	6.54
C - D	3.4	1.7
D - E	5.55	2.78
E - F	3.4	1.7
F - G	22.17	11.08
G - H	3.4	1.7
H - O	31.27	15.63
Total	112.74	56.37[1]

Advantages. The vehicle can go directly to any work group from any point, this is important for urgent deliveries. Also it is the design with less meters of magnetic tape.

Disadvantages. It is the design that takes more time to pass through all the zones. Also as it is a single bidirectional lane if there is more than one vehicle in the system there can be possible collisions, however it is not expected to have more than one vehicle for the moment.

Single loop path with a single unidirectional lane

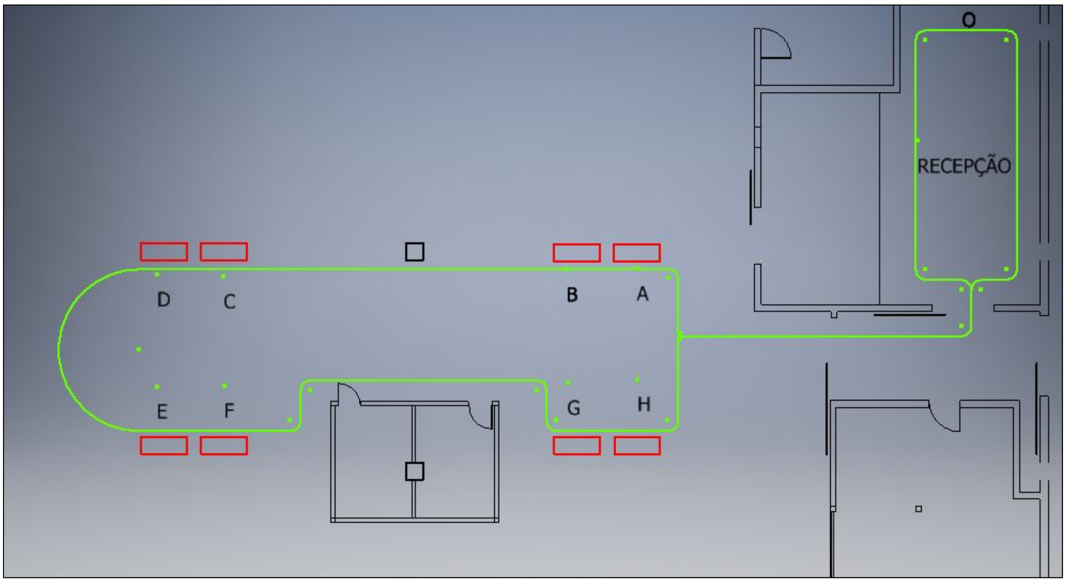

Figure 3.5: Single loop path with a single unidirectional lane.

Table 3.4: Single loop path characteristics.

Range	Distance (m)	time (s)
O - A	27.08	13.54
A - B	3.4	1.7
B - C	13.07	6.54
C - D	3.4	1.7
D - E	8.93	4.47
E - F	3.4	1.7
F - G	15.12	7.56
G - H	3.4	1.7
H - O	25.6	12.8
Total	103.4	51.7[1]

Advantages. If the system has more than 1 vehicle it is safer than the conventional configuration and it is the design in which the vehicle travels faster through all the work groups.

Disadvantages. It takes more time if the AGV only have to reach the stops called E, F, G and H.

[1]This time does not take into account the time that the AGV take to deliver and pick up the materials, it is only the time that it would take to reach to every zone.

Tandem configuration with a single unidirectional lane

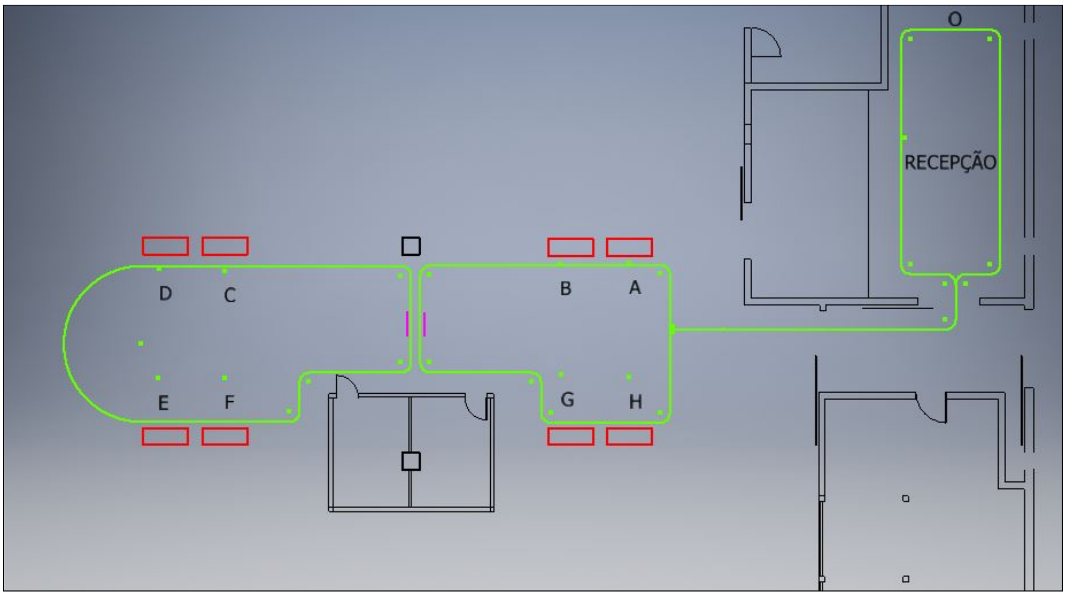

Figure 3.6: Tandem configuration with a single unidirectional lane.

Table 3.5: Tandem configuration characteristics.

Range	Distance (m)	time (s)
O - A	27.08	13.54
A - B	3.4	1.7
B - C	15.62	7.81
C - D	3.4	1.7
D - E	8.93	4.47
E - F	3.4	1.7
F - G	17.9	8.95
G - H	3.4	1.7
H - O	25.6	12.8
Total	108.37	54.37 [2]

Advantages. The AGV can reach quickly any of the destinations of the first loop.

Disadvantages. For this configuration is necessary to have two vehicles and the amount of magnetic tape is also higher, so it is the most expensive design and although the above table does not seem to be the slowest circuit, it is necessary to remember that there is a transfer zone where it would lose some time, making this design the slowest if it is wanted the AGV to pass through all the stops.

After having presented the three designs with their respective data, advantages and disadvantages, the single loop path with a single unidirectional lane was chosen, because this is the fastest circuit and the one that less magnetic tape uses, so if this navigation system continued to be used for several years, this would be the circuit with cheaper maintenance and replacement. In addition, as previously stated the vehicle will have to pass almost always through the 4 work groups, so the main disadvantage of this layout (take a lot of time to reach directly points E, F, G or H) is not a problem.

[2]This time does not take into account the time wasted in the transfer zone.

3.4 Vehicle configuration

The selection on the vehicle type is done through knowing the requirements of the mission and the environment that were presented previously. As explained in section 3.1 , the tasks that the vehicle will have to do will be deliver cargo from one place to another, specifically, from the reception zone, outside the workshop, to the work groups, and vice versa. This cargo is on a cart, which the vehicle should tow or lift, and it is not especially heavy (maximum 150 kg).

For the environment is important to remember that in the middle of the warehouse there is a corridor which separate the work group, this corridor is only 5 meters wide and that would be a problem for a big vehicle with bad maneuverability.

With the above information in mind, a vehicle configuration with a good maneuverability and able to tow or lift carts has to be selected. AGVs that perform similar activities in similar places are all underride types. This is because a forklift is unnecessary since the load is not very heavy nor is it necessary to lift it to a great height. So finally the underride vehicle is selected

3.5 Drive configuration selection

Regarding the drive configuration, the best one (with the better maneuverability) would be 4 mecanum wheels to allow omni-directional motion. This omni-directional motion also could be very useful in the future if it is decided to implement the same vehicle for a similar activity in another environment.

However after searching and talking with the company Hangfa Hydaulic Engineering CO. to ask for advice and budget, the idea was rejected because it was too expensive. Only the price of one mecanum wheel was 250€, this value would be multiplied by four (4 wheels) and it would have to be added the price of 4 electric motors and 4 motor controllers because each motor would work individually.

So finally the most common drive configuration was chosen, this is the tricycle configuration, with one steerable drive wheel and two caster wheels.

To find a steerable drive wheel I got in touch with the company C.F.R. and after giving them all the necessary information they proposed one of their products.

Next will be exposed the information provided (some of this data was estimated, because at this time there is no data such as the weight of the vehicle) to the company and the characteristics of the product (see Tables 3.6 and 3.7; and Figure 3.7).

Table 3.6: Information provided about the vehicle.

Estimated weight of the vehicle plus payload (kg)	340
Maximum Load weight (kg)	150
Vehicle maximum speed (m/s)	2
Maximum Slope (%)	1
Number of total wheels	3

Table 3.7: Steerable drive wheel information.

Product	MRT 10 DC002
Wheel diameter (mm)	196
Material	Polyurethan
Maximum load (kg)	550
Battery voltage (V)	24
Motor speed (rpm)	2500
Gear ratio traction motor	1:20
Traction motor power (W)	400
Total weight (kg)	42

Figure 3.7: MRT 10 DC002

3.5.1 Basic principles of the tricycle configuration

Now the basic principles that must be taken into account for the design of a tricycle configuration will be presented.

Weight distribution. The weight distribution is the ratio of the horizontal weight displaced between the front wheel and the back wheels and this would determine the stability and maneuverability. The higher the weight on the front wheel, the better the turn in tight corners, but too much weight causes the back wheels to skid when the speed is high. If on the contrary, the rear wheels support a lot of weight, the vehicle will have a tendency to overturn. Therefore, the optimal weight distribution is 70/30 between the weight of the front and rear wheels.[27]

Gravity center. Center of gravity is as crucial as weight distribution for optimum tricycle handling characteristics. The lower the center of gravity, the better the maneuverability. Moreover as in the weight distribution, it is better is it is closer to the front wheel. [27]

3.6 Battery selection

Taking into account the information exposed in section 2.6 a study of the characteristics of each type of battery and a market study are carried out to specify which is the battery that fits in a better way in this system.

Next it will be shown the decision table (see Table 3.8) that was used to select the type of battery. It works putting 1 or 0, 1 if that characteristic is good enough for our project comparing with the other batteries, and 0 if it is not.

Table 3.8: Battery decision table.

Batteries	Lead-Acid	Ni-Cd	Li-ion
Specific energy	0	0	1
Energy density	0	0	1
Specific Power	0	0	1
Cell voltage	0	0	1
Capacity	1	0	1
Number of charges	0	1	1
Self discharge rate	1	0	1
Theoretical life time	0	0	1
Recharge time	0	1	0
Memory effect	1	0	1
Maintenance	1	0	1
Acquisition cost	1	1	0
Total	5	3	10

The Li-ion battery is selected due to its several advantages, as observable from Table 3.8.

The only drawback of lithium-ion batteries is that they are more expensive than the rest of the batteries, but like all new technologies, their price tends to fall every year.

Once that it is decided the type of battery that is going to be used, it is time to select the charging scheme. For this case, where the vehicle will perform its activities each half an hour and taking advantage of using Lithium-ion batteries, opportunity charging is the better option because as it was said previously, these batteries do not have memory effect so they can be charged small amounts each time. Also, if the time between activities it is not enough, it can be use the break time for lunch to charged completely the battery, or charge it at night when there are not activities inside the workshop either.

Finally, after the market study it was selected the battery U1-24RT from the Company Valence, with the following characteristics:

Table 3.9: U1-24RT characteristics.

Product	Voltage (V)	Capacity(Ah)	Weight(kg)	Dimensions (mm)	Energy(Wh)
U1-24RT	24	20	6.5	197 x 135 x 183	512

This battery also has the benefit of having an internal Battery Management System (BMS) that is an electronic system that manages the battery by monitoring its state, calculating secondary data or reporting it.

3.7 Safety devices

Safety is a big concern in every AGV system (as it is in TAP and especially in this workshop) because it is an expensive system and also because it is usually working along humans in the same place, so accidents could happen. To prevent accidents with employees Ullrich [5] recommends using restricting access to the area where the vehicle is working, however for our case is not possible to do this, but maybe in some years after optimizing the workshop automation it could be possible. For this case, Ullrich also recommends floor makers, designated danger zones and visual and warning signal to prevent workers from getting close. Nevertheless it should be necessary to train the employees who will work close to the AGV to show them how the safety equipment of the AGV works and in which operations they do not have to get close to the AGV.

For the AGV configuration selected in section 3.4 it is needed a safety sensor, warning lights (on each side of the vehicle), a horn, and an emergency stop button.

Safety sensor. After conducting a market study, and taking into account the first configuration wanted to be implemented, which was the omnidirectional configuration, the first decision was to have a scanner with a wide scanning angle since with this configuration the vehicle can move to every direction. Then it was selected the safety laser scanner S300 mini standard from SICK company, because it had a scanning angle of 270^o, so it would be enough to use two of them, one on the front-left corner and the other on the rear-right corner, to encompass the entire area around the AGV. As it is ”mini”, with this selection the weight and the cost of the AGV is lower, because the first idea was to put 4 laser scanners with 180^o of scanning angle.

Nevertheless, as it was said previously, the drive configuration was changed, so now it is enough with only one laser scanner with a scanning angle of 190^o that would be mounted in front of the vehicle. Finally, another device form the same company was chosen, the safety laser scanner S3000 standard. This sensor is more expensive than the previous one, but before two safety scanners were needed, and now only one, so at the total cost is lower. Moreover, according with the central regulation UNE-EN 1525 if this sensor is implemented it is not necessary the use of bumpers.

Table 3.10: Safety laser features.

Protective field range (m)	4
Warning field range (m)	up to 49
Distance measuring range (m)	49
Number of fields	4
Scanning angle	190^o
Supply voltage (V)	24 DC
Weight (kg)	3.3

Figure 3.8: Sick laser scanner s3000 standard.

Horn. The horn selected would be Rich Tone Horn M26 from Hella Company. This horn is specially designed for the use in forklift and industrial vehicles.

Lights. Led lights will be used in this design. This lights are usually sold in tapes of five meters long and the normal price is 20€/5m.

3.8 Conflict resolution

Regarding the Conflict resolution it is not necessary to impose any rule since in our case we will only have one vehicle in the system, and there will be no problems with other AGVs. The only conflict that can exist is with people or with objects, which will be obstacles for our vehicle if they get in its way. If the AGV finds an obstacle, as the magnetic tape navigation system is going to be used, the vehicle will not dodge it by a secondary route (as it could happen in an open path), but it will stop and sound a signal to indicate that is being hindered.

3.9 Lifting device

All AGV have a lifting system to ”grab” the load in order to transport it safely to its destination. Most use a lifting structure, which raises the load a few centimeters from the ground and favors its transportation, however there are also structures that instead of lifting, are hooked to the cart and carry it ”dragging”, for this the cart must have wheels.

For this project it is decided to install a lifting system because it is a more versatile system. This means that if after putting this system into operation, the company decides to implement this vehicle in another activity, it will be easier to do so with this structure than with the hooking system. In addition, if we cover this lifting structure with a rough material, it could also work as the hooking system, it would not be necessary to raise the load, it would be enough to raise the lifting structure enough until it makes good contact with the cart.

As for the other components, a market study was carried out and a HYMO AXX4 - 8/6 raising table (Table 3.11) was selected:

Table 3.11: Lift structure characteristics

Product	HYMO AXX4 - 8/6
Max. load (kg)	400
Table size (mm)	800 x 600
Max. height (mm)	800
Table height (mm)	200
Lift time until max. height (s)	32
Motor voltage (V)	230; 1 - phase
Motor output (kW)	0.55
Control voltage (V)	24 DC
Weight (kg)	120

As it can be seen, the properties of this device are greater than those needed. The lifting capacity (400 kg) is much higher than the one needed (150 kg), but it was not possible to find a lifting table with less power and with more or less the same dimensions. In addition, although the maximum height is 800 mm, for the mission of the AGV would be enough when the wheels of the car do not touch the ground (150 - 200 mm).

Figure 3.9: HYMO AXX4 - 8/6

However, it can be useful to install this component if in the future the company decides to implement this same system in an activity where the work load is greater or the cargo has to be raised to a higher height.

3.10 Proposed vehicle design

3.10.1 Chosen components

The vehicle dimensions such as length, width, height and weight will be based on the dimensions of the main components that were selected in the previous section.
Below it is the table with the information about the components.

Table 3.12: Components information.

Device	Brand and model	Dimensions (mm)	Weight (kg)
Lifting table	HYMO AXX4 - 8/6	800x600x200	120
Battery	Valence U1-24RT	131x197x183	6.5
Steerable drive wheel	C.F.R. MRT 10 DC002	350x361x249	42
Safety sensor	Sick S3000 standard	160x155x185	3.3
Magnetic sensor	Roboteq MGS1600GY	30x165x25	0.25

3.10.2 Estimated dimensions

To specify the dimensions of the vehicle, the dimensions of the cart presented in the section 3.1.1 were taken into account. For the width it can not be bigger of 640 mm, because this is the width of the cart and the vehicle has to fit between the wheels of the cart; and for the height the cart must be modified because it is impossible to do this vehicle so low (125 mm). The estimated height would be approximately of 300 mm, but it will depend strongly on the dimensions of the components. Moreover, the “head” of the vehicle, where the safety sensor would be placed, has to be in front of the AGV far away enough from the ”body” of the vehicle in order to avoid that the laser rays touch it, because if this happens the safety sensor would detect that something is inside the protective field and the vehicle wouldn’t move.

3.10.3 Real dimensions

In order to have a simplified vision of the organization of the vehicle and the size, the following sketches were designed using the dimensions of the components mentioned in table 3.12. The different components are one after another and they are differentiated by color, the battery is green, the lifting table is blue, the steerable drive wheel is gray, the magnetic sensor is black and the safety sensor is yellow.

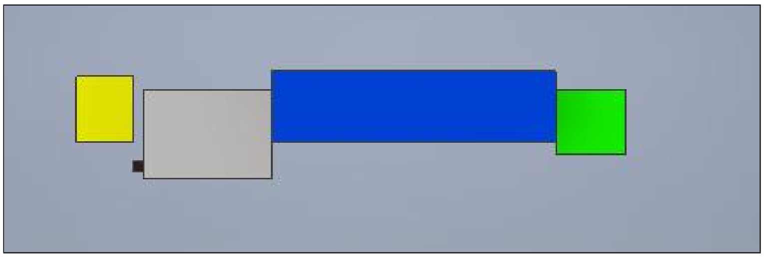

Figure 3.10: Sketch. View 1

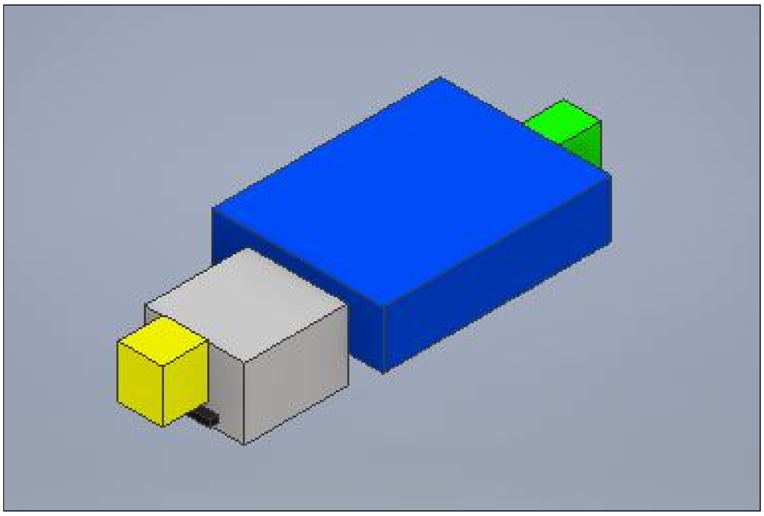

Figure 3.11: Sketch. View 2

The only dimension that it can be determined from the previous figures is the width. This is so because the widest component is the lifting table, whose width is 600 mm, and it is also due to the dimensions of the car, since its width is 640 mm, and the vehicle should be narrower to fit under it.

Now that it was known the value for the width, a simple calculation was performed to know what is the minimum distance between the "head" and the "body". the triangle that can be seen below is on the horizontal plane; it has a width of 300 mm, because the safety sensor would be locate at the center of the vehicle, so it would have 300 mm on the right and on the left; also it is known the angle of 85^{o}, because the scanning angle of the safety sensor is 190^{o}, and 85^{o} is half of the remaining 170^{o}.

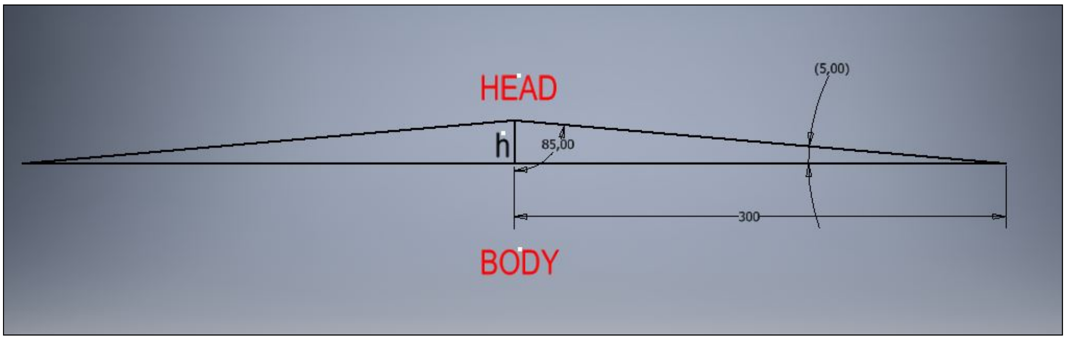

Figure 3.12: Schematic horizontal triangle head-body

$$\frac{h}{sin(5)} = \frac{300mm}{sin(85)}; \qquad (3.1)$$
$$h = 26mm$$

Through this calculation it is known that the minimum distance is 26 mm.

For the length and the height, the dimensions that will have the material with which the main structure will be build must be taken into account. To manufacture the structure of the chassis it will be used a material that the company already has. This material is manufactured by the company Quimilock that is dedicated to the manufacture of materials that can be reused and that are modular. In particular this material will be a square steel tube called HL-220 with dimensions of 45x45 mm and 2 mm thick. In addition, it has a maximum length of 220 cm and can be cut to smaller dimensions.

The structure was designed in three steps. The first step was to decide the organization of the components (it was done in the Figures 3.10 and 3.11). Then the structure was made separately for each main component. The front part was designed to attach the steerable drive wheel and the safety sensor. In the middle of the main structure would be located the lifting table and finally in the last part of the structure would be placed the rear wheels and the battery. And the last step was to bring the three structures together in just one main structure as compact as possible.

The following structure was designed:

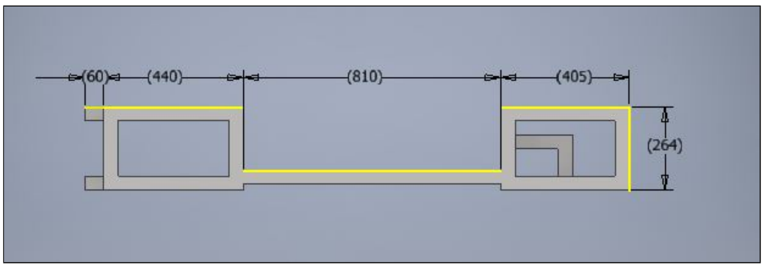

Figure 3.13: Main structure (Dimensions are in mm). View 1.

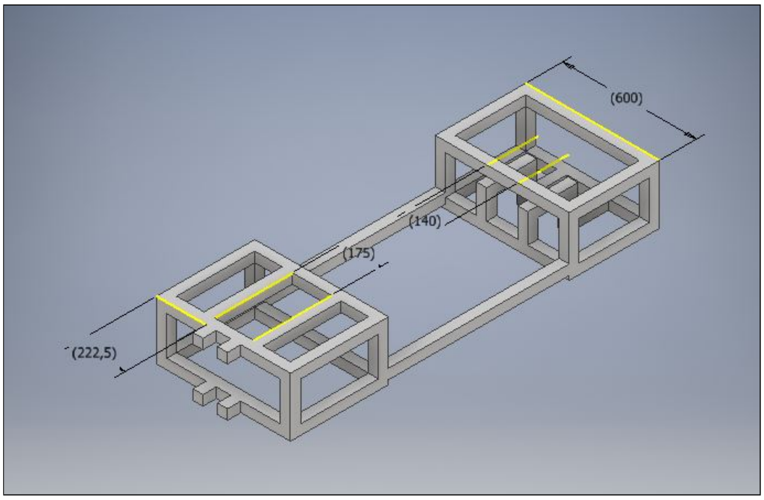

Figure 3.14: Main structure (Dimensions are in mm). View 2.

The organization would be the same as in the sketches, first the safety sensor, then the steerable drive wheel, then the lifting table, followed by the rear wheels and the battery (there is enough space for 2 batteries in case a greater autonomy is needed in the future). The electronic device (Raspberry Pi 3) and the horn would be placed near the batteries since it is the zone where there is more free space.

The total length of the vehicle will be the length of the main structure plus the length of the safety sensor that will be the only component that is outside the chassis. The length of the structure is 1715 mm, so the total length would be 1875 mm.

About the height, the highest component is the steerable drive wheel that is 249 mm high and that should be subject to the main structure above. As it was specified previously the main structure would be build with a square tube that is 45 mm hight, so if these last heights are added, the total height would be 294 mm, that it is very near to the 300 mm that it was estimated previously.

The total height would be 294 mm, however the main structure would be of only 264 mm, this is so because the operating height of the magnetic sensor is between 10 and 60 mm, so it was decided that this height would be 30 mm.

After having the main structure already designed, a simple calculation was made to see the weight distribution between the front wheel and the rear wheels. Remind that according to 3.5.1 the optimal ratio is 70/30.

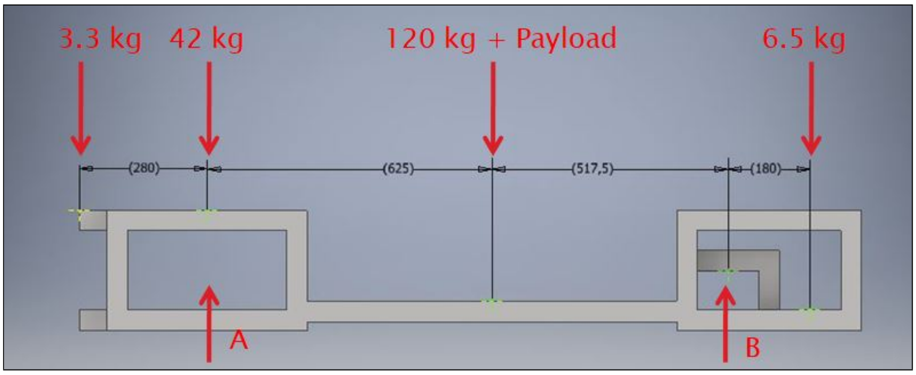

Figure 3.15: Weight distribution

Sum of all forces must be equal to zero.

$$\Sigma F = 0; \\ 3.3 + 42 + (120 + Payload) + 6.5 - A - B = 0 \tag{3.2}$$

The moment in A must be equal to zero.

$$\Sigma M = 0; \\ -(3.3 \times 280) + ((120 + Payload) \times 625) - -(B \times (625 + 517.5)) + (6.5 \times (625 + 517.5 + 180)) = 0 \tag{3.3}$$

Through these equations we get the values for A and B, being A the weight in the front wheel and B the weight in the rear wheels.

Table 3.13: Weight distribution

Payload(kg)	A(kg)	B(kg)	Ratio
0	99.44	72.36	58/42
150	167.38	154.42	52/48

Despite it is not near the optimal ratio, the vehicle has more weight supported by the front wheel that is what matters, also if it is wanted to have that optimal ratio with this organization of the components, the vehicle would end up being too long in order to move the rear wheels away from the lifting table.

With the design of the main structure and ensuring that the weight distribution is good enough, it was design the case to cover the structure and where the lights will be placed on the sides and the emergency button would be on the top. This case should be painted with a warning color, such as yellow.

The 3D model of the complete vehicle is shown in Figures 3.16 and 3.17; and the dimensions are summarized in Table 3.14.

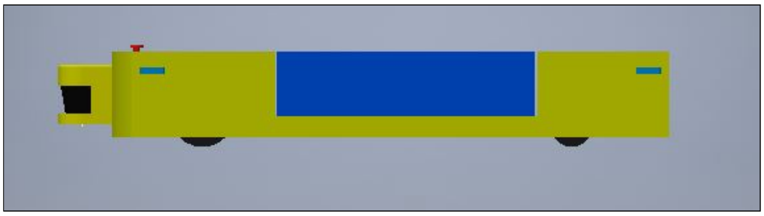

Figure 3.16: View 1 of the vehicle

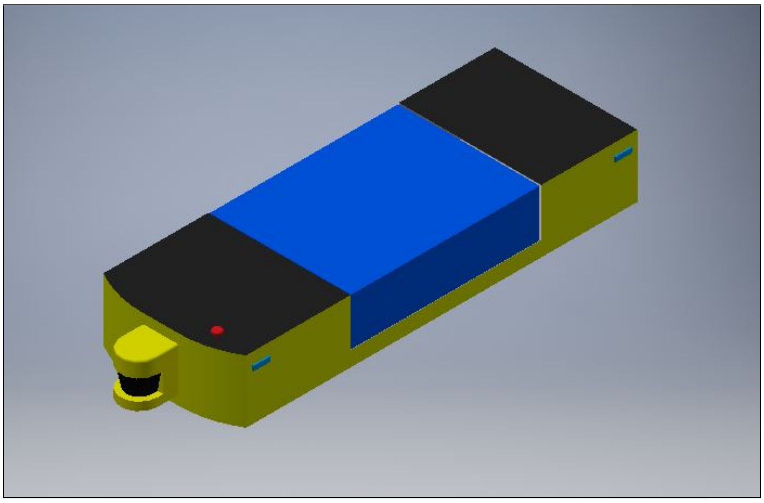

Figure 3.17: View 2 of the vehicle

Table 3.14: Vehicle total dimensions.

Length (mm)	Width (mm)	Height (mm)	Weight (kg)
1875	600	294	172.05 [2]

3.11 Software and control system

This element of the system was the most difficult to find a budget due to its technology and singularity. Finally it was possible to contact with one of the main companies in the distribution of control systems for AGVs; after talking with them it was clear that any of these companies charged based on what is needed for the application, so the more complex the more expensive it can become, so the value can vary.

The simplest system is about $15,000 and the system for which they have charged the most is $500,000. For our system we did not get a price but our AGV system is very simply, the navigation system is based on following a tape (GPS or laser navigation would be more difficult and more expensive) and the layout is not very big or with a lot of stops to load/unload. So we will assume that the price for our software would be $15,000, which are 12,727.5 €(value converted on 23.06.2018).

[2]For the weight it is not taken into account the weight from the main structure because the manufacturer company did not want to give that information. But approximately the total weight of the vehicle would be 200 kg

The product is called Transbotics Movement Optimizer (TMO) and is a supervisory system for control and monitoring equipment and sub-systems used in production facilities. This software also can act as an overall scheduler/router and /or as an object transfer and coordinator between different subsystems. In conclusion TMO runs on any Windows NT operating system and include an interface with host computer, traffic control and routing, efficient order management and diagnostics for easy troubleshooting.

3.11.1 Electronic device

The electronic part is very important within the system, since it is like the brain, it receives the information of the activity that it must carry out and acts giving orders, controlling and coordinating the performance of the different components of the vehicle. The main electronic devices will be a motherboard that will be placed on the vehicle and a central computer. The communication between the motherboard of the vehicle and the central controller would be via Wi-Fi, and the communication between the motherboard and the devices of the vehicle would be by wires.

After research for information to select the ”brain” of the vehicle, a motherboard that is giving good results in several applications is the Raspberry Pi 3 Model B+, it is cheap, with good performance and easy to program, in addition it has already been used in AGV systems so it is a very reliable element to add to our system.

3.12 Delivery and Pick up system

3.12.1 Schedule

Trying not to change the current ”modus operandi” inside the workshop, the schedule of the AGV system should be online and it must be capable of receiving orders at any time if there is an emergency order.

The online configuration is selected because in the workshop is not always perform the same activity, this means that not always the AGV is going to pass through every work group, maybe some times it has to stop in only one and other times in two, but not in the same two always, and another time it maybe stop in every work group.

As it was said previously in the section 3.1, in the actual system every task is performed each half an hour, and as we want to adapt the AGV to it, the orders must be planned at least every half hour.

3.12.2 Delivery and Pick up types

The way in which the cargo is delivered and picked up is important at the time to carry out any task. It is clear that the cargo should be put in carts; however it could be put it on manually or automatically.

Placing manually the load in the cart is simpler and there are two types of material handling. For one of them, there should be 4 carts, one for each work group. The elements that have to be moved would be put on a cart at the beginning of the task, and then the vehicle would move the cart until its destination (one of the work groups) where the cart would be “parked”, the vehicle would leave and then the cart would be unloaded by an employee, who would put later other devices on it and then be picked up again by the AGV.

On the other hand, the other type would start the same way, but when the AGV would reach its destination, it would sound a distinctive sound that would indicate that the elements (every element or only some of them, it would depend on the task and the work group) are ready to be unloaded from the cart. One employee from the work group should be aware of this sound to carry out that action, and at the same time that he is unloading the cart, he can also put some repaired devices in the cart.

The first manual material handling has one main disadvantage and one main advantage; the advantage is that it is very simple from the programming to the assimilation of the workers; however it is of no use when the quantities are few and the task is to deliver material in more than one position. The other way of manual material handling, although it is more complex to program depending on the task, it allows the AGV to go with the same cart all the task, which make it faster to perform any task.

The automatically material handling consists in the *Karakuri* concept. In this system the carts have inclined shelves that facilitate the automatic exchange of the material using the force of gravity. The main advantage of this system is that any employee has to unload and load the cart moved by the AGV, they only would have to worry about picking the devices from the cart of their work group and later return them when they are fixed, so the AGV could transport them again. However the main problem for the present project is that if the task is to deliver and pick up material from every work group, the AGV cart should be very well designed and well organized to ensure that every device reach its destination, and that could be a complex task.

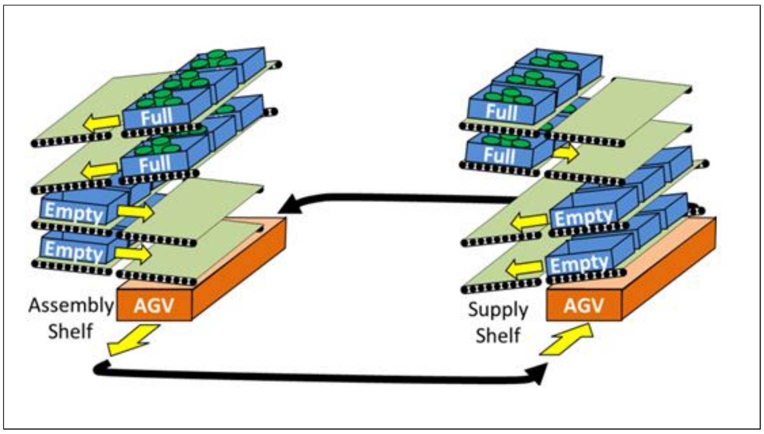

Figure 3.18: Karakuri system

For the current system and the current cart, the best solution would be to use the second method of manual material handling, the one which uses a sound to indicate that it must be downloaded/loaded, because the first one introduced would be very slow if the vehicle have to ”parked” the cart and then pick it up again in every work group and also because for the automatically method the cart should be modified. In conclusion, this is the best way in which the AGV would adapt to the actual activity inside the workshop.

For this method is important to defined the time that the vehicle would wait for the employee to unload/load the cart, this can be done in two ways, one specifying a determined time to do these operations and after this time the vehicle would start moving (through a research it was found that it should be enough with 2 minutes per stop) and the other would be that the employee would give the order to the system that the operation is done and the vehicle can keep its activity. For both methods the time wasted in waiting would be estimated in 2 minutes.

3.13 Automatic carts

In this section it will be introduced two ideas of carts that automatically transfer their load, in order to make this whole system completely autonomous. These new carts will be larger than the one that is currently being used, since to simplify their activity each car will have 4 compartments, each one dedicated to the load of each workshop. These compartments could be designed to transport one or two standardized boxes that they want to implement in the future of 600x400 mm. The best option is to have a capacity of two boxes per compartment, since this way we make sure that if there is a lot of activity in a workshop our system will be able to supply all the components on time, the only disadvantage of this is that the cart will be even bigger. Moreover with the introduction into the system of these automatic carts each workshop will go from having two zones for the change of components to just one, simplifying the system even more.

The two carts are based on two different devices: conveyor belt and pneumatic cylinder.

Cart with conveyor belt. This cart will have two different levels with 4 compartments each as mentioned above, so in the end the car will have 8 conveyor belts. One level will serve to place the damaged pieces that will be delivered to the workshops and the other to receive the components already repaired to take them to the Reception zone.

The carts that will be in the workshops will consist of two levels as well but only with one compartment per level. These carts will only have a conveyor belt at the level where the repaired parts are delivered, since the level where the damaged pieces would be collected, the components will remain there and will be later picked up by a worker.

Cart with pneumatic cylinder. This cart, unlike the other, will only have one level, but it will maintain the 4 compartments. This cart is based on the concept introduced in the previous section 3.12.2, called *Karakuri*. So in order to incline the compartments to facilitate the automatic exchange of the material using the force of gravity, each compartment will have 2 pneumatic cylinders that will allow its vertical movement.

The idea is that to keep the horizontal position balanced, the cylinders are halfway through its travel. To deliver material, the cylinder would lower its level enough in order that the load goes down with smoothness to the cart of to the side. And to pick up material would be practically the same but instead of lowering the level of the cylinder, it would rise. Since the car only has one level, the control programming must be good enough so there would be no problem. Always in every workshop the components that should be repaired will have to be left before receiving any load.

The carts that will be located in each workshop will have two levels, one to receive the materials and the other to deliver them. The upper level will be the level of material delivery and must have some mechanism for the exchange of the load. This mechanism can also be by pneumatic cylinders that lower and raise the shelf, or simply with a barrier that is lowered when the exchange has to occur.

The complete system of collection and delivery of materials is as follows:

1. Pick up of damaged components in the Reception zone. These components can be placed in the cart manually by a worker or with another automatic cart.

2. Delivery of damaged components to the work groups and collection of repaired parts.

3. Delivery of repaired components in the Reception zone.

It has not been possible to develop these ideas due to lack of time. However after a search for information, at first glance it seems that the best option would be the second idea, since the conveyor belts would have to be made specially for the size of the cart and would be more expensive than buying a few pneumatic cylinders.

3.14 Breakdown of expenses

The acquisition cost can be a important factor when deciding to implement this system or continue as before. In the following table (Table 3.15) there is the cost of each component and finally the total price of the entire system.

Table 3.15: Expenses.

Component	Price (€)	Units	Total Price (€)
Safety sensor	4,269	1	4,269
Battery	712	1	712
Magnetic sensor	435	1	435
Magnetic tape	127	2	254
Lifting table	2,974	1	2,974
Drive wheel	2,130	1	2,130
Motor controller	170	1	170
Horn	20	1	20
Lights	22	1	22
Emergency button	43	1	43
Motherboard	40	1	40
Software and control system	12,727.5	1	12,727.5
		Total	23,796.5

The price of the material to build the chassis, the rear wheels and the computer for the central controller of the system are not taken into account since it is material that the company already has.

3.15 Expected profits

The benefits of AGV systems are several, as it was already introduced in 1.2.2, and in this section we will analyzed the profits for the system designed.

- **Time**. As it was said in 3.1.1 the time wasted each day in this activity are 4 hours, because there are 16 rounds per day and each round takes 15 minutes. With the AGV system this time would be reduced, because if the waiting time of the vehicle (2 minutes per work group) and the time the vehicle takes to travel the entire path (more or less 1 minute) are added, the total time per round is 9 minutes. It is saved 6 minutes per round doing the same activity. Moreover if in a future it is used automatic carts this time would be even lower.

- **Cost**. In the long term, this system is cheaper than a worker, because once the acquisition value has been amortized, the only expense that this system produces is the cost of the electrical energy it consumes and the maintenance (spare parts), that although it can be expensive it should not cost per month more than a worker's salary.

- **Reliability**. AGV systems in general have good reliability, and the system designed here is not an exception since it is a robust and not very complex technology. Anyway it is good to have some spare component and trained personnel to overcome any problem.

- **Workforce**. This system removes 4 hours of work from an employee, but it does not mean that you have to dismiss this worker (who could also happen and save his payroll), he can be dedicated to other functions or trained for the maintenance of the AGV system.

- **Safety**. This system provides more safety to the employee since he does not have to make a physical effort to drag the car to the work groups, as it is done by the AGV.

Chapter 4

Concluding Remarks

The main objectives of this work were carried out successfully, getting all the current information of AGV systems in the section of System requirements and the preliminary design of an AGV system in the System Design section, although there are some sections such as the Software and control system or the of Electronic devices that should be extended in subsequent works.

Several companies from several countries were contacted to carry out market studies and ask for advice on different components of the system.These contacts were of great help for the accomplishment of the project, since there was not much information neither on the characteristics nor on the price of the components because they are so specific and technologically advanced. Even so, some companies refused to give information, however, they asked for information about the system and they answered with their best component for this system, or they just said if it served or not.It would have been preferable if they had given some more information to be able to do the calculations but it was not possible.

As the project progressed, different problems were found and they had to be solved. These problems were for example the difficulty to find certain type of information, to be answered by some companies, changes in the design produced by changes of cheaper components or because they adapted better to our system.

The final conclusion of this work is that it is entirely possible to implement an AGV system made and developed by TAP Air Portugal Company within the workshop. This is possible, firstly because the operation inside the workshop is not very complex as it could be seen previously. Moreover, the cost is not very high for a company of this dimension and if with further projects on this subject are possible to develop more this system with elements that the company already has and they are able to develop its own software, the cost will be even lower.

4.1 Future work

This project despite the efforts to make it as complete as possible, it is not finished. It would be necessary to finish the whole part of electronic components and some of the devices could be modified in the future if there is a better component or the company wants to change it.

After the design of the vehicle, the path and the main components, the next step would be the development of the software and of all the electronic and electrical systems, which would eventually allow the construction of the entire system. After the construction of the system it should be checked if everything works correctly or if any change is necessary. Moreover if the software is very well programmed it will not be necessary to buy it, so we would save a big amount of money ($15,000). Also, if it is developed the software within the company, it could facilitate a future expansion that would allow linking this autonomous system with other possible systems within the workshop or if it is wanted to move this system to another workplace.

As future work also it would be good to continue to investigate the issue of automated carts, since for this project I did not have time to develop the idea, the idea of the pneumatic cylinders.

As the implementation of this project is likely to take place in a few years, the technology may have improved and/or become cheaper, so if a lot of time is spent from this project before its implementation, it should be revised in order to check if the project is already outdated.

Although if the technology has not improved and/or become cheaper, it would be interesting to propose evolutions of the system. These evolutions have to do with the possible future works previously exposed because the maximum development of this system would be to have it fully automated (automated carts) linked with other related activities (own TAP software) and with a Global Positioning System (GPS) navigation system which allows a great flexibility to this system that would be very useful in case the company decide to introduce this system in other workshops or activities.

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