Preliminary Design of an Automatic Guided Vehicle (AGV) System

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Abstract

Nowadays it is normal for all industries to replace human labor by robots or automatic systems to improve their performance.There are many types of automated systems depending on what activity is going to be done. For the case of this project whose activity is going to be the material handling, 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

1. Introduction

Material handling is an invariable part of any manufacturing or service operation. Manual material handling is the method more used by companies, and 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]

1.1. 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 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.

1.2. METHODOLOGY

There were several steps taken for the realization of this project. First was the search for bibliography on the subject, as well as the search for companies related to this kind of system. This search was made in order to have as much information as possible about current AGV systems.

After obtaining this information, a study of the activity was made within the workshop where this system will be implemented. This study was facilitated by the manager of the workshop giving all the necessary information. 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, it had to be carried out some market studies to choose the best components to build the system.

At the end, the vehicle was designed in 3D and the price of the system was estimated. Finally the main benefits of the system for the company and the conclusions and future work were explained.

2. System requirements

2.1. Guide Path

The guide path can have different configurations depending on the flow topology, number of parallel lines and the flow direction [4] (see Table 1).

Table 1: Guide Path configurations.

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

2.2. Navigation System

There are two main classifications for the navigation systems: close path and open path [5].

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.

Open path.This kind of system has not physical paths for the AGV, though the paths are virtually pre-defined in the control unit.

The existing navigation systems are:

- Inertial navigation
- Magnetic tape guidance
- Magnetic grid guidance
- Wire guidance
- Optical guidance
- Laser triangulation
- Natural feature navigation

2.3. Vehicle Type

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 [6].

The main classification is:

- 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.
- Underride vehicles. An underride AGV goes under a roller cart or wagon and lifts it slightly.
- 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.
- Custom. These vehicles are designed to move special loads.

Regardless of the type of vehicle, the drive configuration can be:

- Tricycle configuration
- Differential wheel configuration
- Quad
- Omni-directional

2.4. Safety

These vehicles are expensive and heavy, so they must implement safety systems to guarantee that both, vehicle and employees won't 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 [6].

2.5. Batteries

Although some outdoor AGVs run on diesel engines, most of them run on electrical power, supplied by batteries that are rechargeable. According to Ullrich [6] the most common batteries are lead-acid batteries and nickel cadmium batteries, however there are modern batteries such as lithium-ion that are increasingly being used in this application.

Lead-acid batteries [7] are the most widely used batteries in the automotive industry, and the most common battery in AGVs. 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 Pb-acid battery for use in electric vehicles [8]. They have a longer life cycle and nearly twice the specific energy of Pb-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 battery for electric vehicles [7]. In Table 2, the characteristics of these batteries are summarized.

Table 2: Batteries characteristics [9]

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	700	1500	500-2000
Self discharge rate (per month)	5-20	10-20	2-8
Theorical life time (years)	3	2	6
Recharge time (h)	8	1	2-3
Memory effect	No	Yes	No
Maintenance	No	Yes	No

In addition to choosing the type of battery it is also important to choose the charging method and the charging scheme. Nowadays there are three methods of battery charging used in AGV, charging traction batteries, non-contact energy transfer and hybrid systems. In relation to the charging schemes, there are five different charging schemes for AGVs [10], manual battery swap, automatic battery swap, opportunity charge, automatic charge and combination charge.

2.6. Control System

AGV system is able to follow a determined path, detect and dodge obstacles, and carry out its task without constant human supervision. So the programming of the control system is very important.

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 ; however it is better to have a central control system which gives orders to each vehicle [11].

2.7. Scheduling

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 system:

- Offline. All tasks are known in advance, so the routes can be constructed and optimized before the vehicle stars to move.
- Online. The schedule is continuously adapting to the necessities of every moment.

3. Preliminary design

3.1. Work environment and activity performance

The place where the AGV system will 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 TAP airplanes. 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.

Nowadays, to perform the tasks of pick-up and deliver material inside the workshop they use 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 this frequency is high, the cargo quantity is low. These transport tasks are made entirely by three people and every half hour one of them is responsible to carry out the activity that we are going to implement with the AGV with a "small" cart, while the other two do other activities.

3.2. Analysis of current activity

It was necessary to analyze the current activity in order to obtain useful data for the AGV system.

The first question that was clarified was that 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, 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 and the number of urgencies is low.

About the dimensions of the pieces, previously it was said that they put the components inside standardized boxes and right now they are using different sizes of boxes, however in a near future they want to use only one size, 600x400 mm.

The cart that they are using now only have capacity for 4 boxes with the measures they want to implement.

About the cargo weight, 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 + four boxes) would be about 150 kg (the majority of AGVs used in workshops are designed for much higher loads).

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 concluded 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.

3.3. 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 considered. In this case, in order to select one appropriate guide-path design it was followed the next scheme:

- Selection of the type of path: close or open.

For the type of path it was selected the close one because it is cheaper than the open path and although it is not as flexible, it is not needed too much flexibility due to 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.

- Selection of the navigation system.

After carry out an analysis of the main navigation system for a close path, it was chosen the magnetic type guidance due to its simplicity and robustness

- Selection of the design-path configuration.

For this section, it was designed 3 paths with different configurations. 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. The advantages and disadvantages of these three paths were analyzed regarding the time it took the AGV to travel the circuit and the meters of magnetic tape that were necessary (because more meters of magnetic tape are translated in more money spent). After this analysis it was agreed that the best one for the mission of the system was the Single loop path with a single unidirectional lane, because this is the fastest circuit and the one that less magnetic tape uses.

3.4. Vehicle Configuration

The selection on the vehicle type is done through knowing the requirements of the mission and the environment. As it was said previously, 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 not too big 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 neither the load is not very heavy nor is it necessary to lift it to a great height. So finally the underride vehicle is selected

Afterwards the drive configuration was chosen. At first it was selected the omni-directional configuration because it is the one with a better maneuverability. However it was rejected because of the price, the wheels were expensive and it is necessary an electric motor for each wheel. After that decision, the tricycle configuration was selected due to it is the most common drive configuration used in AGVs, so it was clear that it is a reliable configuration and not very expensive.

3.5. Selection of components

For this section of the project only the components that could not be found within the company were searched.

The selection of vehicle components was a hard and long task because they are technologically advanced and very specific. So for each component some manufacturer companies were contacted to get the necessary information to perform the market studies.

The components searched for the vehicle were:

- Steerable drive wheel;
- Magnetic sensor;
- Safety devices;
- Lifting device;
- Electronic component;
- Battery.

3.6. Proposed design

For the design of the vehicle it was searched vehicles with a similar configuration and mission. Also it was calculated the distance between the safety sensor and the cart to avoid laser rays from touching the cart and create confusion on the AGV system.

After the research, first it was designed the main structure which would support the weight from the components and the cargo, and it would give shape to the vehicle. Later it was design the case, and finally it was put everything together to have a 3D view of the vehicle.

Below is the 3D model of the complete vehicle (Figures 1 and 2)and the dimensions (Table 3).

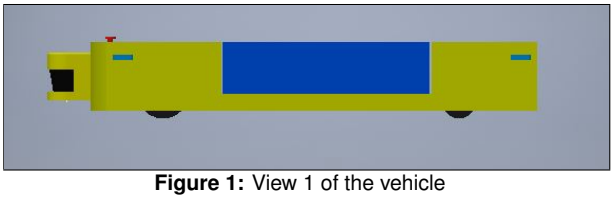

Figure 1: View 1 of the vehicle

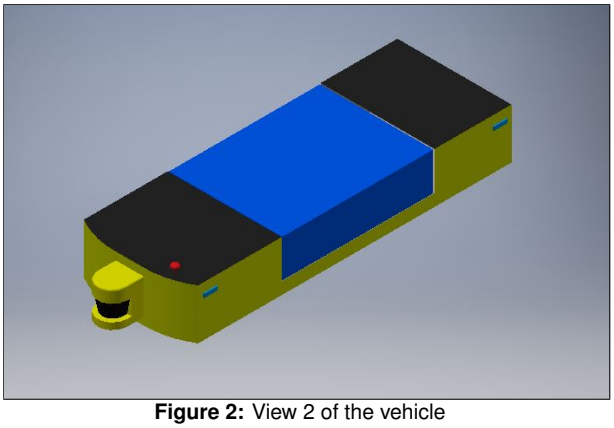

Figure 2: View 2 of the vehicle

Table 3: Vehicle total dimensions

Length (mm)	Width (mm)	Height (mm)	Weight (kg)
1875	600	294	172.05 [0]

Regarding the weight, a calculation was made to ensure that the front wheel will support more weight than the rear wheels. This distribution will give us a better vehicle handling.

3.7. 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 managed to contact with one of the main companies in the distribution of control systems for AGVs and, 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 software for the simplest system cost 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, so we will assume that the price for our software would be $15,000.

3.8. Delivery and Pick up System

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 re-

[0]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.

ceiving orders at any time if there is an emergency order.

It is selected the online configuration 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.

In this section it is defined how will be the delivery process, which is not about changing the way they perform this activity, but about adapting this technology to the operation of the workshop. So the best way in which the AGV would adapt to the actual activity inside the workshop would be placing manually the elements that have to be transported on a cart. When the AGV reach the work group of destination it would sound a distinctive sound that would indicate that the elements 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. This worker knows which elements he has to take because of the color of the box in which the material is transported .

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.

3.9. Automatic Carts

In this section it was introduced two ideas of carts that automatically transfer their load, in order to make this whole system completely autonomous.

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 locate 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.
- 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 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.

It was not 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.

3.10. 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 there is the cost of each component and finally the total price of the entire system.

Table 4: Cost

Component	Cost [Euro]
Safety sensor	4,269
Battery	712
Magnetic sensor	435
Magnetic tape	254
Lifting table	2,974
Drive wheel	2,130
Motor controller	170
Horn	20
Lights	22
Emergency button	43
Motherboard	40
Software and control system	12,727.5
Total	23,796.5

3.11. Expected profits

In this section was analyzed the profits for our system, which are:

- Time. 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 we add 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), we come up with a total time of 9 minutes per round. 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.
- Workforce. This system removes 4 hours of work from an employee. 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.

4. Conclusion

The main objectives of this work were carried out successfully, getting all the current information of these systems in the section of State of the Art 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.

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.

Also the lack of information provide by the manufacturer companies about their devices did not allow us to make all the calculations by ourselves, so we have to trust them when they told us if one of their devices serve for the purpose of the AGV.

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; and if with further projects on this subject is 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

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. Also, if the software is developed 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.

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