KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Jobi Paulose Chirangara

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RESEARCH AND ANALYSIS OF AUTOMATIC GUIDED VEHICLE FOR INDUSTRIAL LOGISTICS

Master's Degree Final Project

Supervisor

Assoc. Prof. Dr. Rūta Rimašauskienė

KAUNAS, 2016

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Industrial Engineering and Management Code (621H77003)

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KAUNAS, 2016

KAUNAS UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering and Design

Jobi Paulose Chirangara

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DECLARATION OF ACADEMIC INTEGRITY

________ June 2016

Kaunas

I confirm that the final project of ours, **Jobi Paulose Chirangara,** on the subject "Research and analysis of Automatic Guided Vehicle for Industrial Logistics "is written completely by ourselves; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, internet-based or otherwise recorded sources. All direct and indirect quotation from external resources are indicated in the list of reference. No monetary funds (unless required by law) have been paid to any one for any contribution to this thesis.

I fully and completely understand that any discovery of any manifestation/case/facts of dishonesty inevitably results in me incurring penalty according to the procedure(s) effective at Kaunas University of Technology

(Name and surname)

(Signature)

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Faculty of Mechanical Engineering and Design

Jobi Paulose Chirangara

Vignesh Gopal Raja

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(Name and surname) (Signature)

KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND

Approved:

Head of Production

Engineering Department

____
(Signature, date)

Kazimieras Juzėnas
(Name and surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT

INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Research and Analysis of Automatic Guided Vehicle for Industrial

Approved by the Dean Order No.V25-11-7, 3 May

2. Aim of the Project

The aim of this thesis to conduct a research on industrial logistics and analyze the use of fork lifts and develop an automatic guided vehicle to replace forklifts by finding out the efficiency and effectiveness of automatic guided vehicles in logistics.

3. Structure of the Project

1. Introduction
2. Literature Analysis
3. Concept Design
4. Warehouse Design
5. Cost Efficiency Analysis
6. Manufacturing Cost
7. Market Research
8. Conclusion

4. Requirement and conditions

1. Motor Speed and specification.
2. Electronic components to be used in the robot.
3. Warehouse plan.
4. Prices of fork lifts
5. Answered questionnaire for market research

5. The task assignment is an integral part of final project

6. Project submission deadline: 2016 May 27

Given to the student ______________________________

Task Assignment received ____________________ ____________________

(Name and surname) (Signature)

Supervisor ____________________ ____________________

(Name and surname) (Signature)

____________________ ____________________

(Position, Name and surname) (Signature)

Jobi Paulose Chirangara, Vignesh Gopal Raja, *Research and Analysis of Automatic Guided Vehicle for Industrial Logistics*. *Masters* in Industrial Engineering and Management. Final Project/ Supervisor Assoc. Prof. Dr. Rūta Rimašauskienė; Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Production Engineering and Design.

Study area and field: Production and Manufacturing Engineering, Technological Sciences

Keyword: *Logistics, Industry, forklift, Automatic Guided Vehicles*

Kaunas, 2016, 90p.

Summary

The thesis covers the information about internal industrial logistics that are carried out in automotive industries and warehouses. Fork lifts are the most commonly used device when it comes to logistics and these forklifts are have few downfalls which are analyzed and to rectify these downfalls, an automatic guided vehicle is designed theoretically. The design of the automatic guided vehicle provides the necessary information such as motor torque, size of the vehicle to analyze the space and time consumed by the AGV and compare it with the forklift to understand that AGVs are more efficient than forklifts. A simple logistics floor plan was designed and based on the mechanical design energy efficiency cost was calculated and compared between AGVs and forklifts. A market analysis was conducted in few industries to assess the position of AGVs to enter the logistics market and the outcome has influenced the manufacturing cost. Manufacturing cost also plays a major role since the AGVs were found to be less expensive compared to the forklifts.

Jobi Paulose Chirangara, Vignesh Gopal Raja. *Automatiškai valdomo vežimėlio skirto pramoninei logistikai kūrimas ir tyrimas*. *Magistro* baigiamasis projektas / vadovas doc. Dr. Rūta Rimašauskienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis: Gamybos inžinerija, Technologijos mokslai.
Reikšminiai žodžiai: *logistika, pramonė, krautuvas, valdomas vežimėlis*
Kaunas, 2016. 90 p.

Santrauka

Magistriniame darbe pateikti vidinės logistikos pagerinimo sprendimai, kurie gali būti naudojami įvairių sričių pramonėje arba sandėliuose. Analizuojant vidinės logistikos sistemą dažniausiai aptinkamas įrenginys yra krautuvas, tačiau šiame darbe pateikiama jo alternatyva. Sukurtas ir suprojektuotas naujas automatiškai valdomas vežimėlis (AVV), atiliktas jo charakteristikų palyginamas su dažniausiai naudojamu įrenginiu ir aptarti jų privalumai bei trūkumai. Nustatyta, kad AVV pagalba galima sutaupyti transportavimo laiką ir pastato erdvę skirtą transportavimo įrenginio važinėjimui, todėl teigiama, kad naujas įrenginys yra efektyvesnis įrenginys nei krautuvas. Atlikus rinkos analizę ir apskaičiavus AVV savikainą nustatyta, kad įdiegus naują įrenginį į logistikos sistemą būtų sutaupomos gamybos išlaidos, kadangi jo kaina yra mažesnė, taupomas laikas ir pravažiavimui skirtas plotas.

Contents

List of Tables

List of Figures

Introduction

Our research project is on AGV (Automatic Guided Vehicle) which can used in Industrial Logistics and Warehousing Purposes, making it easier for the mobility of goods and bulk products within the storage facilities, thus eliminating the tedious use of forklifts and installation of huge conveyor belts. What we are trying to establish here is that, by implementing the use of AGVs in industries we eliminate the excess use of fuel for the forklifts, thereby reducing cost of maintenance and operations, excluding the number of labors working on an actual forklift, save electrical energy which is used on an extensively on conveyor belts, its working and maintenance. We are in a world where energy is being depleted day by day and over-usage of fuel is leading to crisis of fuel insufficiency in most of the countries, and hence coming up with our energy efficient compact, eco-friendly, light weighted, battery operated(rechargeable) with features like obstacle sensors, which actually senses the path completely for human as well as non-living obstacles in its path, and self-equipped with monitoring systems, linked to the supervisor who has complete control on his screen in front of him, about the complete ware bouts what, when, how much time and how the battery level of the device is capable of performing are collectively displayed.

Aim

The aim of this thesis to conduct a research on industrial logistics and analyze the use of fork lifts and develop an automatic guided vehicle to replace forklifts by finding out the efficiency and effectiveness of automatic guided vehicles in logistics.

Task

1. To make a literature study on existing logistics carried out by industries and ware houses.
2. To analyze the features of existing forklifts and develop a concept design based on the literature study conducted on logistics and forklift.
3. To make a mechanical design and calculate the required torque for the motor to be used in the AGV.
4. To create and analyze path plan for the designed AGV by analyzing the multiple path planning method.
5. To analyze and compare the space and time constraints between AGV and forklift.
6. To calculate the cost efficiency based on energy consumption and manufacturing aspect.
7. To do a market research analysis for AGV.

1. Literature analysis on logistics

The following are some of the references from journals and how we apprehend what each of the authors/engineers have to tried to implement and how much of a difference we can bring about from our proposal of the AGV (Automatic Guided Vehicle) which we have planned to implement to improve the logistics in any of the warehouses and manufacturing plants/floors.

1. From the journal titled **Job assignment model for conveyor –aided picking system,** written by Jiang-Liang Hou, Nathan Wu, Yu Jen Wu, et al, develops a model to generate workload-balanced job assignments to a planner. In the proposed methodology the expertise of job assignment for conveyor-aided picking system is extracted via interviews in order to derive the empirical rules for the conveyor assignment. The empirical rules are quantitatively converted into empirical indices and the weights of the empirical indices can be determined via the historical job assignment records. On the basis of the derived empirical indices and corresponding weights, the optimal assignment plan can be determined [1].

   Further they have concluded that this proposed model can be applied to conveyor-aided picking system to enhance the workstation utilization and workload balance and to shorten the time and labor required for job assignment in a logistic center. As a result the operation costs of the Distribution centers, can be lowered and competency of the logistics centers can be increased.

   We are using the line tracing technique in the warehouse, and the manufacturing floors, so the energy consumption used to power the conveyor belts, and its picking system is saved on a larger basis as we use rechargeable DC batteries to power the robots. The cost of setting up the AGVs is again less expensive than the setting up of a complex conveyor belt operating system. Also the labor used for our proposal involves only the designation of one supervisor for an entire floor, rather than the employing different technicians for maintenance of different sections of the conveyor belts. The overall time to execute is lowered as the line tracing paths, is more feasibly executed to work compared to the complex space and time used to execute the conveyor-belt picking system.

2. From the journal titled, **Failure of Fork Lifts** written by Juan M Masson and Roberto E. Boeri et al, states the fatigue cracks inside the heels of the forklift forks as a result of the abusive service conditions. Some service operations induced static loads that exceeded the specific limits. Waste transportation involving large dynamic loads, damage the forks, as it involves the large dynamic loads to be carried on uneven paths

at relatively high speed. The integrity of the forks in service was examined by a technique called MPI (Magnetic Particle Inspection). According to their research, MPI proved to be more reliable than liquid penetrates for this application for servicing [2].

They have concluded that Routine periodic Non-Destructive Testing (NDT) by using the magnetic particle inspection was advised. Changes in the loading and transportation practices to avoid future fatigue cracking of the forks were also recommended [2].

The above journal states the failure of the use of forklifts under extreme conditions, resulting in the fatigue cracks of the forks, and when compared to what we have to propose with AGVs,

- Since the use of forklifts involve, risks of maintaining the forks and designating a technician for the operating and the servicing of the forklifts, we replace this with a much more modern and maintenance free device which reduces the total maintenance cost of investment
- Also saves the time that is spent on the maintaining such problems and making the mobility of logistical operations much more efficient compared to the use of forklifts.

3. From the journal titled, **Disagreement over carbon footprints: A comparison of electric and LPG forklifts,** authored by Eric Johnson gives us as the title suggests the comparison of LPG (Liquefied Petroleum Gas) and Electric forklifts. Carbon footprint is an increasingly popular concept for the labelling, marketing, finance and regulation. In individual cases carbon footprints can be contentious, especially in the case of LPG and electric forklifts.

They gave two conclusions at the end of this journal,

- Definitions will continue to complicate the footprint comparison
- Fuel carbon footprints of electric and LPG forklifts are in principle, about equal while practically, the footprints of LPG is smaller than that of electricity.
- The paper also concludes that footprint definitions should be sensible and transparent, but not prescribed [3].

Now when it comes to the carbon emissions, our project of AGV runs completely on electricity, and as mentioned before our AGVs are powered by DC motors and hence the normal current supplied to an industrial warehouse or production plant is the only necessary energy source needed. In some cases, the consumption of electricity is actually lesser than that of a regular warehouse/ production-manufacturing plant, as we employ and execute only charging points for the AGV platforms, which is in turn running on DC current, therefore giving out no emissions and thus helps us to preserve the green energy for a cleaner environment.

In this article they compare the carbon footprints of both LPG and Electric forklifts, and as a result they just manage to find out that LPG forklifts have lesser emissions than electric. But when we employ AGVs in this same situation, we neither have any emissions and it is possible to maintain a greener and serene atmosphere than both of the former mentioned forklifts.

4. From the journal titled **Automated Guided Vehicle with Robotic Logistics System,** written by Jaiganesh .V, Dhileep Kumar. J, Girijadevi . J et al, they are developing an AGV(Automated Guided Vehicle) which plays a major role in engineering industries to improve the material handling techniques used in common place. AGV includes a material transfer system located on the top and the driving device at the bottom to move the vehicle as desired. The vehicle works on its own once the program is fed into the control device. The control device is common to both driving device and transfer device which are connected together. The control device operates the vehicle and maintains the ultimate process.

   Proximity sensors are set up in the AGV‘s pathway to detect the vehicle movement. Photo sensors are incorporated to detect the material or object in the station. The material transfer system includes the loading and unloading of the material. The control device receives signal from the transfer device and transmits the signal to the driving system to move the vehicle to the next destination point. The magnetic tape method is used for the mobility of the device. It is a battery powered vehicle in which it charges automatically.

   Further they have concluded that it is a modern and advanced device, which uses a PLC as a paramount factor. The robotic arm on the top is the crucial part in the vehicle which accurately performs under the great influence of the PLC, leading to the higher efficiency of this product. The inductive battery system implemented in the vehicle gives an additional benefit to the entire system [4].

   Most of the working of the AGV is quite similar to what we have done with our project, but the below listed factors makes a huge deal of difference in the production line and the process.

   - Complexity is one factor that we have to point out here as the AGV uses robotic arms which requires more power from the mechanism using inductive charging, and hence when there is a failure in mechanism which powers the arm, as the arm fails to perform where as in the AGV we don't use a robotic arm, eliminating the complex process.

- Magnetic strip pathways are powered with the 3-phase power supply, which when the device passes through, induction occurs, powering the motor and extra charge is collected and saved, as back for more power later, i.e. charging and recharging happens at the same time, but when the power is given to these pathways, it is not at all safe for mobility through these pathways. A technician who passes through this pathway have chances of being electrocuted, hence unsafe. AGV on the other hand uses just black paint or yellow depending on the working environment.
- Power consumption is more as a 3-phase line is used to power the entire process, whereas AGVs are powered by solar energy which is more eco-friendly and greener in the long run.

The Scope of Logistics in Business

- Maximum customer service level is achieved.
- High Quality product is assured.
- Achieve minimum (possible) cost
- Adapting flexibly with respect to market changes [5].

Logistics management tries to have the "right product", in the "right quantity", at the "right place", at the "right time", with the "right cost"

Logistics management must balance 2 basic targets:

- Quality of Service.
- Low Cost

1.1 Types of Logistics

There are 6 types of logistics given below:-

- Return Logistics(Reverse Logistics)
- Military Logistics
- Third Party Logistics (3PL)
- Fourth Party Logistics
- Inbound Logistics
- Outbound Logistics[6]

1.1.1 Return Logistics (Reverse Logistics)

In order to increase the sales as well as the market share, many companies advertise that their goods will perform well over a period of time. The customer is, therefore, led to believe that in case he buys the product of that company, he is assured of satisfactory performance of the product. But at the same time, it is very much obvious that the company cannot assure the satisfactory performance of each and every of its product which is sold in the market. Few of the products sold may not perform as advertised over the specific period of time.

Such products need to be brought back by the company to confirm good customer service.

The company has, therefore, to take into account the defective goods that would be returned while framing the total logistical system network and calculating the total cost of such a system of network. Incorporating the goods returned in the total logistical systems network and cost is called as Return Logistics.

The most significant aspect of return logistical operation is the need for maximum control when a potential health liability exists.

Ex.: a contaminated drug in the market is extremely dangerous and the company has to recall all the stock of contaminated drug [6].

1.1.2 Military logistics

Military logistics is the process of planning and carrying out the movement and maintenance of military forces. It deals with most of the military operations that deals with:

- Design, development, acquisition, storage, distribution, maintenance, evacuation, and disposition of material,
- Evacuation, and hospitalization of personnel,
- Acquisition or construction, maintenance, operation, and disposition of facilities.

1.1.3 Third Party Logistics (3PL):

3PL, Third Party Logistics describes businesses that provide one or many of a variety of logistics related services. Types of services would include public warehousing, contract warehousing, transportation management, distribution management, freight consolidation. A 3PL provider may take over all receiving, storage, value added, shipping, and transportation responsibilities for a client and conduct them in the 3PL's warehouse using the 3PLs equipment and employees or may manage one or all of these functions in the clients facility using the clients equipment, or anything combination of the above.

3PL can be defined as the "Business of proposing physical distribution reforms to a client and undertaking comprehensive physical distribution services."

1.1.4 Fourth Party Logistics:

While third-party logistics outsourcing is accepted business practice (though not without risk), corporations are now looking to outsource to a single partner who will assess, design, build, run and measure integrated comprehensive supply chain solutions on their behalf. This evolution in supply chain outsourcing is Fourth-party Logistics or 4PL [7].

Thus a fourth party logistics provider is a supply chain integrator that assembles and manages the resources, capabilities and technology of its own organization with those of complementary service provider to deliver a comprehensive supply chain solution [6].

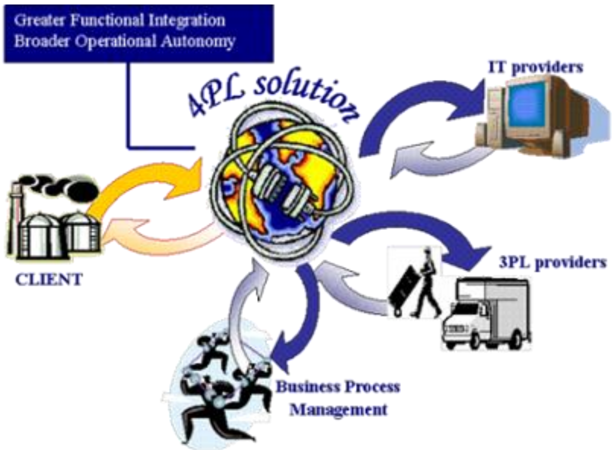

Figure 0.1.1.4.1 Fourth Party Logistic Schematic Diagram [7]

1.1.5 Inbound Logistics:

Creation of value in a conversion process heavily depends on availability of inputs on time. Making available these inputs on time at point of use at minimum cost is the essence of Inbound Logistics. All the activities of a procurement performance cycle come under the scope of Inbound Logistics.

Several activities or tasks are required to facilitate an orderly flow of materials, parts or finished inventory into a Manufacturing complex. They are sourcing, order placement and expediting, transportation, receiving and storage. Overall, procurement operations are called inbound logistics. Inbound logistics have potential avenues for reducing systems costs [6].

1.1.6 Outbound Logistics:

Value added goods are to be made available in the market for customers to perceive value. Finished goods are to be distributed through the network of warehouses and supply lines to reach the consumer through retailers' shops in the market. During conversion value is added to the raw materials and as a result value of the inventory in this case is very high unlike inputs. Now the size of shipment, modes, of transport and delivery time are different as compared to inputs. Activities of shipment, distribution performance cycle come under the scope of Outbound Logistics. They are order management, transportation, warehousing, packaging, handling etc.

1.1.7 Materials Handling in Logistics

The movement of raw materials, semi-finished goods and finished articles, through various stages of production and warehousing is called Materials handling. In a manufacturing and distribution process, the moving of goods, their storage and control of handling the materials all together sum up to Material handling.

Materials handling and logistics are expensive operations which accounts to 10-80% of the product cost and this percentage tends to rise for inexpensive or commodity products. Physical distribution alone, which consists of delivering the product from production plants to customers, accounts for 25% of the product cost. In inbound logistics, within a facility, more than 90% of the product flow time is spent on materials handling functions [8].

1.2 Principles of Material Handling

Material handling does not add value to the product, besides it only increases the cost of the product, as there is the cost of modes of transport/logistics of them in the market. There are number of principles in material handling, which are listed below

- **Planning:** It involves the detailed flow process of the movement of material from manufacturing end to the distribution end. Inventory schedules and checks are also included in this phase.

- **Standardization:** The process should be based on an industrially approved standards and qualifying certification, would be helpful to cope up with the existing market scenario. If standardization is achieved, the process will be more precise and efficient which will help to improve the material handling process.

- **Work Principle:** The materials handling process should have a working principle, for ex. The batches of raw materials come to the production plant which is then assembled, checked and packed in huge containers, all part of the same process.

- **Ergonomic Principle:** Material handling and equipment should be worker friendly, to adapt best working conditions

- **Unit Load Principle:** A unit load is one that can be stored or moved as a single unit at one time. The size of cartons or package should be uniform which helps in handling propose.

- **Space Utilization:** Optimal capacity should be facilitated for the space of the storage location of goods.

- **Systems:** A particular system of handling should be installed and capable of the smooth movement of finished/unfinished goods to the market/within plant.

- **Automation:** Inventions like AGVs are to be set up, alongside conveyors and forklifts if necessary.

- **Environment:** It should be sustainable and eco-friendly, so as to safeguard the policies of pollution/harm to the environment. Also the environment for the entire process of logistic movement should involve the use of green technology.

Life Cycle Cost: Life cycle costs are the total costs-estimated to be incurred in the design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span [6].

1.2.1 Methods/Systems of Material Handling

Some of the methods of material handling systems are listed below. Several solutions can be used to handle the load, and to move it from one place to another, without any altercation.

- Forklifting: The goods are picked up by a forklift and then it is moved from point A to point B, the operation is discontinuous and the Flexibility is possible as to certain limits of the warehouse.

- Conveyors belts: The goods are supported by the machine and is carried by the movement of the belt or the rotation of the rollers. Operation is usually continuous, but with very little flexibility, as it is spread through the floor and occupies most the space.

- Overhead conveyors with or without trolley: The goods are hanged to a chain moving continuously through the whole process. Operation is uninterrupted with little flexibility if any.

- Motorized overhead conveyors running on a common monorail with switch points. Operation is discontinuous. Flexibility is possible within some limits.

- Automatic Guided Vehicle (AGVs): AGVs can move the goods from point A to point B, by following the line laid within the floor of the facility within a short span of time and flexibility simply is unlimited. The process is a discontinuous process, which favors the engineer at work to supervise the whole plant, to shut down and start up at any point of time. [9]

1.3 Significance of AGVs over Forklifts and Conveyor belts

We have designed the AGV in such a way that, it will automatically catch the attention of Inbound Logistics majors to implement this in their own facility, as the setup, installation and working is simply less complicated, involving actually no labor at all. A lot of budget is saved from using our technology, as they tend to target the easy movement of goods to transport using the most little possible energy of electric current through DC powered, rechargeable batteries than compared to huge installation setups of conveyors and compact, in its dimensions to access the inventory of goods, is swift with its small size. With the implementation of 3-4 AGVs for a start could make a huge difference for any possible storage facility, located in any location.

A direct comparison with Conveyor belts in not possible, as conveyor belts favor flow process, and it is continuous process. And hence replacing them will not be possible sooner as the direct competitor, Forklifts. Forklifts are in direct competition to us as they are used mostly in batch process of movement of goods which we tend to target. The movement of goods from one place to another by forklifts is expensive as the fuel they consume needs to be separately brought in and the maintenance on it is huge, while our product is just using the normal electricity at a facility, making it more cost efficient, and a greener sustainable viable option in inbound logistics.

1.4 Comparison of Forklifts to AGVs

When we discuss about the comparison of Forklifts, the first thing that comes to our mind is the types of existing forklifts that are deployed in the Industries for internal logistics. We have the LPG, Diesel and Electric powered forklifts that are in motion in the factory floors and their respective inventories, warehouses etc.

Disadvantages of Forklifts (Diesel)

- High initial cost for the diesel forklifts as they are more expensive than LPG forklifts
- It cannot be used indoors without the implementation of expensive accessories and proper ventilation facilities, to let the exhaust fumes of the forklift to clear the area.
- An extra bulk tank is required to be installed in the facility, or a storage room for fuel with its mandatory safety standards. This might be way over expensive than the cost of the forklift itself.
- Since they are employed indoors, their bulkier size needs more space to operate.
- Loud and noisier in operation, which sometimes hinders the communication to the operator and hence headphones have to worn to give commands.
- Maintenance is much more complex than the electric and the LPG forklifts as they have extra parts making it more bulkier to handle, and parts get more easily worn out, requiring constant maintenance.
- Not eco-friendly with the fuel emissions coming out of the exhaust, especially when we refer to inbound logistics [10].

Disadvantages of LPG Forklifts

- The emissions are still a fatal threat to the workers in the facility as they find it difficult to withstand it. It often leads to headaches and other side effects, so well ventilated and spacious area is desired.
- Operating costs of LPG does not pay off, as they are the least efficient when it comes to Electric and Diesel forklifts. Consequently the maintenance cost is also high compared to the other two.

- The risk of having LPG fuel cylinders in the facility, higher the rate of insurance, and it is very hazardous if the fuel leaks.

- Propane fuel regulators have been known to freeze when a lift truck has been sitting for a period of time in temperatures below freezing. In general, the performance and reliability of most propane forklifts, operating in very cold temperatures, will be less than acceptable [12].

- They have low endurance as their life is less due to the LPG engine, which is not so durable, summing up to **Zero Economic Cost Efficiency**

- They are noisy and have low power (torque) and hence goods moved per hour is lesser compared to its counterparts.

- Rear visibility is hindered by the existence of the propane cylinder which is located in the back side of the forklift as shown below [11].

Figure 1.4.1 Fork lift [11]

Disadvantages of Electric Forklifts

The technology of electric forklifts grow every day and sales have outpaced that of traditional internal combustion forklifts for a few years, but electric forklifts are not suitable in all applications. Some of the disadvantages are listed below [13].

- Charging time is approximately up to 8 hours and another 8 hours of waiting for it to cool down for use.

- Charging stations for the battery should be adequately installed.

- Slow charging time, between 30-45mins including changing battery.

- Voltage requirements may become issue at older facilities.

- Higher initial cost due to the installation of the battery and charger [6].

- Heavy batteries make it bulkier to use and sometimes requires special lifts to change it.

- Not advisable to use outside, especially in wet weather conditions [14].

As we can see above the forklifts used for batch processing in an industry has a lot of major disadvantages when compared to AGVs. AGVs are very reliable as they consume lower amounts of electricity as it is a DC battery charging the robots. Maintenance is less compared to the tedious maintaining processes of Forklifts. Also no designation of qualified personals on the floor, with additional benefit of knowing the load specification/details on the robot.

1.5 Our Customers

Wherever there is the use of production and distribution, the concept of logistics works, and hence we need to employ the use of Material handling systems to move the goods, which are designed and produced in a facility. So our customer targets Auto-motive industries, Bottling plants, Production/Assembling Units, and Warehouses where they are stored, on an inventory basis and then transported to different distributors and suppliers. The figure below shows the percentage of our customers that we are targeting.

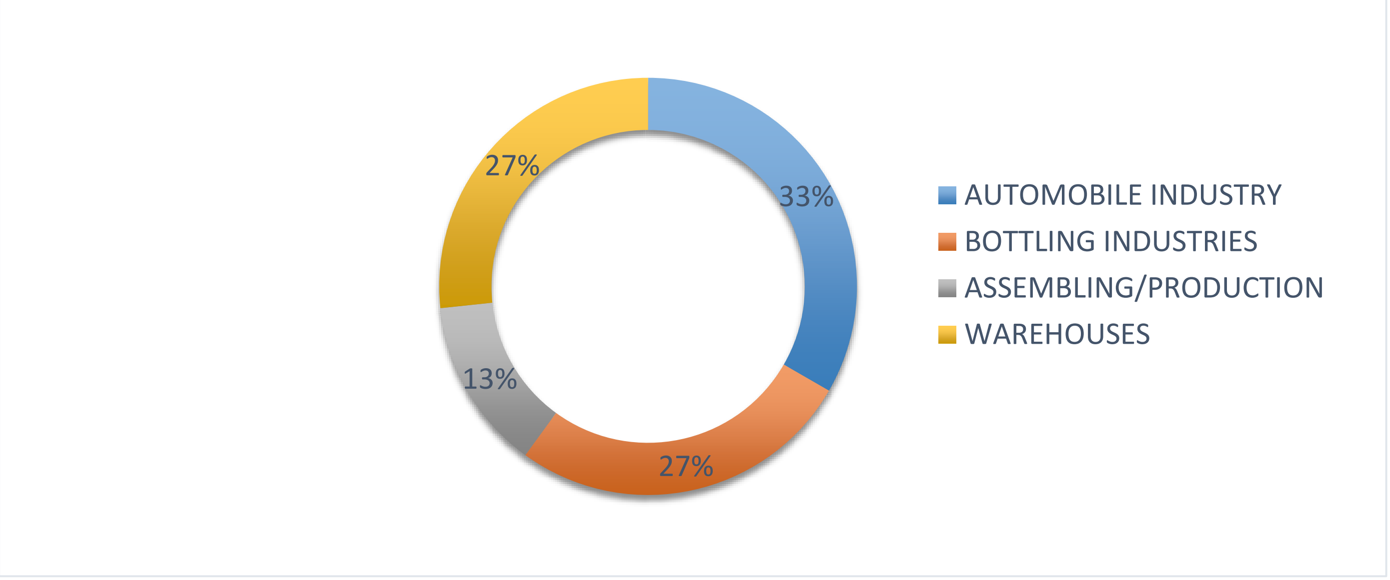

Figure 1.5.1 Customer Classification

A detailed description about different types of industries are discussed below which helps to identify the need of each industry in detail. This enables the manufacturer of AGV to customize the machine according to the needs and requirements of every industry.

Making logistics easy is the main goal of our product, and we are looking to slowly replace the usage of forklifts and conveyors in a given facility. It is total not possible to replace in complex operations of flow process in an assembling unit, but if the space and time are well utilized then, we could let AGVs customize it to our own needs based on the floor plan.

Automobile Industry

As you can see in the graph above, AGVs can make a huge change in the existing facilities of automotive production, management and logistics. It be very easier and economical to implement as they are comparatively smaller in size and the pathway to sense the lines along the area of the facility is also feasible to setup, unlike the conveyors and the forklift stations.

A conveyor belt uses up the entire space of the facility and often workers find it difficult to commode inside the plant and move equipment from point A to point B, due to the huge area requirements of the conveyors running around almost eating up the entire space.

When it comes to forklifts, they need a parking station, they need to move around the facility, and need an operator to use it. Also technicians are required to run the maintenance of the forklifts every now and then, according to the maintenance plan of the company. Still the disadvantage being a technician or a forklift operator being included in payroll, which might not be a viable inexpensive option. Fuel for the forklift, be it, LPG, Diesel or Electric, they still are bulky and difficult to maintain, due to the depletion of our natural resources and also due to the high utility maintenance of them.

AGVs can smoothly run the process, if there is a Plant Layout, planning and budgeting the use of the installation of AGVs equipment. In an automotive industry, we need to focus on the important agenda that, logistics inside are well managed and it’s a flow process, which is now run on conveyors. To carry spare parts from point A to point B, for assembling different parts in an car, for example, the wind shields of a car, attached to its chassis, the wheels and suspension being installed, and etc., can be implemented using a more reliable and convenient option of AGVs. Recently the implementation of AGVs (Automated Guided Vehicles) by a forklift company was a step to bring about a quick replacement, to their own “becoming obsolete” product. However the design that they came up with was surprisingly large and they require special heavy lifts to get installed also. We expect that our product will be a new attraction to the people in the automotive industry, as most of the major giants in Car manufacturing, even some of the niche marketing ones like Ferrari and Porsche, have greater ideas to transform their production plants to a greener and safer environment with minimum energy utilization and sustainability of fuels.

Bottling Industry

In the bottling industry, the caps, the body, the beverage and the label, all are produced in flow of processes that happen, nowadays with the use of hanging conveyor belts and other forms of conveyors. The amount of power that is being used for this is usually more than needed, as we know conveyors are not really efficient and they consume energy while they are on standby. The power consumed by the conveyors, in the bottling industry is considerably more, as they run continuously and they only shut down when there is a yearly/bi-yearly shut down or when there is a glitch in the whole system. And when there is system glitch, there is a technician who is employed to tackle this, which again is a loss time, money and energy.

Now, when all the beverage has been bottled up, they still need material handling equipment like the trolleys or forklifts, which can help to sort them and dispatch them, from their production facilities to the warehouse, where they are assigned to be shipped off to where they have ordered from, by the potential distributors. Even though arguments can arise, as to what different can AGVs do to make this easy, to which we have an answer. If AGVs cannot be implemented at the production level, which is still possible, they always make the logistics part, i.e. the sorting and transporting/dispatching can obviously be more efficiently done, than when compared to Forklifts and conveyors.

AGVs in bottling industries would be huge leap from the traditional setup of the conveyors and forklifts and pickup trucks/trolleys, as they consume trivial amount of energy compared to the former, and gets work done in a more economical and eco-friendly way. They have the least of emissions problem as they are fully run, on rechargeable batteries and have a more reliable path with obstacle sensing proximity sensors which can sense hindrance in the path. Also as the conveyors and forklifts are very noisy and fail to comply with or acts as disturbance for communication between the workers operating it, which is never a problem in AGVs, as they have the traffic controlled by supervisor in a facility, which saves more time, also worth mentioning is the ability of an AGV to re-route its path, in case of a glitch, putting things back to normal, without the involvement of back staff and technicians, saving a major share of capital asset, without going to loss. Also this prevents the breakage/damage of bottles, as they are securely moved.

Assembling/Production Plant

Production plants and assembling units are our tier-3 customers, which we tend to focus on. In a production plant, not that of an automotive one, we focus on the handling of goods after they are produced in a facility, to the warehouses and then to the customers. What usually happens with forklifts and conveyors, are again that they need a lot of time and energy to transfer the manufactured components to the next stage of the assembly process, and even though their flow processes is handled by the conveyors, the area and the energy loss are never the same, when an AGV is substituted. AGVs can take small tools/parts to workers or robots that assemble it into a product, also they can carry heavy machinery with easy and lesser energy, than their counterparts.

Assembling and Production facilities will be more efficient and consume less energy with the implementation of AGVs, and with the replacement of forklifts and conveyors, they can work better with lesser area for the material handling, lesser energy being wasted, and also no sound or emission creating the workplace difficult to communicate.

Initially we will try to implement it in small scale manufacturing units, for example the assembly of laptops, mobiles and other factories which assemble electronic goods. Our next step would be to go further beyond and make it as a permanent solution in these facilities, with more complex assembling units, such as an aircraft manufacturing unit.

Warehouses

As we can see in our customer's graph, a significant 27% of customers that we target to achieve is the warehouses, where we can completely eliminate the use of forklifts and conveyor belts. As most of the warehouses are focused on storage of manufactured goods and they need to be segregated and handled, in an efficient way, so as to keep track of the number of units produced.

In a typical warehouse where there is a lot of inventory, and it needs to be dispatched to random distributors, the batch of goods produced are first stored, from where they are accessed by the AGVs, and they are easily loaded and unloaded from the incoming/outgoing consignments with a box with wheels, which consumes less energy and less maintenance as compared to forklifts and conveyor belts. This is what we want to achieve with the warehousing logistics, which is a great improvement in the field of Supply Chain Management.

We concentrate more on the inbound logistics, of the complete logistical aspect of the firm, and hence it makes AGVs, evolve more with warehouses, and warehousing technology of firms. Companies who have the infrastructure to improve and enhance their overall logistical performance to maximum efficiency, which includes the material handling from component manufacturing to product dispatch, are our primary targets and we hope to achieve it soon.

1.6 Lean Side of AGVs

Conveyors and forklifts have been the same machinery used in the assembly line and production for nearly 2 decades. When a lean world is considered, these equipment for material handling, are always disappointing.   AGVs on the contrary, are targeted to reduce waste and eliminate lag in the production time, and streamline production flow.

New industries seek lean manufacturing machinery, which a mandatory requirement for the firm, and AGVs would be a good replacement when compared to its counterparts. They are flexible, cost-effective, reliable and harmless, due to its obstacle sensing technique. A completely lean manufacturing design must require special consideration on system design of the material handling system, and also what capital is invested in it. Customers who seriously take lean manufacturing into account and accept that it will improve the long-time running of the firm, AGVs would be a great solution. Human delivering of parts to the lean assembly lines, the process cycle time and elimination of errors, are possible and highly achieved with the AGVs. AGVs can work on a mixed-model production process, by doing the tasks of conveyors and forklifts, delivering parts and tools to assembly lines in a lean environment, where wasteful practices, reduction of cost and increase in the quality of product is ensured.

Some of the customers often change the design of their manufacturing plants/floors, and even then there will some part of the infrastructure within the facility that remains constant and cannot be changed. AGVs can be used in this circumstance to connect between areas and make the whole floor accessible to production, making it useful to the whole cause, and not waste area. AGVs can also be used to transport parts and components, which do not require packaging, which saves process time and space in the plant.

The rising problem of increasing the amount of labor costs, have made companies seek new technological innovations, especially in the field of logistics, to go for ideas like the AGVs, used for lean material handling. The attributes that companies prefer or consider using AGVs include, cutting the labor costs, less damage to products, and sequential monitoring of the process flow, with the movement of products from a component to becoming a product.

Companies looking for a short-term solution, and expecting ROI (return on investment), quickly will never go for this kind of technology, but on the other hand, companies with the goal of establishing a long-term solution to its logistics in its inbound processes, will definitely finds its way to AGVs [15].

2. Concept Design

The line following robot is more of an open source platform and can be adapted to any field of usage. Since the course is related to industrial engineering and management, the field of working is confined to logistics in industries. The concept was built based on Internal Industrial Logistics. This chapter describes about the process of design and steps involved in the development of the conceptual model of the line following robot.

Family of Robots

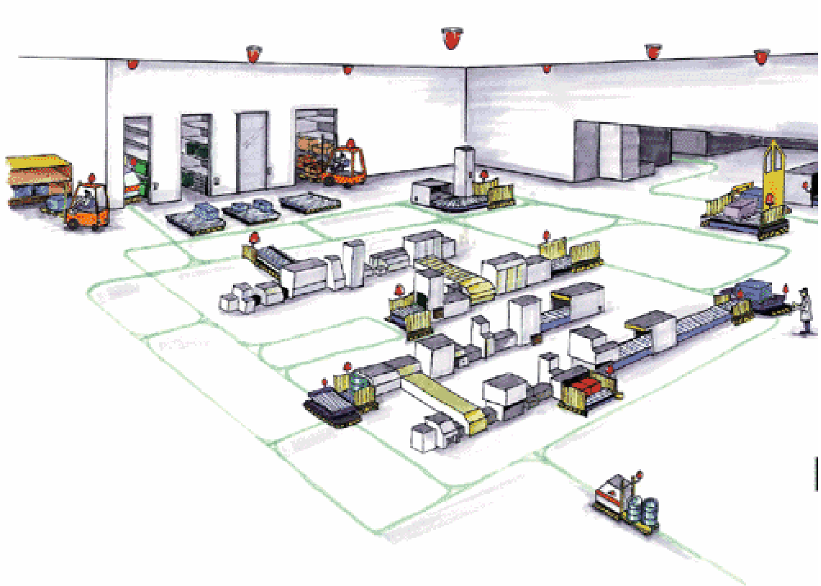

Figure 2.1 Family of Robots [42]

The automation of industrial process has been going on since the industrialization took place and now robotics play a major role in any industrial process and it completely automated or partially automated. Forklift companies are focusing on automating the logistics process by replacing fuel operated forklift to battery operated ones and so on. Now they are more concerned about replacing manual labor to programed self-operating vehicles also known as automated guided vehicles. The set of robotic parts change the whole working process of an AVG. This denotes that an AVG can perform a set of operations not only confined to logistics. Therefore they have to be provided with appropriate power source to support their designated operations. The family of robots make their contribution by performing certain set of operation in the manufacturing floor.

The family of robots are capable of doing a series of process apart from logistics. The use of new methodology for path planning will improve the decision making of the robot during traffic in path. Instead of using straight black lines they will be replaced with magnetic strip encoded with data that could be interpreted by the micro controller and the operation will be performed at that particular location. For example, when the material handling takes place in a warehouse, when the robot requires to carry the materials from one place to another and during the process the robot will vary the speed based on the data given on the magnetic strip. Let’s assume when the material is inside a rack, the speed of the robot is lowered for safety purpose when it commutes between racks. When the robot is moving towards the loading dock the speed can be increased to a certain limit. This process is carried out by the magnetic strip as the strips laid on the loading bay floor is filled with data to increase the speed of the drive motor. By this method the efficiency will not be compromised.

Figure 2.2 Line tracing robot with robotic arm

The above figure show how a line tracing robot will look with a robotic arm swapped in place of rollers. The chassis have a specific configuration which suits all the parts that could be interchanged. The power for the robotic arm is supplied form the chassis. The connector consists of the pins that are placed in the appropriate sockets when the robotic are is placed on the chassis. The AGV with robotic arms help in industrial logistic during picking and placing of parts. The robot will help to replace the people and forklift at the same time. The design of AGV increase the efficiency of work and reduces the overhead expense. The price of the robot would be more than a normal forklift but on the overall expenditure of the company will be significantly reduced. On the managerial aspect the expense for the company will be lowered on a long run. There are lot of industries that implement fork lift for logistics but they follow a static design, by replacing forklifts with AGV, the company can have a dynamic floor plan for logistics. The logistics plays an important role in every industry.

The line tracing robots are fit with rollers which act as temporary conveyors that can be used in material handling. They are not stationary since they are supported by motors at the base that are controlled by microcontrollers. These microcontrollers once again performs the operation at the right location and time from the magnetic tape's data. The line tracing robots have slots over the chassis that can be replaced with other parts like a box or a robotic arm that can be used in pick and place process. The robotic arm is placed on a flat plate to which the axis of the arm is placed. The arm can rotate 360°. The base plate has a connection pins soldered to the base which has a similar connector at the base of the robotic arm for communication of data from micro controller and power supply from battery.

Analysis of existing robots

Prior to developing an intelligent line following robot in the field of logistics there was a background check made on the existing line following robots. The design of the robot is highly customizable based on the application. Next step in the design process is to create a set of unique design features related to the field of logistics in industries for the concept model of line following robot [16].

Identification of design features

The line following robots are designed to adopt to the industrial environment, which leads to certain unique features. The features are mentioned below. They need to be designed based on the protocol of the industries [1].

- Easy to use
- Eco-friendly
- Light weight
- Compact space
- Interlinked with other robots
- Monitoring systems
- Obstacle sensors
- Battery operated

These features will be included in the concept design process. The next step in design process is to make a research on existing line tracing robots in the field of logistics and add the missing features to the upcoming design.

Existing line following robots

Another critical step in the mechanical design process is the investigation and analysis of existing line following robots. Researching existing products provides the opportunity to learn about the line following technologies that already exists as well as the opportunity to improve on what already exists. The list of robots that already exist are given in the table below [17].

Table 2.1 Survey based on existing line tracking robots

Line Following Robot	**Key Features**
LDR in Medicine	Line detection, Obstacle sensors, Battery operated
Line following robots in shopping malls	Based on line detection, MOSFET controlled motors, capability to pull high load
Line following robots in Car parking systems	Proximity sensor for better monitoring, Low lying body for better dynamics, Solar power charged batteries

Design Features

In this step, the goal in to utilize the knowledge from the existing line following robots to generate the list of design features that will serve as a benchmark for developing the concept model. The existing model uses the concept of line tracing, now in this design process there will be improvements made and the features will be perfected. The desired design features are mentioned below [17].

Table 2.2 Desired Features of the robot

Desired Features	Description
Intelligence	Possesses the ability sense obstacles on the way and stops to indicate the supervisor
Battery indicator	It indicates the battery when it is low and goes back to the charging dock as programmed
Load sensors	Sense the load that it carries and show the personnel if over loaded
Eco-friendly	Uses DC power which can be obtained from solar energy
Communication	If multiple robots are used they can communicate between each other
Easy Monitoring	A supervisor can always monitor the position of the robot

Components of the robots

The robots are designed by combining the mechanical and electronic components into one and the electronics components will be calibrated before they are used. The list below will describe the mechanical and electronic components.

- Electronic Components
    - Line sensors
    - Motor controller
    - Obstacle sensor
    - Micro controller
    - Batteries
    - Load sensor
    - Current sensor
    - Voltage sensor
    - Radio Frequency transceiver
    - LCD displays
    - Solar Charge Controllers

- Mechanical components
    - Chassis
    - Wheels
    - Motors

Mechanical Components

The mechanical components form the skeletal structure of the robot. They provide a rigid platform and housing for the electronic components to function. The placements of components will be surface mounted inside and at the bottom of the chassis depending on their function. The line tracing module will be placed on the bottom of the chassis to sense the line and the microcontroller will be place inside the chassis. The line tracing can also be replaced with magnetic tape sensors which has an upper hand during path planning to make them less time consuming and provide an efficient logistics operation. Magnetic tapes have more durability compared to black line drawn on the shop floor.

The Chassis

The chassis is the primary platform to house the components and load on the robot. The design will be concrete and strong to avoid mishaps and breakage during the function. Chassis of different types can be used based on the application. The chassis will be the primary part of the robot which will affect the whole design of the robot based on the operations carried by the robot. As mentioned before the purpose of the robot vary depending on the usage since the design is highly customizable based on the requirement of the industry requirements. Few operations like carrying goods can be performed by simply placing the box on the robot as well as placing pallets to carry the goods from one point to another. Rollers can be placed on the body of the chassis which temporarily makes them like a conveyor to transfer goods from the truck to the loading station or vice versa. The chassis design will be the same since they have socket type of base to which box, rollers, robotic arm can be replaced based on the purpose they serve.

The chassis will be made of aluminum since the structure should be sturdy and light weighted. The chassis will also be carrying the load and if the chassis has its own weight, powerful motors have to be equipped to pull the load along with the weight of the chassis which will in turn increase the capacity of the battery which will indirectly add weight to the base weight of the robot.

Motors

A DC motor is any of a class of electrical machines that converts direct current electrical power into mechanical power. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor. Most types produce rotary motion; a linear motor directly produces force and motion in a straight line [18].

The DC motors are a must in the line tracing robots as they are powered by direct current. Choosing a motor for the robot is one of the important steps to have a good efficiency. The steps below is a guide used to choose the robot for the robot.

The speed of the motor indicates how fast its shaft is turning. DC motors without a gearbox spin at 3,000 to over 12,000 RPM (revolutions per minute). With a gear box, the speed can vary from under 1 RPM, on up [43].

Stepping motors are not rated in RPM, but pulses (or steps) per second. The speed of a stepper motor is a function of the number of steps required to make one full revolution, times the number of steps applied to the motor each second. Typical values are 200 or 300 PPS.

Based on the guide the appropriate motor was chosen for the robot. There is a calculation made for supporting the selection of the motor.

Table 1.3 Motor Requirements [43]

REQUIRMENTS						
LOAD kg	No. of Motors	Radius of the wheel inches	Robot Velocity Ft/s	Supply Voltage V	Desired acceleration Ft/s^2	Desired operating time Hrs
150	2	4	3	12	5	4

Gear motors are essentially DC motors with an added gear down. Adding a gear down both reduces the speed and increases the torque. For example, an unloaded DC motor might spin at 13000 rpm and provide 0.2 kg-cm of torque. A 225:1 gear down is added to proportionally reduce the speed and increase the torque: 13000 rpm / 225 = 50.9 rpm and 0.2 x 225 = 45 kg-cm. The motor will now be able to move significantly more weight at a more reasonable speed.

Table 2.4 Required motor output [43]

OUTPUT FOR EACH MOTOR				
Angular velocity Rad/s	Torque Nm	Total Power Watts	Maximum Current Amp	Battery Pack Ah
9	17.866	160.79	13.99	107.20

The reason instead of carrying 100 kilograms the desired weight is 150 kilograms is to cover the weight of the spare parts of the robot so that the user can load the robot with 100 kilograms of weight. The output of each motor is known therefore the material that is to be used will be calculated. During the motor operations the battery will not be completely used since the motors are controlled by a controller during straight line both motors will be working and during turn only one motor will run depending on the direction of the turn [43].

ELECTRONIC COMPONENTS

The electronic components are the major factor for automation as they are programmed to perform a set of particular operations that will be automated on a long usage. Line tracing robots have to be designed in such a way that they are suitable for all type of working conditions in an industry. The description below briefly describes the components used in the robot for its primary function.

Line tracing sensors

The line tracing sensors are majorly used with the help of infrared technology where a tray of infrared sensors are fit parallel to each other in a line or there will be an infrared LED and an infrared light sensor in one module.

Figure 2.3 Line Sensors [41]

The sensor is used to find the line on the ground depending on the programmed value. For instance the infrared LED will project the infrared light and the light will be reflected which will be sensed by the infrared LED sensor. When the reflected light is high the sensor gives a low value and when the reflected light is low the sensor gives out a high value. The low and the high value are the factors that define the operation of the motors.

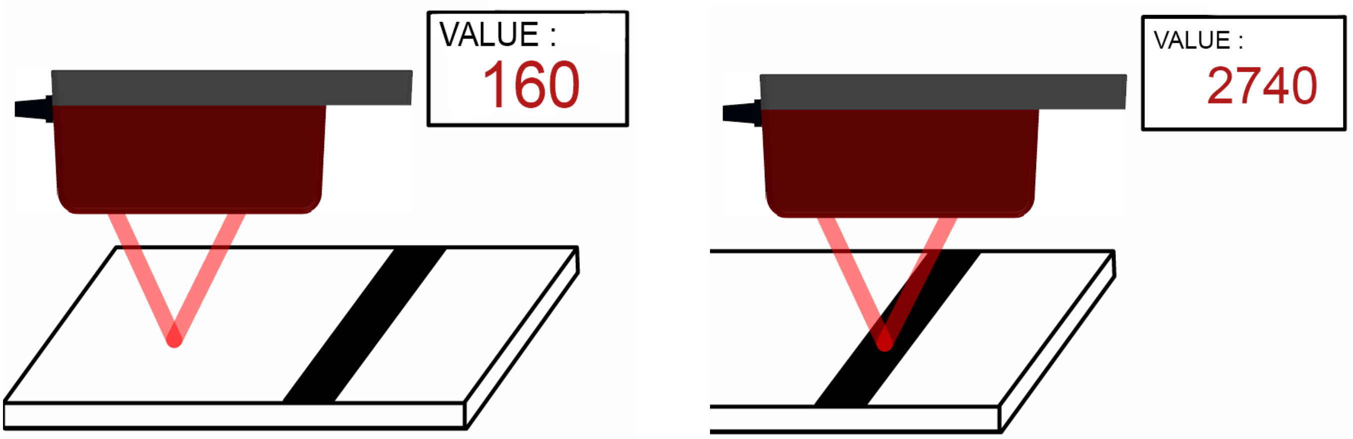

Figure 2.4 Low and high values of line sensor

When the value is low to set its course on the line and when the value is high the motor will have a constant speed which indicates that the motor will run through the line with a constant speed. Line tracing sensors are the primary component of the robot for tracking the line and moving on the set course of direction. The line sensor doesn't have a metric unit for measurement.

Obstacle sensor

Once the course is set the robot can sense the obstacle with a help of ultrasonic range detector using sound waves. The metric unit for measurement is centimeters. This sensor senses the object like any other ultrasonic device by sending sound waves to a particular distance and calculating the reflected sound waves by a sound wave sensor and converting the time of reflected waves into distance. Once the distance is known the motor is programmed to stop if the obstacle is 30 centimeters.

The ultrasonic projecting system and the sound receiving sensors are placed adjacent to each other to calculate the distance of the reflected sound wave

Figure 2.5 Distance Sensor [36]

The sensor has two set of pins which is an input and an output pin. They are made to integrate with Arduino micro controllers. When the signals from the distance sensor is received at the micro-controller end the motors are programmed to stop and this operation is carried with the help of the motor driver which is also connected to the micro-controller.

Micro-Controllers

Micro controller is the brain of the robot which decides the basic function to complex function to be performed. They are programmed to be automated which is done once during their set up. Arduino is an open source micro controller that is efficient and easy to program. The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and V_{in} pin headers of the POWER connector [19].

Specification

Table 2.5 Specification table [19]

Microcontroller	ATmega328
Operating Voltage	5V
Input voltage	7-12V
Digital I/O Pins	14 of which 6 provide PWM Output
DC per I/O Pin	40mA
Flash memory	32kb
SRAM	2kb
Clock speed	16Mhz

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and V_{in} pin headers of the POWER connector. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

Figure 2.6 Arduino UNO [19]

Motor controller

A motor controller device is another electronic component to control the motor speed and direction of rotation to turn the robot. The line sensors output is the information that controls the motors and the motor controller acts as the interface between the line sensor and the motors through the microcontroller.

Figure 2.7 Motor Controller [20]

Load Sensor

The load cell is a transducer used to weigh the amount of load carried by the robots. Load cells are designed to sense force or weight under a wide range of adverse conditions; they are not only the most essential part of an electronic weighing system, but also the most vulnerable. In order to get the most benefit from the load cell, the user must have a thorough understanding of the technology, construction and operation of this unique device.

Figure 2.8 Load sensor [21]

Current Sensor

There will be a current sensor which will sense the current available in the battery for usage and keeps displaying it on the LCD to indicate the battery level. The current sensor is a module that will sense the current in the circuit. The module measures AC current up to 30 Amps and DC Current from -30Amps to +30Amps. Dual outputs allow the user to measure both the AC and DC components of complex current waveforms separately.

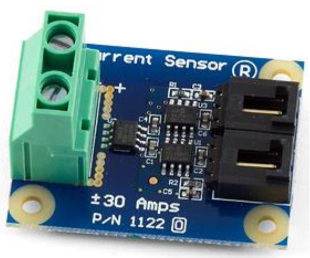

Figure 2.9 Current sensor [22]

Voltage Sensor

The Voltage Sensor measures the differential voltage between the input terminals and outputs the difference proportionally. The maximum differential voltage that can be measured accurately is ±30V. The voltage sensor is a necessary to sense the output voltage of the battery in order to find out if the battery is low.

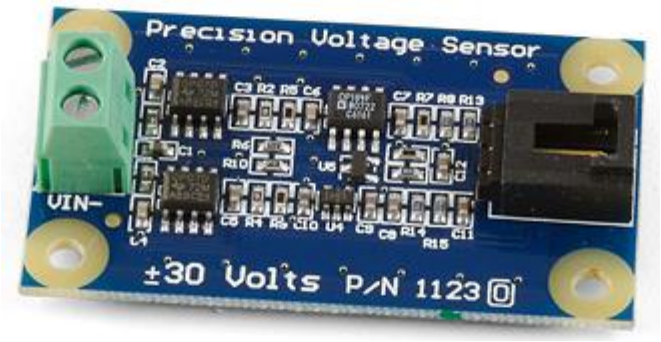

Figure 2.10 Voltage sensor [23]

The voltage sensor will be used to identify the battery capacity and indicate the power in the battery in real time which helps the supervisor to understand the whether the robot is suitable for the next shift of operation.

Radio Frequency transceiver

The radio frequency transceiver is a device that can be used to transmit and receive data simultaneously. This device will be integrated into the robot for transmitting the data which is the position, destination and load carried by the robot to the supervisor. By this device the supervisor always has an eye on the robot.

Figure 2.11 RF Transceiver [24]

This module sends and receives data by AM or CPCA modulation, thus offering a higher average output power which extends its range. This module is equipped with an RSSI feature that can be utilized to improve power efficiency by waking up circuitry only when an external signal is detected.

Solar Charge Controller

A solar charge controller will be integrated at the charging docks of the robots to charge the robots. The solar panel is used as the source of charging but the output is not constant due to the environmental factors. To stabilize the output of the solar panel and feed the robot with a power, a solar charge controller is integrated. The charge controller will control the output voltage and current to stable 12V DC and required current to charge the batteries of the robot. By using the solar panels these robot can be classified under eco-friendly robots.

The solar charge controller is a simple device with eight diodes that restrict the flow as well as store the electricity and dissipate when required. It is also in-built with a micro-controller which is programmed to store the electricity with help of a servo switch and release the electricity when there is no sun light to produce electricity from the panel. Solar charge controller is important to mention since it a primary component for charging the batteries in an eco-friendly way.

Magnetic Strip

Every robot needs a path to follow and automated guiding vehicles also need a path to follow. They have similar purpose that is to guide the robot on a path to its destination using a magnetic track which adds value to the robot since the data on the magnetic strip can optimize the operation of the robot at particular points. The magnetic markers will be placed on the sides of the robot which gives the location information, lifting or robotic operations to be performed. Magnetic strips are easy to lay and modify. They also provide good durability and reliability. The chassis design has a little bit of variation when magnetic tracks are implemented [25].

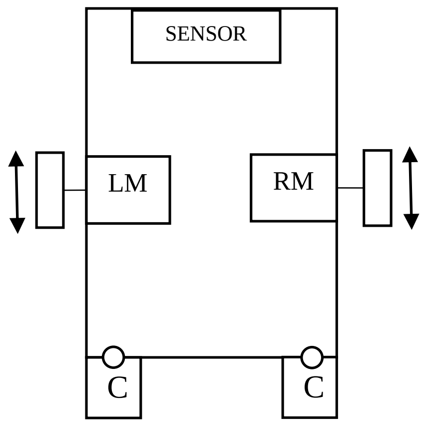

Figure 2.12 Chassis Design for Magnetic Track

Algorithm for the robot

The algorithm explains the working of the robot with its basic actions and programs that will be automated which will serve as the platform for the robot to function. The algorithm of the robot is to receive data from the sensor and give it as an input to the micro controller. The microcontroller will first get the data from the line sensor by calibrating the sensor to adjust to the line drawn on the ground. Once the calibration is done the motor begins to run and the robot moves in the forward direction.

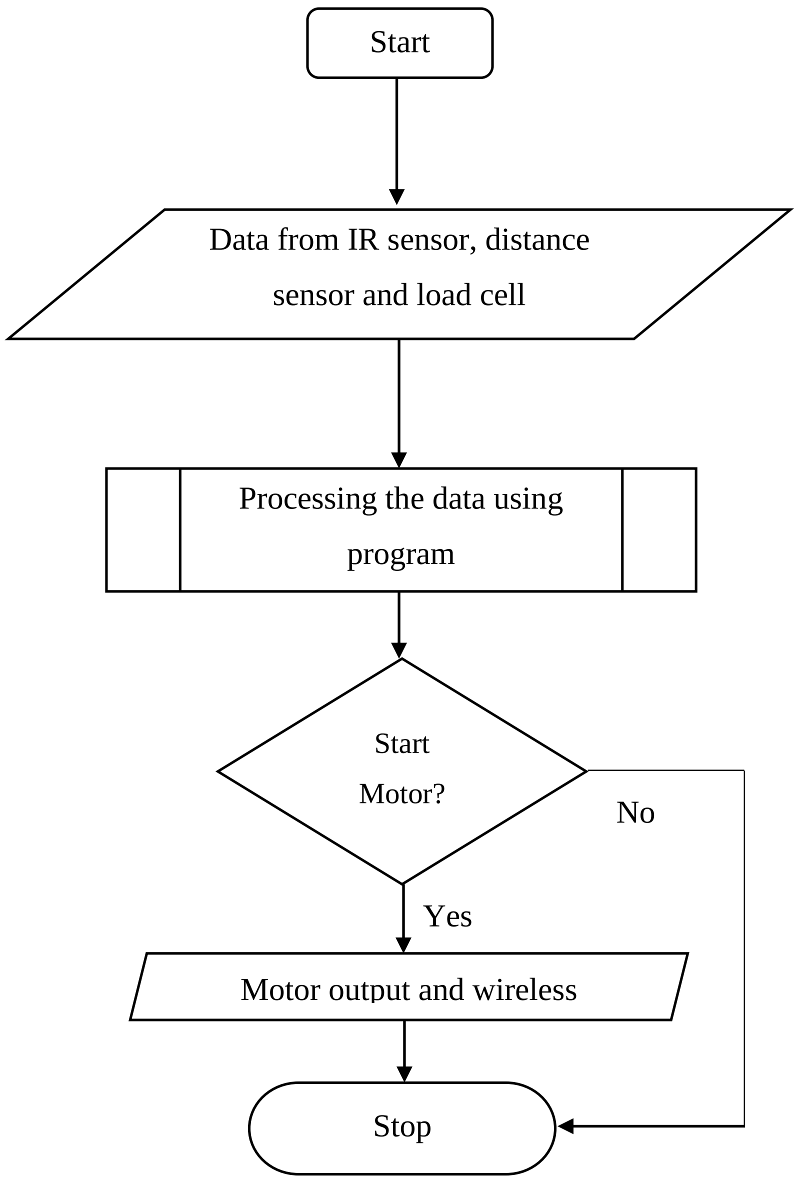

Figure 2.13 Basic Flowchart [43]

This is an overview of the operations performed by the robot. The detailed algorithm will be displayed during the mechanical design of the robot.

Block Diagram

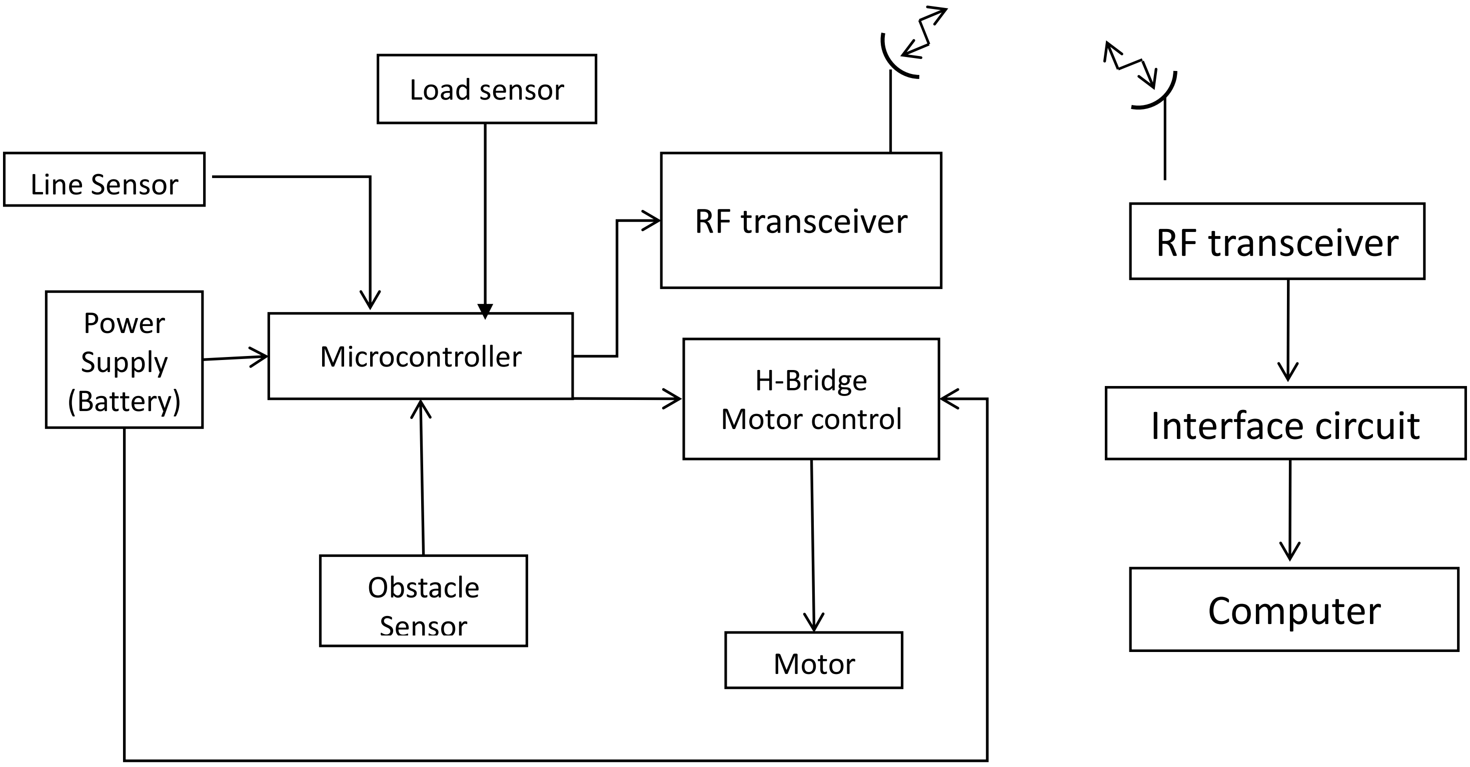

Figure 2.14 Block Diagram [43]

The microcontroller is the main source of information which has calculates the input value and gives the required output. Line sensors provide the appropriate value for the microcontroller and the microcontroller sends the information to the H-Bridge motor control which defines the speed and rotating direction for the motors. The load distance sensor senses the distance and between the obstacle and the robot whose information is sent to the microcontroller and the motor control. This information decides whether the robot should proceed forward or stop at that point.

The load sensor senses the load and it will be displayed on the LCD screen for the user reference. In case of over load scenarios the robot will beep an alarm indicating the user that it is overloaded and cannot function. An RF transceiver is used to send out information to the supervisor regarding the positon and load carried by the robot. A similar device is used at the supervising end to receive the information transmitted by the robot and it is seen through the computer interface. The concept of AGV requires mechanical design to carry out the analysis task in order to get a precise result. The next section is about the mechanical design and design process of the robot.

2.1 Mechanical Design

The line tracing robot is an automated guided vehicle which is used for logistics in the internal sector of an industry. They are programmed to follow the line painted in the manufacturing shop. The robot is used to transfer bulk finished products or sub parts for the manufacturing process in small scaled and medium scaled industries. This thesis consists the mechanical design of the robot including their mechanical structure and dimensions. Since the robot is used for transportation of parts or products within the industry, aluminium is chosen as the base metal for building the robot. Aluminium has the quality of light weight and tensile strength which enables it to be bended and welded and it doesn't break on excessive bending. The robot box can be made out of aluminium and all the components will be placed in the space provided. The details of the design will be discussed later.

During the design process lot of factors are considered for the formation of the design and the functionality are taken into consideration. The robot needs to have a good mobility and has to make smooth turns in sharp corners if needed without damaging the goods inside, so it is designed in an efficient way to have less power consumption and make perfect turns in the corner. Since most of the manufacturing lines have concrete flooring so rubber tires are used for better grip and to avoid slipping. The mechanical design will be discussed in detail which involves the motor torque calculations and design analysis. This robot is mostly suitable for transferring batch products from production facility to storage facility without manual labour and fuel. This increases the efficiency and reduces the cost for the industry. Products like bottled drinks, boxed electronic products, brake wires, pistons, etc., can be transported to the storage facility. The robot is battery operated and it can be charged either by solar panels or electricity. Usage of solar panels make them eco-friendly and environment friendly. The robots can be integrated into a supervision system where it requires only one person to control all the robots that are functioning in the logistics system. The robots have integrated load sensor that defines the maximum capacity of weight it can carry from point A to point B which will be helpful in calculating the gross weight of the packaged material. The ZigBee transceivers help the supervisors to know the location of the robot at any time of the operations. The battery indicators indicates the batter power left in the robot and the distance it can carry which will help the supervisor to know if the robot can complete the operation in the calculated time. Material selection defines the base weight of the robot which will make a big difference during the motor torque calculation. The material selection is the next section which describes what material is used and what features make it suitable for the selection.

2.1.1 Material Selection

The suggested material for the chassis will be aluminium alloy due to high rigid structure and light weight. Aluminium alloys are hard to break and they are economical for building the chassis for the robot. Aluminium is also very easy to recycle [26].

The table below give the information of aluminium alloy with magnesium and silicon.

Table 2.1.1.1 Aluminum Composition

COMPOSITION	
Component	Wt.%
Al	95.8-98.6
Cr	0.04-0.35
Cu	0.15-0.4
Fe	Max 0.7
Mg	0.8-1.2
Mn	Max 0.15
Si	0.4-0.8
Ti	Max 0.15
Zn	Max 0.25

Characteristics of Aluminium 6061

- Excellent joining Characteristics
- Good acceptance to applied coating
- Combines relatively high Strength
- Good workability
- High resistance to corrosion
- Better chipping characteristics.

These are the properties of the AlMg alloy which will be appropriate for the robot chassis. The chassis of the robot will generally be manufactured by bending the metal sheets and since the elasticity of the alloy is 10000 ksi it will not break during the bending process

2.2 Wheel Design

The wheel is one of the important component in the line tracing robots since it has roll on the concrete floor without any slippage. The wheels are covered with rubber material for better efficiency and friction towards the concrete surface [16]. The wheels plays a major role in the overall kinematics of the robot. The standard wheels and the castor wheels have primary axis and are thus highly directional.

Wheels are one of the major parts to support the locomotion of a robot. The appropriate wheel has to be chosen to define the efficiency and speed of the robot. The wheels usually can be a pair of one or two. For precise turning it is always better to have one pair of wheels supported by motor and a set of support wheels. If more load is to be carried then two pairs of wheels powered by motor is necessary. Depending on the design and requirements, standard wheels are used especially for classical methods of driving and steering while orientable and ball wheels are included in the same category and user for balancing a robot. Omnidirectional wheels are very good for driving and steering and are used when the robot should have the ability to move in all directions. There is a list of different set of wheels that will be used in the line tracing robots below.

Table 2.2.1 Classification of wheels

Standard Wheels		
Type of wheels	**Features**	**Description**
	Degree of freedom 2	Solid Rubber wheels are quiet, absorb shock, can roll over small objects and protect costly floor surfaces. They also minimize vibration. Temp -20°C to + 60°C
	Degree of freedom 2	This custom-designed plastic wheel from Pololu has a rubber tire measuring 42 mm in diameter and is designed to fit the output shafts on our micro and mini metal gear motors as well as the Solarbotics metal gear motors.

Based on two types including center and off-centered oriented, orientable wheels are standard wheels mounted to a fixed or Omni-directional fork designed to catch the wheel. Compared with standard wheels, these wheels are used in robotic projects for balance and less or not at all to drive a robot.

Based on a ball, these wheels have a total freedom of 360 degrees and like orientable wheels are used to balance a robot. The ball can be built from metal or plastic and is positioned on the frame with a holder. Bellow there is an overview of ball wheels for robots.

Table 2.2.2 Types of supporting wheels

Ball Wheels		
Type of wheels	Features	Description
	Includes mounting holes and hardware. Package contains parts for two complete casters	The robot can pivot in one spot, but it must also allow the other wheels on the drive train to move or slide during a turn.
	This ball caster kit includes a black ABS housing, a 0.2 m diameter metal ball, two spacers and two 2 screw sets.	The total height of the ball caster, 0.3m, can be increased to about 0.5m" using the included spacers.

The key difference between these two wheels is that the standard wheel can accomplish this steering motion with no side effects, as the centre of rotation passes through the contact patch with the ground, whereas the castor wheel rotates around an offset axis, causing a force to be imparted to the robot chassis during steering. The line tracing robots will have two normal 4” rubberized wheel as drive wheel (fit to the motor) that will provide the acceleration to move forward and backward. The four corners of the robot will have four castor wheels to support the robot and avoid from tilting forward and backward. The below diagram will show the positioning of the wheels in the robot.

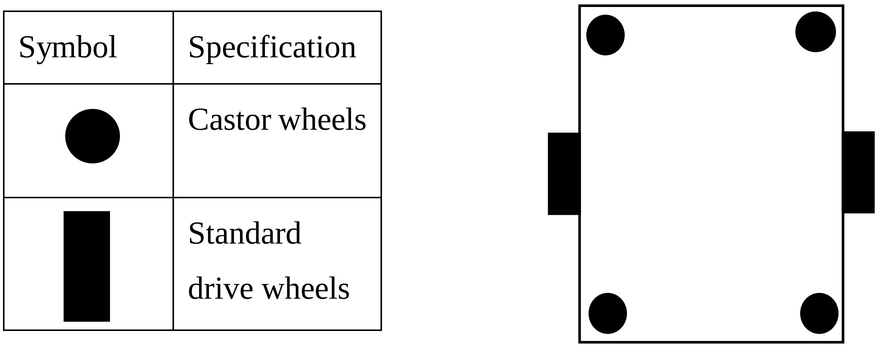

Figure 2.2.1 Wheel Design of the Robot [43]

The line tracing has two drive wheel motor fixed at the centre of the chassis to drive the robot and the castor wheel supports the robots motion since they are omnidirectional. The reason for using four castor wheels is to increase the manoeuvrability and stability of the robot during the turns. During sharp turns the robot is prone to flip if it carries heavy weights. The schematic diagram 2.1 will explain the situation with better visuals of the situation.

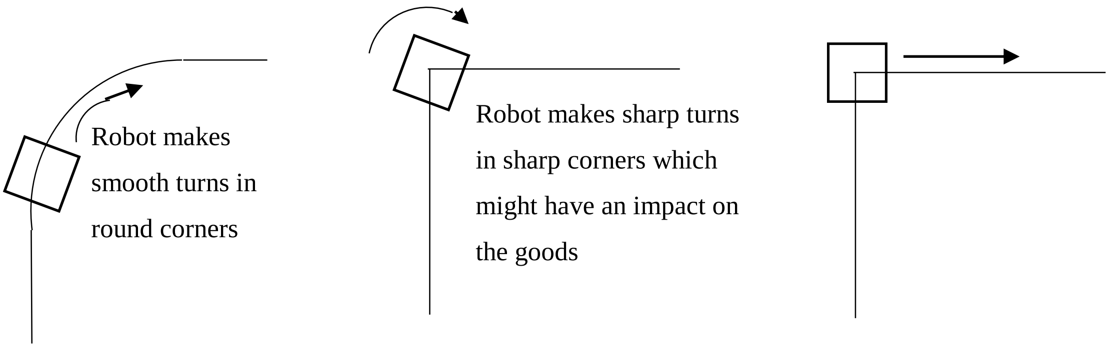

Figure 2.2.2 Path comparisons [43]

The robot can turn curves smoothly but when they have to make sharp turns there will be wiggly movement since the sensors have to detect the line and align themselves to the centre of the line. If the robot has four drive wheels it will be hard to control the turn and the stability will affected in a bad way directly decreasing the efficiency of the robot. To counter that the robot is replaced with only two drive wheels to turn smooth and sharp corners at the same time. During the turn the wheels will rotate in the opposite direction to reduce the time for turning and it will be quick. If the robot is turning right, the right wheel will spin in backward direction and the left wheel will turn in forward direction. The turn will be quick and there will be more stable. The motor driver is programmed to sense the line and drive the motor based on that. The castor wheels are not steered by any force so they will just follow the way the robot moves and helps the robot to avoid from flipping. This is the reason why the castor wheels are placed at four corners of the chassis of the robot.

2.3 3-D Model

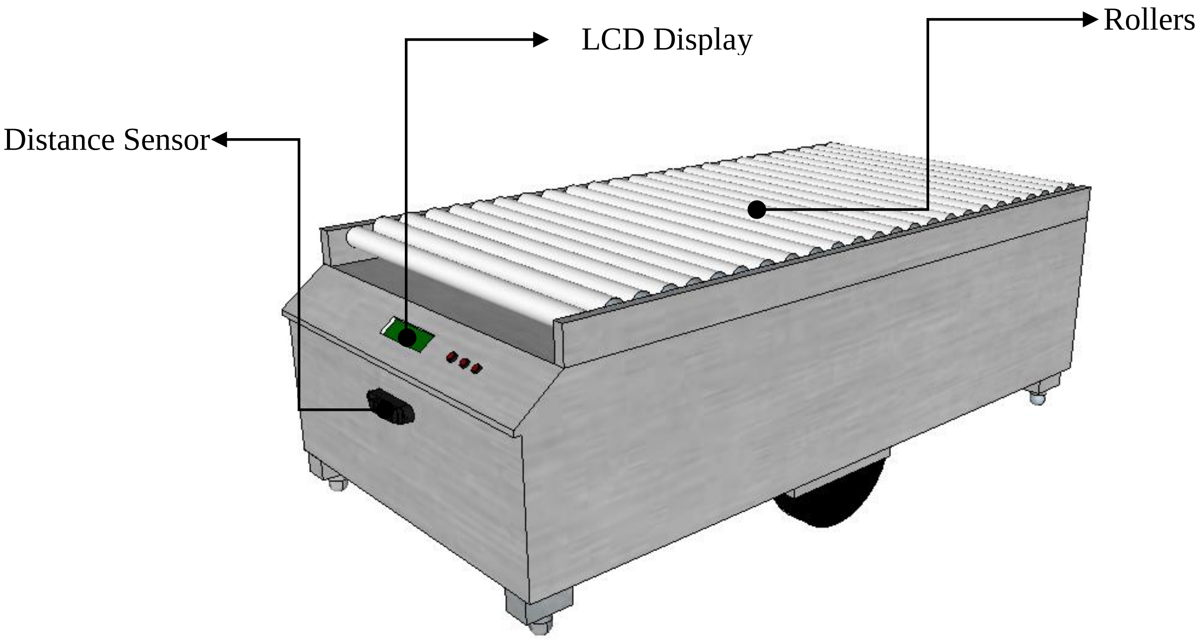

Figure 2.3.1 Basic design of robot [43]

The figure 2.3.1 represents the bottom view of the line tracing robot which has four castor wheels in the corners for balancing the robot from tilting and there is two empty rectangles which acts as a motor housing and the wheels will be attached to the shafts of the motor through the motor housing. The front end of the robot consists of the infrared sensor to sense obstacle. There is always an inverse correlation between controllability and manoeuvrability for example four castor wheel configuration requires significant processing to convert desired transitional and rotational velocities into wheel commands but here we have to motor driven wheels which provide them the command to move in the desired direction. Therefore such omnidirectional design has a great degree of freedom at the wheel. This robotic design concentrates on stability and controllability.

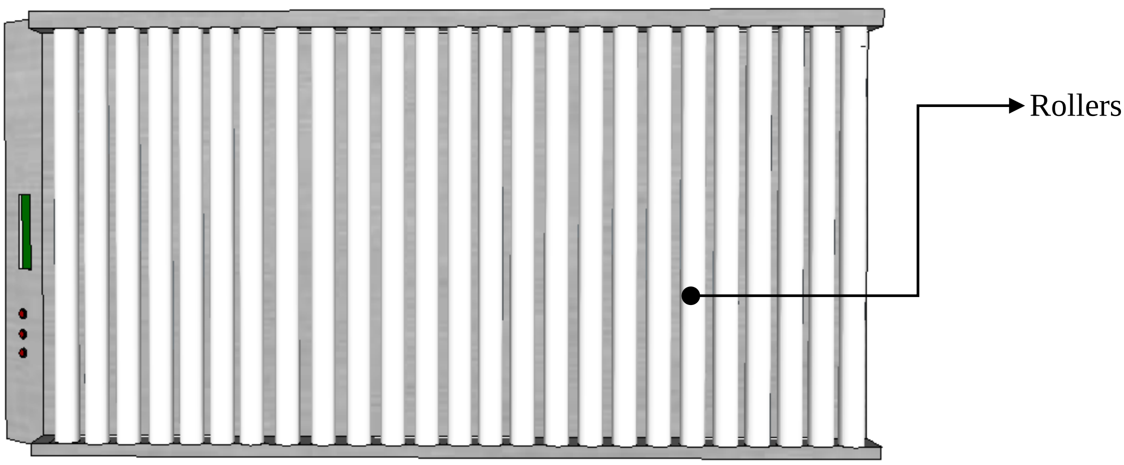

Figure 2.3.2 AGV with rollers

The AGV with rollers act like temporary conveyor belt which is used to move goods from the truck or like a temporary docking bay when the operation overlaps. Operation overlaps usually occur when the AGV is carrying an object but the same AGV is assigned with another docking operation, the AGV has to place the object at a docking bay or a temporary docking bay and continue with the priority operation. A group of AGV with rollers can align themselves with the help of sensors placed in the front and form a temporary conveyor to move heavy object from truck to the aisle or back and forth. This is where family of robots concept can be achieved. Stationary conveyors occupy more space which can be converted into dynamic conveyors which can save a lot of space when no operations are carried out.

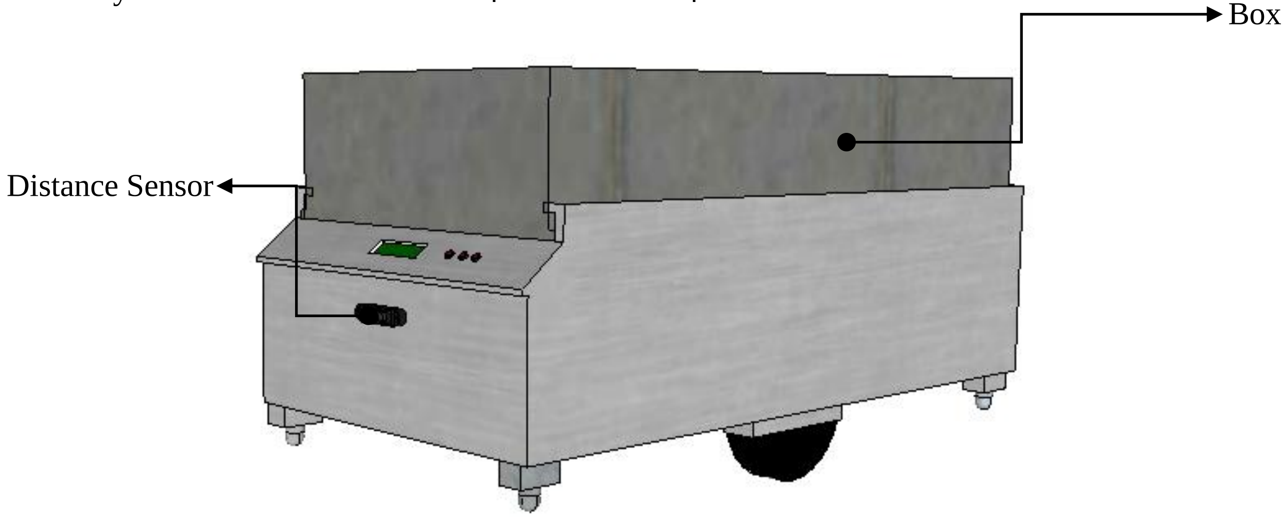

Figure 2.3.3 3D view of the Robot

Figure 2.3.3 represents the diametric view of the robot where there is a box placed on the chassis and the components are placed in the chassis for electronic functionality of the robot. The robot basically consists of two components out of which one is the box that carries the goods and the chassis which carries the wheels, motors and electronic components.

The features of the box is just simple as the user has to place the objects in the box that has to be moved from one place to another. The chassis has a lot of features which includes all the electronic components placed including the load sensor. When the box is placed on the chassis the sensor will calibrate the base weight of the box and goes to zero to calculate the weights of the object placed in the box. The chassis it the functional part of the robot since all the components are placed in the chassis. There is a compartment on the rear end of the chassis where all the components will be stored including the battery.

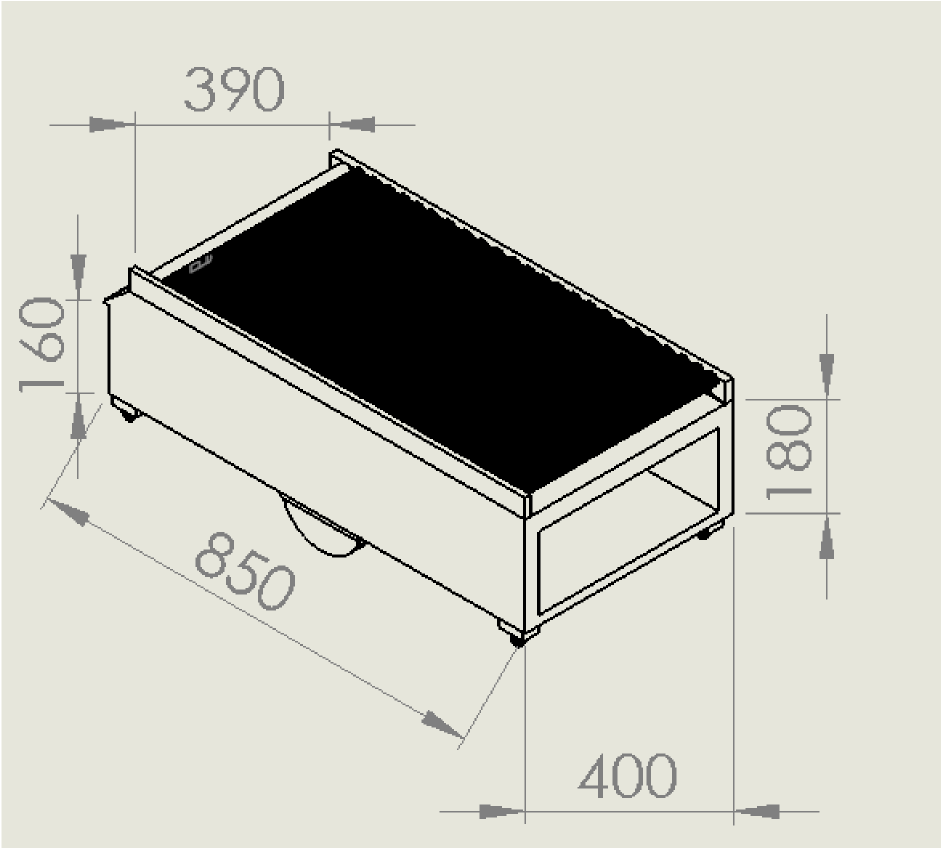

Figure 2.3.4 Dimensions of the Robot

The above figure show the dimensions of the robot which is includes the dimensions of the outer frame of the line tracing robot. The size of the chassis is standard with an empty space of 5cm to house the electronic components. Below the chassis there is a box attached either by welding or screws which houses the motor and the shafts will be protruding outside the box to which the wheels will be fixed. The housing of the motors are constructed keeping the dimensions of the motor including the body and the shaft of the motor. At four corners of the chassis there will be a rectangular protruding with a length of 6cm to fix the castor wheels to support the robot from tilting. The radius of the wheels is 4cm so the radius is mentioned as 8cm. The rectangular hollow body is placed on the chassis with a base plate of 2cm thickness that will either welded or screwed to the chassis. The plate is made of 2cm thickness is because of the aluminium's property. When the load is placed in the box there will be a bend in the centre of the plate which helps the load sensor to sense the weight of the robot. Since aluminium has low conductivity the direct current doesn't pass through the metal surface which will be an advantage. The total weight of the robot including the chassis will be 20 kilograms so the robot can move with a desired top speed. The castor ball has radius of 2.5cm which was considered during the design of the platform for the castor wheels.

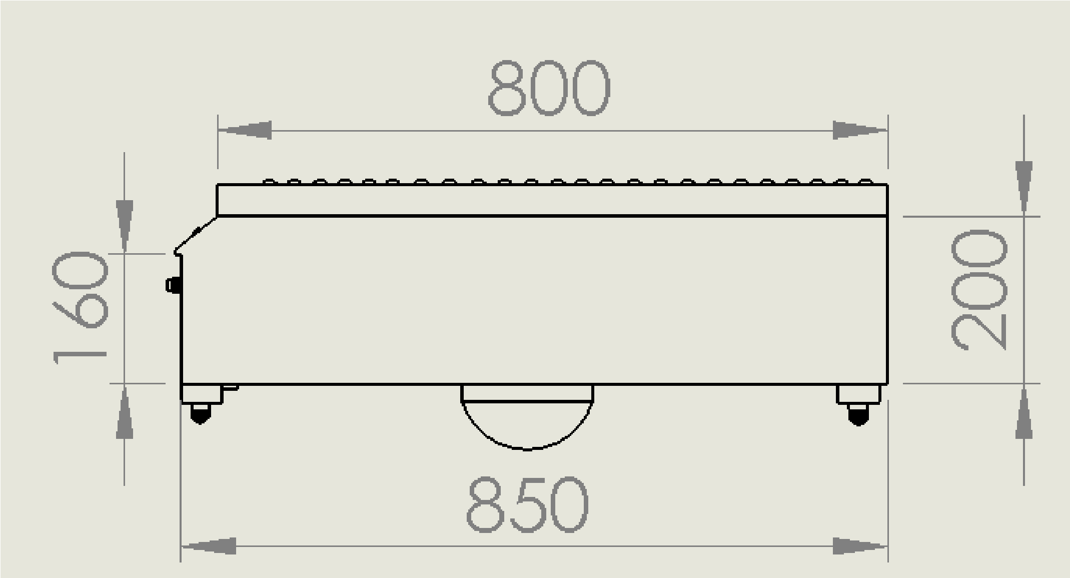

Figure 2.3.5 side view of the chassis

The chassis has enough space to accommodate all the electronic components under the hood. The load sensor is placed in the middle of the chassis so when the box is placed on the chassis there is a pressure applied on the top surface of the chassis which in turn applies the pressure on the load sensor and helps to sense the loads. The microcontrollers are placed next to the load sensors and they are connected to the load sensor, line sensor, obstacle sensor, motor drivers and batteries with the help of patch cords. The motor driver is placed in the chassis which is connected to the motor in the chassis housing. The battery is placed in the chassis which powers the whole system of the robot. The obstacle sensor is placed in the front of the robot to sense obstacle on the path. The line tracing sensor, one of the important component of the robot is placed below the chassis perpendicular to the obstacle sensor. This sensor sense the line on the floor and give the required data to the microcontroller to keep the line as the centre and the robot follows the line throughout its path. The wheels are controlled by motors and the other four wheels are castor wheels so they have a high degree of freedom. When the robot has to align itself to the line the motor driver receives command from the microcontroller based on the information received from the line sensor, during this operation the motors work in different direction to align the chassis to the line. As in if the chassis has to turn right, the motor on the left propels forward and the motor on the right side either stays still or propels in the opposite direction of the left motor. This is how the manoeuvrability of the robot is performed. The chassis is the major component that controls and governs the stability and manoeuvrability of the whole robot. With the help of the 3D design the motor required can be found by doing the motor torque calculation.

2.4 Motor Torque Calculation

An important component that is an integral part of all electric vehicles is the motor. The amount of torque that the driving motor delivers is what plays a decisive role in determining the speed, acceleration and performance of an electric vehicle. Electric vehicles save fuel cost, cause less pollution and bring lucrative tax cuts. They are a much safer ride as they can't travel too fast and have less tyre wear. Direct current electric motors to drive the wheels. However, these motors are available with a number of variations in speed, size and method of operation, the torque required from the vehicle to obtain desirable characteristics is the same. It is the torque that forms the part of the force to drive the wheels and set the vehicle in motion. The torque of the motor is calculated to determine the motor specification which would help to calculate the manufacturing cost of the AGV. There are few factors that needs to be considered during the calculation for maximum torque required. The following factors are

- Rolling resistance
- Grade resistance
- Acceleration force

Desired Requirements for the robot are

Mass of the vehicle	: 150 kg	(2.4.1)
Weight of each drive wheels	: 75 kg	(2.4.2)
Radius of the wheel	: 0.1 m	(2.4.3)
Desired top speed	: 0.083 m/s	(2.4.4)
Desired acceleration	: 10 m/s^2	(2.4.5)
Maximum incline angle	: 1^o	(2.4.6)
Worst working surface	: 0.15 (fair)	(2.4.7)

Rolling Resistance

Rolling Resistance is the opposing force that the vehicle has to overcome due to the rolling motion between the wheels and the surface of motion of the vehicle. The rolling resistance depends on the co-efficient of rolling friction which varies depending upon the material of tyres and the roughness of the surface of motion.

$$RR = GVW \times C_{rr}$$ (2.4.8)

RR = Rolling Resistance

GVW = Gross Vehicle Weight

C_{rr} = Co-efficient of Rolling Resistance

RR = 150 x 0.15 (Taking values from equation 2.4.1 & 2.4.7)

$$RR = 22.5 \text{ kg}$$ (2.4.9)

Grade Resistance

Grade resistance is the form of gravitational force. It is the force that tends to pull the vehicle back when it is climbing an inclined surface.

$$GR = GVW \times \sin\theta$$ (2.4.10)

GR = Grade resistance

GVW = Gross Vehicle Weight

Θ = Angle of inclination

GR = 150 x sin 1^o

GR = 150 x 0.017

$$GR = 2.55 \text{ kg}$$ (2.4.11)

Determination of Acceleration Force

Acceleration force is the force that helps the vehicle to reach a predefined speed form rest in a specified period of time. The motor torque bears a direct relationship with the acceleration force. Better the torque, lesser the time required by the vehicle to reach a given speed. The acceleration force is a function of the mass of the vehicle

$$FA = GVW \times V_{max} / (32.2 \times t_a)$$ (2.4.12)

FA = Acceleration force [kg]

GVW = mass of the vehicle [kg]

V_{max} = Maximum speed [m/s]

t_a = Required acceleration

FA = 150 x 0.833 / (32.2 x 10) (from equation (2.4.1), (2.4.4) and (2.4.5))

FA = 0.38 kg (2.4.13)

Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2, and 3. (On higher speed vehicles friction in drive components may warrant the addition of 10%-15% to the total tractive effort to ensure acceptable vehicle performance.)

$$TTE = RR + GR + FA \tag{2.4.14}$$

RR = Rolling resistance

GR = Grade resistance

FA = Acceleration force

TTE = 22.5 + 2.55 + 0.38

TTE = 25.43 kg (2.4.15)

Wheel motor torque

To verify the vehicle will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (T_w) based on the tractive effort. The "resistance factor" accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

$$T_w = TTE \text{ x } R_w \text{ x } RF \tag{2.4.16}$$

T_w = Wheel torque [Kg-cm]

R_w = Radius of the wheel

TTE = Total tractive effort [Kg]

RF = Resistance factor

T_w = 25.43 x 10 x 1.15 (Values from equation (2.4.15), (2.4.3) are used)

T_w = 292.45 kg-cm (2.4.17)

The final step is to verify the vehicle can transmit the required torque from the drive wheel(s) to the ground. The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

$$MTT = W_w \times \mu \times R_w \tag{2.4.18}$$

W_w = Weight on drive wheels [kg]

μ = Friction coefficient between the wheel and the surface

(Friction coefficient of rubber on concrete is 0.6)

R_w = Radius of drive wheels [cm]

MTT = 75 x 0.6 x 10

$$\text{MTT} = 450 \text{ kg-cm} \tag{2.4.19}$$

Total Tractive Effort is the net horizontal force applied by the drive wheels to the ground. If the design has two drive wheels, the force applied per drive wheel (for straight travel) is half of the calculated TTE. The Wheel Torque calculated in Step Five is the total wheel torque. This quantity does not change with the number of drive wheels. The Maximum Tractive Torque represents the maximum amount of torque that can be applied before slipping occurs for each drive wheel. **The total wheel torque calculated must be less than the sum of the Maximum Tractive Torques for all drive wheels or slipping will occur.** Since the maximum tractive torque is greater than the wheel torque there won't be any slippage occurring during the working [27].

The motor toque calculation was used to find the perfect motor to run the robot based on the guidelines the following robot was found. The number of motors used will be two and these motors will be controlled by the motor driver controller which is controlled by the micro-controller. The motor is a brushless DC motor which operates in 24V DC supply therefore which concludes that it can operated with a help of battery. The power supply from the battery to the motor is regulated and this power is alternated to both motors based on the command provided by the micro-controller. Based on the calculations the required motor for the robot will be DC Gear motor which has the following specification.

Figure 2.4.1 24V DC Motor

Table 2.4.1 Motor Specification [28]

Voltage	24 VDC
Current	900 Amp
Speed	1750 RPM
Horse Power	0.25

Since torque of 450 kg-cm is required to run the robot at full load, we couple the motor with a worm aluminium gear box which provides a torque of 402 kg-cm. the specification of the gear box is mentioned below.

Figure 2.4.2 Aluminum worm gear box with right hand shaft [29]

Table 2.4.2 Gearbox specification [29]

Output	350 RPM
Output Power	2.62 HP
Output Torque	574 Kg-cm

The specification list is considered on no load condition. If the specified motor is used under loaded condition the average speed of the AGV will be from 5 m/min to 50 m/min. If this is converted to km the speed comes to 0.3 km/h to 3 km/hr. The speed is variable depending on the position.

2.5 Path Planning

Every industry has a floor plan according which they place their machine to increase the productivity efficiency on an overall level, the same the robot needs to follow a path that is makes required time for logistics less and increase the efficiency of the robot during the process. Therefore path planning is an important factor to be considered during the design process of the robot path. There are many methods to determine the closest path to reach the determined point. The path planning process can be approached through many methodologies but since the line tracing robots are confined to only two degree of freedom, road map path planning method is utilized to define the route of the robot [20].

While considering the path of the robot there are few situations handpicked that can be used to plan the path. The situations majorly depend on the industries floor plan where the robot is deployed. As said before this robot cannot be used in all the industries but are confined to specific industries that have batch process floor plans. Some of the industries like bottling industries, warehouses and assembling industries can use these robots. The planning of the path also involves how many robots are deployed on the shop floor. It can vary from 1 to 3 robots for one shop floor and their efficiency greatly depends on the number of robots used in a shop floor. Path planning for assembling industries a discussed below which gives a detailed analysis of routes that can be used for the robot.

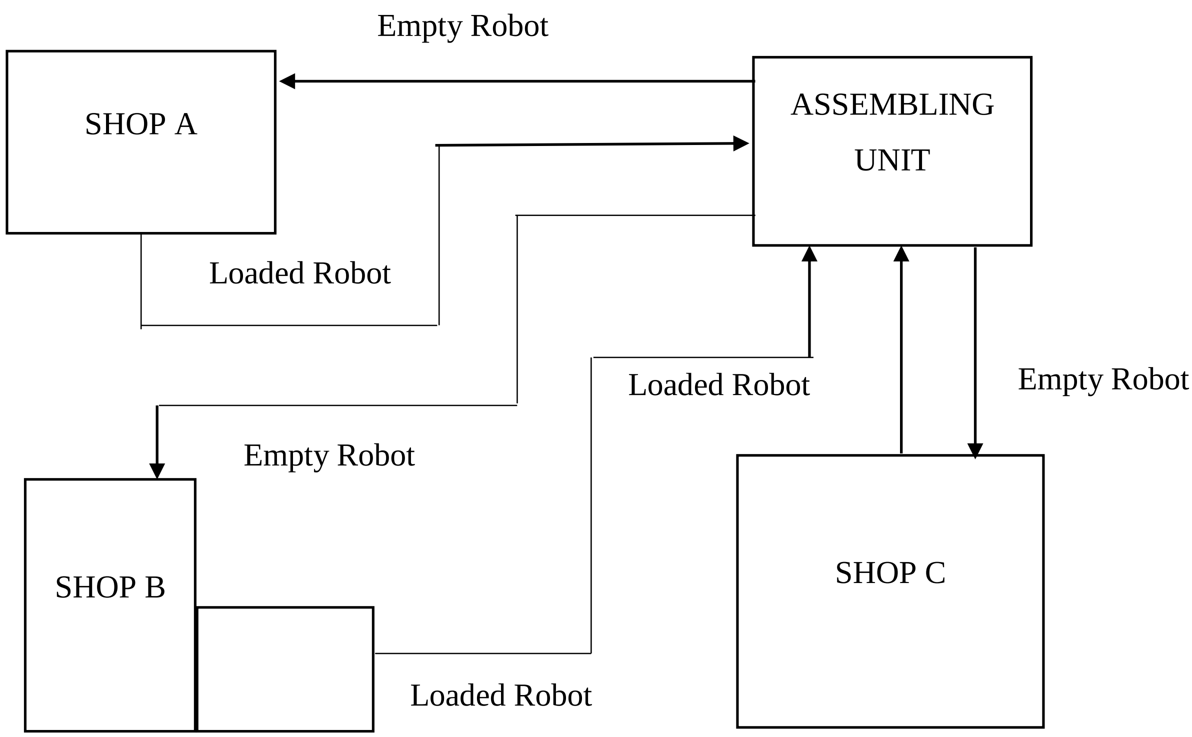

Figure 2.5.1 Path planning with return paths

The above floor plan explain the route of the robot with return routes to their shops. When the robot is loaded with the package they move to the assembly shop from their respective shops. Once they reach the assembly shop, they are unloaded by manual labour and the empty robots will return to the respective shops from where they departed. It will be a cyclic process till the shift ends in the shops. This path planning takes space and time but it is efficient if two or more robots are implemented in each shop. Since the robots use line to track down its path it is advisable to keep the routes. Let us assume that there are 3 shop floors and one assembling unit that receives parts or products from the shops. The assembly units assemble a product with the parts received from the shops. On a hypothetical situation all the shop on the floor use batch process to make their parts. Once the finished parts are grouped into a box they are ready for dispatch. The industry uses the in straight lines and not curves. If the shop implements only one robot then the path planning is altered and the following plan is used.

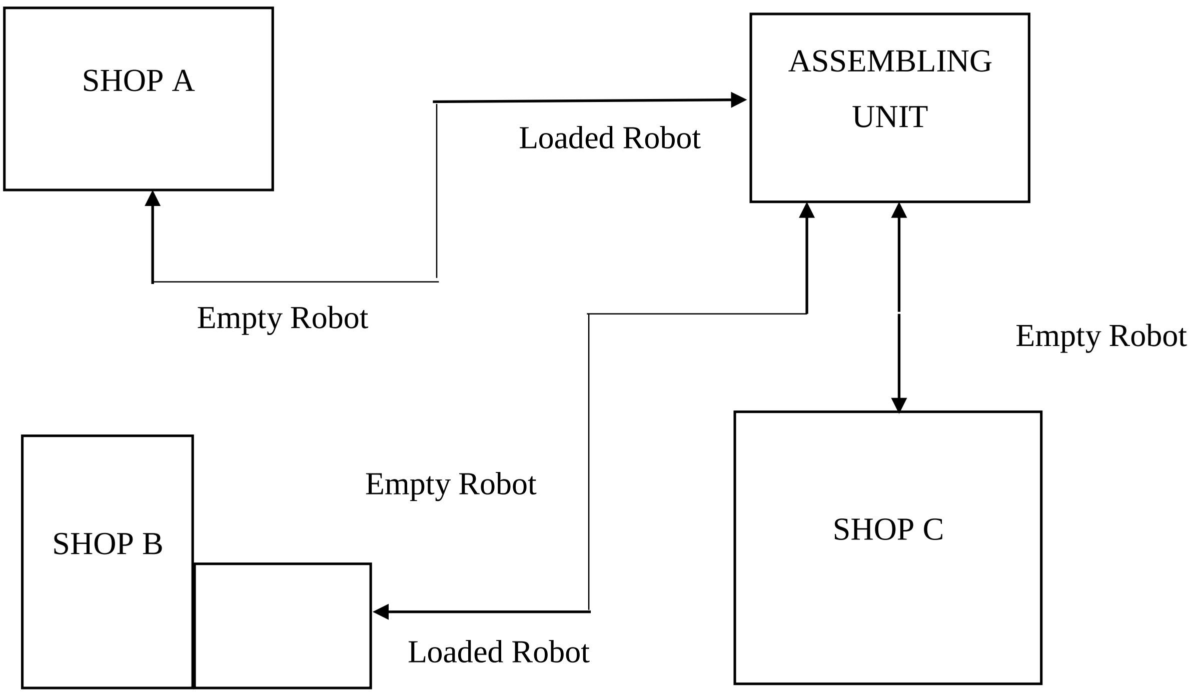

Figure 2.5.2. Path planning with one way return path

The path planning has been changed when only one robot is deployed for a shop. The robot will be programmed to return to their respective shops once they are unloaded and follow the same route which they used to reach the assembly shop. The one return route will be very efficient and less space consuming when only one robot is used and it is reduces the complexity of path for the robot. The time for logistics will also be reduced since it takes the shortest route laid by the implementer depending on the real time shop floor plan.

The sensor will be placed ahead of the chassis that helps to sense and analyze the data then perform the action. It is important to analyze the operation first than to perform. The sensor outputs a value that is tape's distance from the center of the track, the robot uses this information to keep the body of the robot centered to the track. If the tape is centered there will be no steering action. The sensor also provides a throttle control by producing analog voltage or variable PWM signals that adjust the speed of the motor. Since the robot will be having four castor wheels the micro controller will control the speed of two drive motors which will be more efficient since there will be a precise control of the robot. The speed regulations can be encoded in the magnetic markers which will be sensed by the magnetic strip reader alias the sensor. The magnetic strip sensor will be of great help in easing the process of path planning.

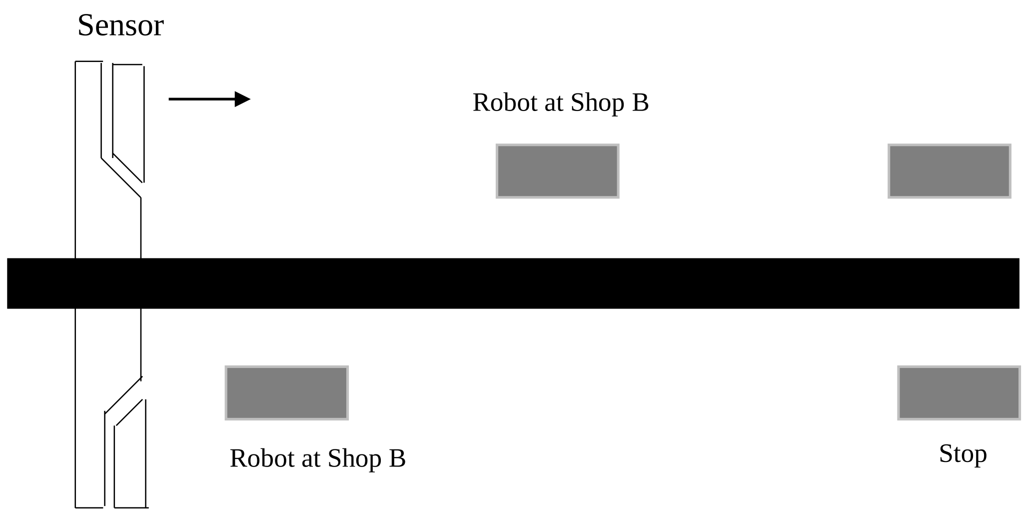

Figure 2.5.3 Sensor and magnetic markers

Magnetic markers are a piece of magnetic strip of opposite polarity and that is located to the left or right of the center track which provides a cost effective way to track the location and provide information to the robot. The magnetic markers are more useful in providing the information to the robot about the process that has to be performed, the magnetic markers can be filled with process operations. With the help of magnetic track, the robots cannot only be tracked but also alter their operations based on their location, which give an upper vantage point to AGV over conventional forklifts. The line tracking robots can also be used in shifting materials from production shops to warehouses. The manufacturing cost of line tracing robots will be calculated and the most effective way to manufacture them will be determined through this process [25].

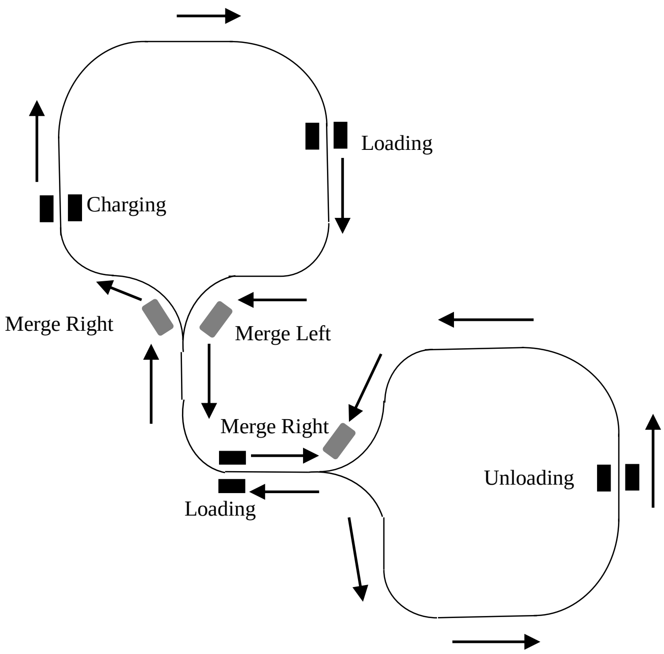

Figure 2.5.4 Path planning with Magnetic strip

Figure 2.5.4 is a test track to plan the path for the robot. This is the most efficient way to plan the path of the robot since there won't be any collision when two or more robots are implemented on the same shop floor. The use of multilevel markers will be easier to define multiple operations. By using multilevel, it provides more information about the location and the robot can change its behavior based on the location.

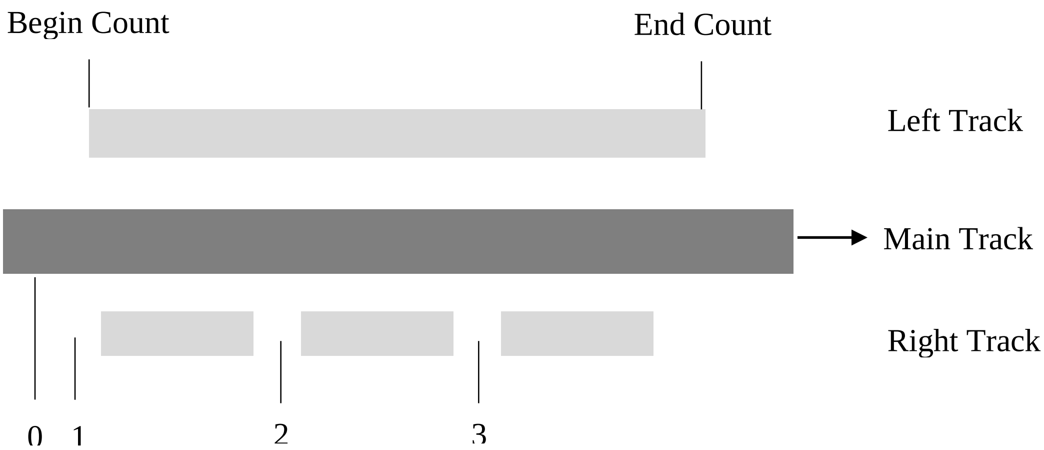

Figure 2.5.5 Magnetic marker working

The ideology of multilevel markers helps the robot clearly understand the process that has to be carried out and perform the right action. The markers will be encoded with data and the gaps between the markers denote the duration of the process which is an easier way to communicate with the AGV.

3. Warehouse Designing Key Factors to Consider

Warehouse Designing is an important factor for the mobility of commodities, storage and easy access of goods for inbound and outbound logistics. These key factors decide the optimum design to which the warehousing and storage needs are met, for the desired requirement.

The key factors can be easily memorized in a simple way as “FAST”. The factors are each equally important and not arranged or explained in preference, as all 4 of them are necessary. In case, there is a change in any of the factors listed below, each of the other factors are to be revisited again, to see how this change in one factor, alters the impact of total process of the warehousing facility.

Flow

The “Flow” factor deals with the logical sequence of operations within the warehouse, where each process is located from a particular point (say A to B), which is easily accessible. The activity and process leads the flow in the warehouse to move goods.

The main focus here is to control the uninterrupted flow of materials, people and traffic with no clashes or crossheads in work area possibly with high work density. All this is done to ensure the smooth flow of processes with minimum amount of obstacles and interruptions.

Accessibility

The two major questions that are asked for this factor are, “Can we to the product?” and “Can we get to the particular product?” Usually, in a warehouse, goods are accessed using the pallets, which contains specific batch no. and lot no. of the product on a collective basis. Hence, accessibility should meet the requirements levels of fast moving processes, which can be efficiently achieved, as it has to be in a minimum compromise to the next factor “Space”.

Space

This factor decides how much space is utilized by the equipment in the warehouse. The maximum storage capacity is allocated for operational storage and stock processing purposes. The minimum space is assigned to associated functions, office space, working areas, free pallet space and battery charging docks.

The modern warehouses uses not only the floor area, but also the cubic capacity of the building, as most of the equipment used are free standing and no structure is needed to support. Hence the design of the building can be that of a big box. This allows us to make changes to the building, inexpensive and disruptive. Also, it allows us to give information on the existing inventory stock, and based on this info on space, future storage of commodities can be achieved.

Throughput

It depends on the nature of the product and the velocity of it through the flow of processes. By nature, we imply, handling characteristics, dimensions etc, on how it is moving the flow. Hazards, bulk, fragility, security and compatibility are also considered, while the equipment moves the commodities through the floor. When velocity is taken into consideration, it is defined as the volume of goods moving on a routine basis, depending on the season. Availability of accurate throughput data, assists greatly in the design of the warehouse. The better the data, the lower the risk.

3.1 Design of a Common Warehouse (Forklift)

The design of a common warehouse is drawn below to understand the flow of the forklift operation in a facility where forklifts are employed to perform their daily logistic tasks.

The different faculties shown below work together to utilize the space and time for dispatch of order commodities that are inbound and maintained with the facility.

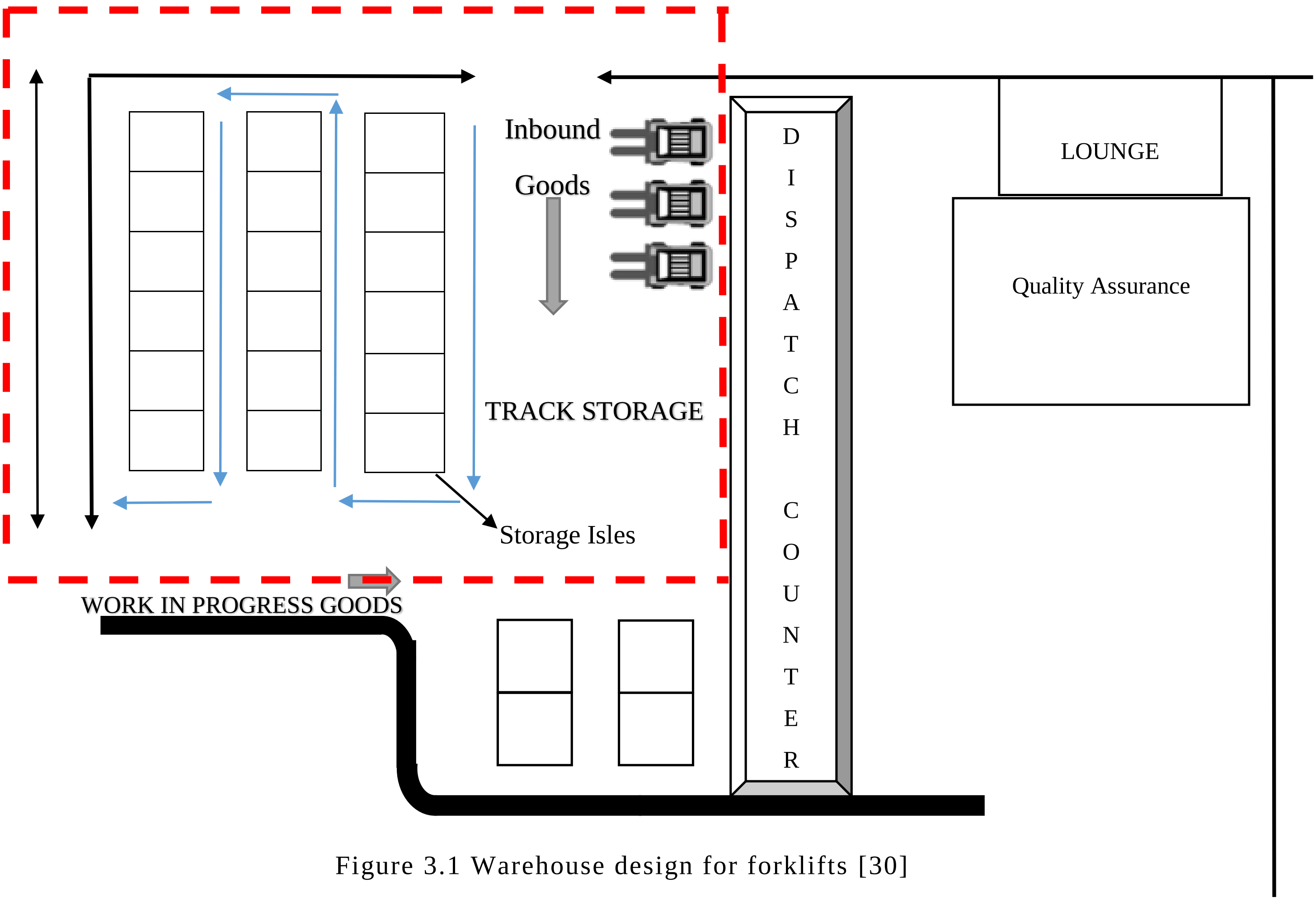

Figure 3.1 Warehouse design for forklifts [30]

The blue lines indicated above shows the path of a general forklift, from the inbound goods area to the loading trucks. Forklift access these goods in order sequentially according to the traffic of commodities that are inbound and outbound goods depending on an inventory full house, (Inventory full house being the total capacity of the warehousing reaching maximum). The dispatch counter act as a medium between the picking up of goods to the delivery area, which undergoes inspection for quality assurance and then loaded to the trucks as the required consignment order.

Now we are trying the scan the area that has been mentioned in the above diagram for doing a “Space” and “Time” Analysis.

Space analysis for the forklift will be the area that the forklift has been travelling or the path of the forklift, to access the goods. In the case above, the 3 isles of products, are drawn above and from the forklift parking area a definite path is designed for the forklift to go and pick and drop the goods. The goods are then brought back to the dispatch counter where, there are sorted for quality control. The quality will be decided by an engineer, whose job is to segregate each of the pre-ordered commodities to the set of standards mentioned by the company that has ordered it. After quality assurance the trucks which are used to load and transport these goods are docked at the Loading of Outbound goods section. We however, will only access the space that is like a small quadrant that has been highlighted in the floor plan diagram above.

Time analysis for the floor plan above is defined on how much time the forklift performs its normal task of mobility of goods, from point A to point B, which is used to measure the efficiency of the forklifts in warehousing, as they can be subjected to improve in the logistics, especially in the material handling section of the commodities. This is later compared to that of an AGV (Automatic Guided Vehicle), and a comparison is made on which can be more efficient.

The warehouse however will have a pre-defined set of parameters. The area of the warehouse will be 40000 sq. meters. The floor plan used above can be used for any kind of commodity which employs the use of a warehouse in any industry. This analysis is not confined to a warehouse such as the above, as the space and time analysis can be done on a particular area with area and time spent for the working of the concept or phenomenon that is being tried to be analyzed. Here we want to do the analysis of how efficient the forklift will perform in given area and how long it will take to perform its normal tasks.

3.1.1 Warehouse Conditions/Parameters for the Analysis (Isles to Columns Change)

The warehouse that we have designed have certain set of conditions that we have made as assumptions, but not really far from reality. The conditions are mentioned below as a list to shed more clarity on the analysis. These conditions and parameters are taken with accordance with real time parameters, but with a slight variation rounding off some of the numbers for better and easier calculations. The end result is the same with forklifts and AGVs giving us which is more efficient in a given warehouse.

- The total area of the warehouse is 40000 sq. meters, this is the standard size that we would like our forklifts to work and it is assumed to be the range between Large and Medium scale industries, which are our primary targets.
- The columns consists of goods that are packed, stacked and kept close to each other above the pallets of the forklifts. The pallets are of length 1.2m by 1m, which defines the dimensions of the cartons. There are 5 cartons in a row and there are 5 rows, so making it 25 cartons in one block of the columns. So if we check in the diagram, in Column A, block 1, has 25 cartons. We have 7 columns in this fairly big warehouse and we will analyze, how much distance the forklift can cover.
- The width of the column is 5m, and from the above mentioned dimensions, they contain 10 sections within a column. These sections are named and sequenced in the space and time analysis to explain the working pattern of the forklift.
- The length of the columns is 60 meters each, which gives us plenty of area to access the space, for both forklift and AGV.
- The distance between the columns is 5meters, as the dimensions of the forklifts is fixed to width-2m, length-4m (2m for car, 2m fork-length). Hence this distance is of 5m between the columns will be sufficient enough for the forklift to move and access the pallets of the cartons and bring it back to the dispatch counter.
- The forklifts are never together in one path, and they are accessing the goods in a sequence, such that there is no problem of crossing each other’s path.
- The analysis is done for the area of the part of the warehouse which is marked in red path, and we concentrate on this same part for the AGV movement also and use the parameters time and space to do an analysis, to find out which one can be more efficient.

3.2 Space Analysis for Forklift in Warehouse

Based on the conditions that are mentioned above, we analyze the space that is being utilized in a warehouse facility. We calculate the area of the forklift parking, area of the path that the forklift moves from parking space to the column of commodities, the area that the forklifts moves between the isles, and the space which is above and below the columns (5m) apart which is the path in the outward region for the forklifts to move. The total area of this will give an idea of how much space the forklift uses to move commodities, every time there is an order to be delivered. The floor plan of the warehouse with the listed dimensions helps us to do this analysis.

Area of the Forklift Parking

Length of the forklift: 4m (2m-car, 2m-Fork length)

Width of the forklift: 2m

Area of the forklift alone: 4m x 2m = 8m^2

Width of the parking space with forklift,

2.68m (Gap between forklift parking and Parking space) + 4m =6.68m

Length of the forklift Parking Space = 0.5 x 60m (Length of the column) = 30m

Total Area of the Forklift Parking with Forklifts = 6.68 x 30m = **200.7m^2** *('x')* (3.2.1)

Now there is a condition that we have to mention, before we proceed,

Area taken for 8 forklifts = 8 x 8 = 64m^2

Area of forklift accessories

Total Area of the parking – Area consumed by Forklift = 200.7m^2 – 64m^2 = 136.7m^2

Distance between the columns = 5m

Area of one aisle = 5m (Width of the Aisle) x 60m (Length of the Aisle) = **300m^2** *('y')* (3.2.2)

No of isles between 7 columns = 6 isles

So, area of 6 isles = 6 x 300m^2 = 1800m^2

Calculation of Area of movement of Forklift between Parking Space and Columns

Length of movement between parking space and column = 60m + 5m + 5m = 70m

Width of the movement between parking and column = 15m + 8.94m =23.94m

Therefore, total area of movement = 23.94m x 70m **= 1675.8m^2**

Area of Movement above and below the columns with 5m path, (outward region of columns)

= 2 x [5 x 60m] = **600m**

Total area of movement = 600m^2 + 1675.8m^2 = **2275.8m^2** *('z')* (3.2.3)

From the equation above, (3.2.1), (3.2.2), and (3.2.3), the total area of the forklift usage space can be calculated.

Total Area of the forklift usage (Space) = *x + 6(y) + z*

Total Area = 200.7m^2 + 6(300m^2) +2275.8m^2 = **4276.5m^2** (3.2.4)

This is the total area that has utilized by the forklift to access goods in an industrial warehouse of above mentioned initial conditions.

Space analysis of the forklift is completed here for our given warehouse. This will be later used to compare that of AGV, in the latter half of the analysis that follows.

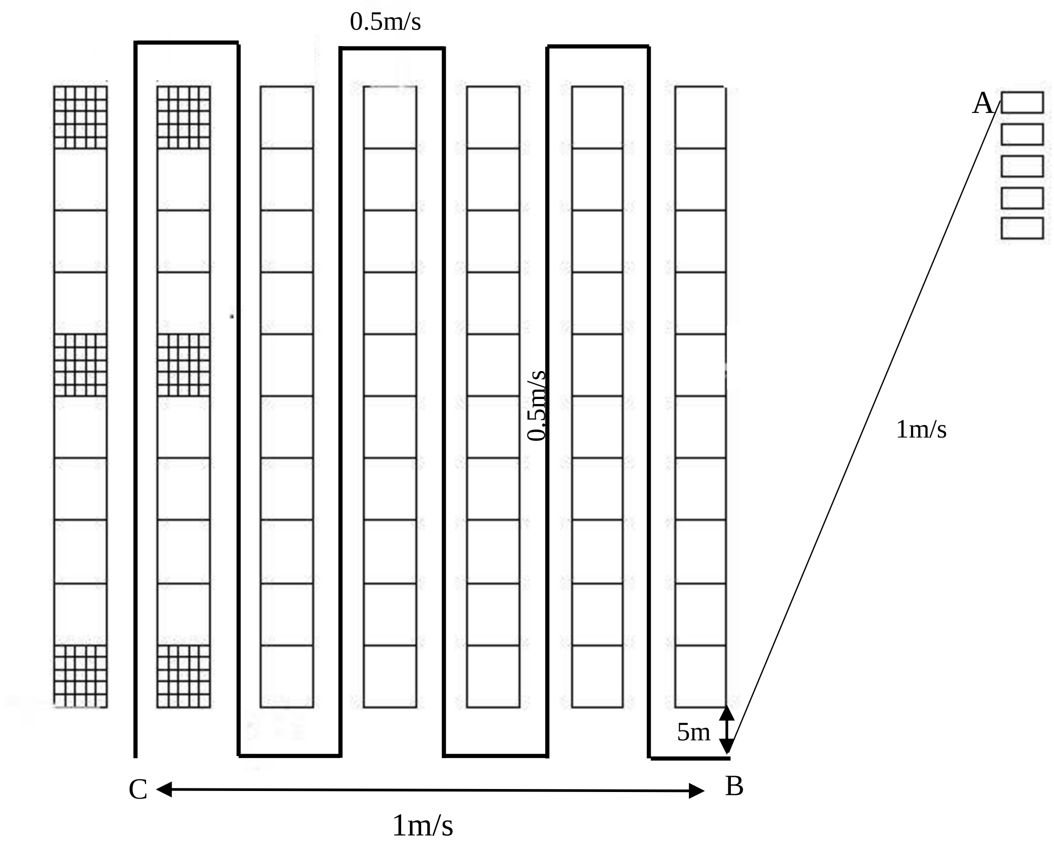

Figure 3.2.1 Space analysis for fork lifts

3.3 Time Analysis for Forklift in Warehouse

Here we have the basic assumption that the forklift speed is between the range of **0 – 1.5m/s**. But due to the conditions of operation of forklift in a warehouse facility, we assume a speed of **1m/s**, at the longer dimension of movement of the forklift and a speed of **0.5m/s** at the shorter dimension (i.e. Along the path of the AGV through the aisles).

The time analysis is done on a defined path, which is divided here into three sections which is shown below in the diagram. This is done purely based on the assumption to bring out the result of time that the forklift travels, with the respective distances calculated at the given assumed speed.

Calculation of Distance covered by Forklift

Shortest distance between forklift parking and first column = $\sqrt{(26.62)^2 + (60 + 5m + 5m)^2}$

= **74.89m**

In the above distance, the diagonal of a rectangle is considered as the hypotenuse (AB) and the formula used is the Pythagoras theorem:

$$h = \sqrt{x^2 + y^2}$$

A distance of '5m' is the dimension that we have to add above and below the 60m aisle length, which is the path for the forklift to operate along the path defined below.

Calculation of Time for movement of forklift from A to B

Here the assumption is as above that the forklift is moving at a speed of 1m/s, from A to B and the distance of AB was calculated as 74.89m.

We use the basic formula for calculating time,

$$Time = \frac{Distance}{Speed}$$

Time for movement from A to B = $\frac{Lenth\ of\ AB}{Speed\ from\ A\ to\ B} = \frac{74.89m}{1m/s}$

= **74.89 secs, [1.248 mins (approx.)]** (3.3.1)

Calculation of Time for movement of forklift from B to C

From the point A, the forklift moves 5m to reach the end of the aisle, and then it moves 2.5m to fit in the middle of the path between two isles. Therefore, the initial distance is from B to the middle of the isles, so as move in the middle of the path to access the commodities in the columns. Here, we make the assumption that the speed from B to C, is 0.5m/s, because the forklift has to move safely with a human operator, which is manually operated, so we keep the optimum speed to 0.5m/s for safety reasons inside the isles to carry goods.

The path for this particular movement is shown as the figure below.

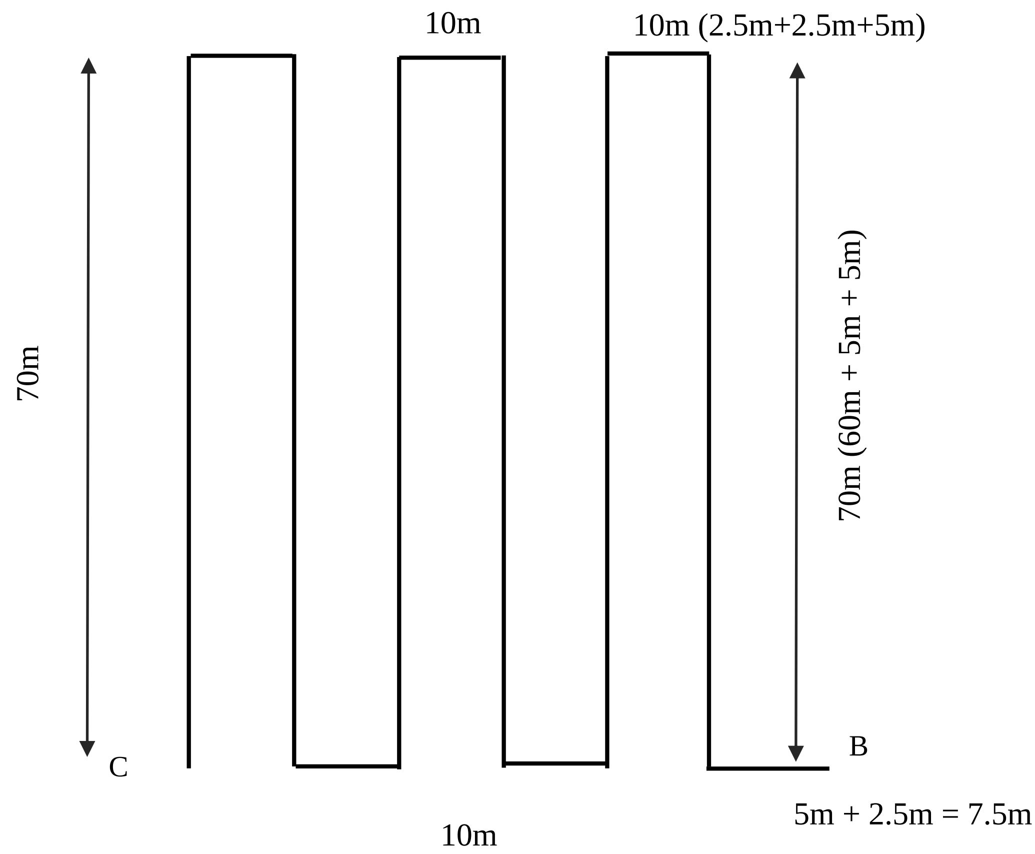

Figure 3.3.1 Assumed path plan for fork lift

Total Distance covered by forklift B to C = 7.5m + 6(70m) + 5(10m) = 477.5m

Time taken for forklift from B to C = $\frac{Distance}{Speed} = \frac{477.5m}{0.5m/s} =$

955 secs, [15.91mins (approx.)] (3.3.2)

Calculation of Time for movement of forklift from C to A

The total distance from C to B is calculated in two steps, the distance from C to B is calculated first and then the distance from B to A is calculated. Here also the speed is fixed to 1m/s as it's in the outer movement along the length from C to B and then from B to A. The figure below shows the path from C to A.

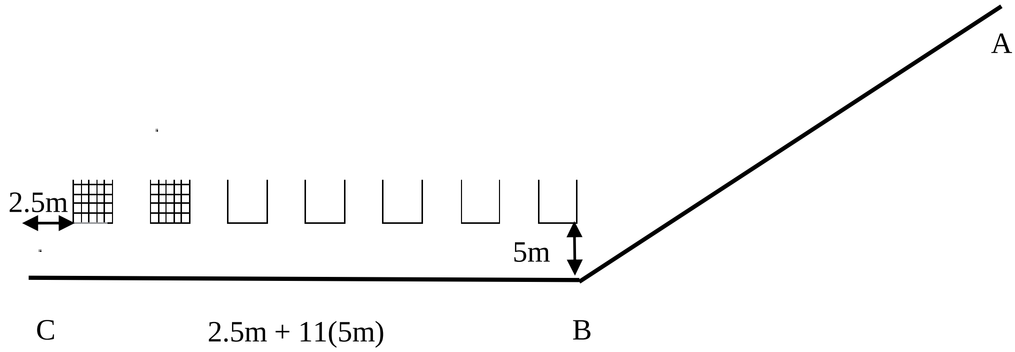

Figure 3.3.2 Movement of fork lift

Total Distance from to C to A = Distance from C to B + Distance from B to A

Distance from C to B = 2.5m (length moved to be in line with columns) + 11 columns x (5m)

= 2.5m + 11(5m)

= **57.5m**

Distance from B to A = 74.89m (Already Calculated)

Total Distance from C to A = 57.5m + 74.89m

= **132.39m**

$$= \frac{\mathbf{132.39}m}{\mathbf{1}m/s} = \textbf{132.39 secs, [2.0265 mins (approx.)]} \qquad (3.3.3)$$

Total Time taken by the forklift in a defined path from A to B, B to C and C to A

= 74.89secs + 955secs + 132.39secs = **1162.28secs** (From equations (3.3.1), (3.3.2) and (3.3.3))

= 19.3713mins (Approx.)

This completes the time analysis of forklifts in a given warehouse with the initial conditions specified and assumptions that has been taken into consideration. As we mentioned above, this will be used later to compare with the time analysis of the AGV to prove how efficient the latter is in an industrial warehouse.

3.4 Design of a Common Warehouse (AGV)

The design of the warehouse with AGV (Automated Guided Vehicle) as we can see below, has some changes from that of a facility that employs forklifts. The area that has to be used for movement of AGVs are much less and the time and space analysis will give us the further clarification on this.

The different faculties shown below work together to utilize the space and time for dispatch of order commodities that are inbound and maintained with the facility.

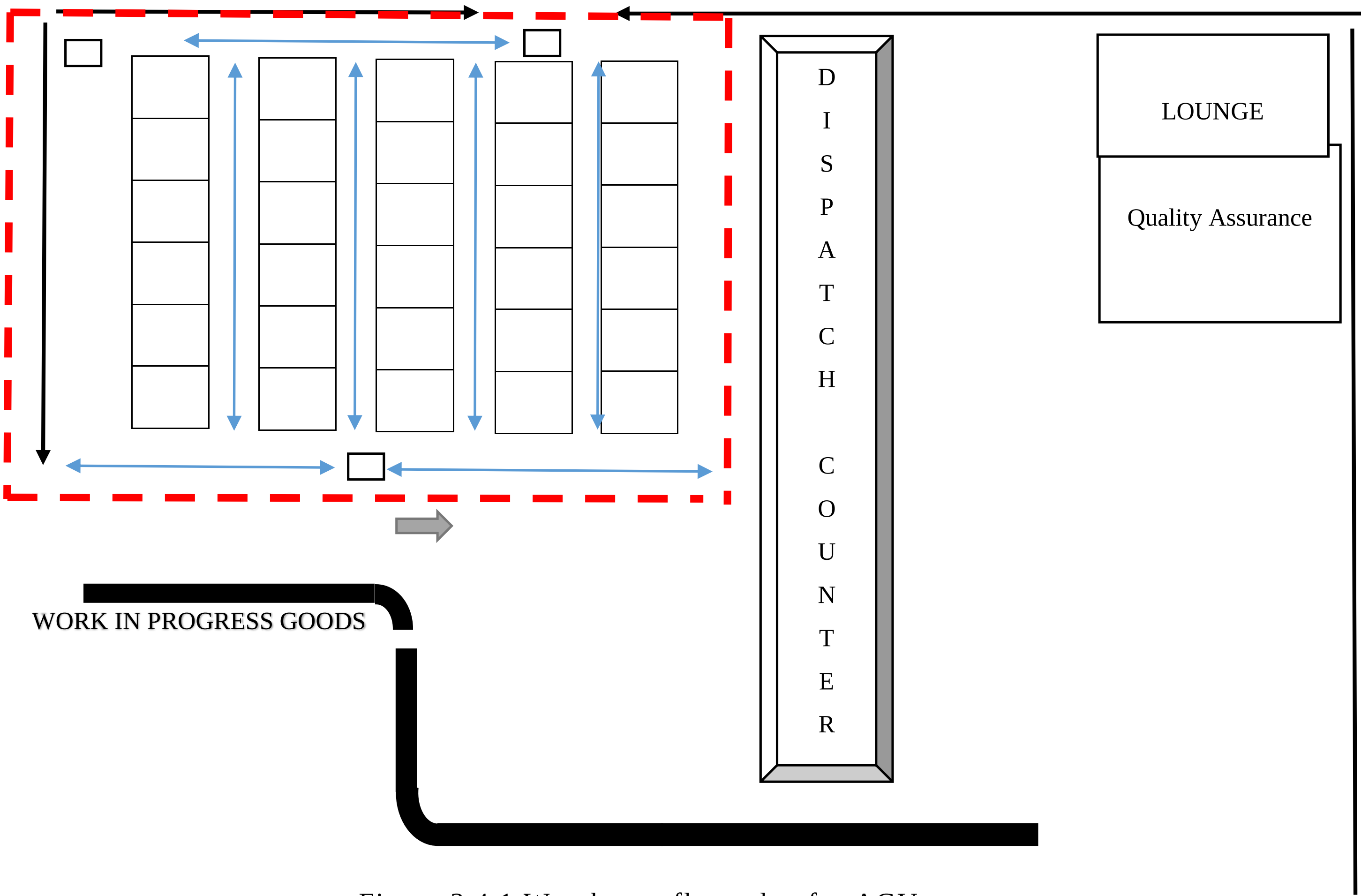

Figure 3.4.1 Warehouse floor plan for AGV

The above diagram shows the path in which the AGV moves from the optimum position which is the center of the 5 isles, which is an addition of 2 more than the bulkier forklifts, and it moves to and fro in this path and the arrow head which depicts two ways, imply that they can be go both ways and not in one defined path. The goods are accessed only in a single direction and hence we need path only in a single direction, so as to move and access goods. This way the efficiency is improved and the warehouse is automated to suit the quick accessing of commodities in the long run.

Isles dropping mechanism

Since the AGV designed is having a flat surface, question arises on how the goods at each of the isles with sections of commodities accessed? The answer lies in the mechanism of the packed/stacked commodities that are carefully arranged in the cubical/cuboidal dimensions. A hydraulic arm which is fitted at the end of each row of the storage, and it has the exact dimension of the box, cut out at the other end, to make the drop on the AGV. The hydraulic arm pushes the stack of boxes with stored commodities and they drop the box, that is required to be dropped on the surface of the AGV and the AGV carries it to the dispatch counter for quality assurance, prior to dispatch.

Space analysis in a warehouse with AGVs, clearly show us how much space is saved in the facility. Saving the space means that more no of columns, more no. of commodities to process, which will in turn improve the business of the facility. Often warehouses have difficulties in achieving enough space for the facility, to improve the flow processes. The forklifts operated space is considerably varying when compared to that with the AGV, as the size of the device also varies here. The automated process does not need human interference and hence the columns will only be accessed by the AGVs and a technician in the whole facility takes care of it, while a backup AGV runs to cover the process that is pending. The space analysis here also has the benefit that the path runs in both directions along the length and width columns.

Time analysis on the AGV, for a defined path gives us the total distance which is covered to access the goods on the columns/ racks. Once we know the distance of a pre-defined path, with the speed of the AGV being the maximum, from the set range, the time can be calculated to compare the time taken to cover one cycle of AGV in the given conditions of the warehouse.

3.4.1 Warehouse Conditions/Parameters for the Analysis (AGVs)

The initial conditions of the warehouse is the same except that the no of columns have increased from 7 to 13 columns, which is a major improvement in the logistical statistics as there more columns bring in more commodities to be stacked. This increases the traffic of goods in the process flow of the warehouse, but not tedious like managing the operation of forklift in the facility.

- The total area of the warehouse is 40000 sq. meters, this is the standard size that we would like our AGV to move and it is assumed to be the range between Large and Medium scale industries, which are our primary targets.

- The columns consists of goods that are packed, stacked and kept close to each other and also on top each other. Unlike in a forklift, where the pallet size has to be fixed and pallets are prepared to stock inventory. The length and width of each carton/package is considered to 1.2m by 1m. There are 5 cartons in a row and there are 5 rows, so making it 25 cartons in one block of the isles. So if we check in the diagram, in Isle A, block 1, has 25 cartons. We have 13 isles in this fairly big warehouse and we will analyze, how much distance the AGV can cover.
- The length of the columns is 60 meters each, which gives us plenty of area to access the space, for AGV.
- The width of the column is 2m, and from the above mentioned dimensions, they contain 10 sections within a column. These sections are named and sequenced in the space and time analysis to explain the working pattern of the AGV.
- The distance between the columns is 2meters, as the dimensions of the AGV is fixed to width-0.4m, length-0.85m. Hence this distance is of 2m between the columns will be sufficient enough for the AGV to move and access the cartons and bring it back to the dispatch counter.
- The AGVs are never together in one path, and if they are accessing the goods in a sequence, such that there is a problem of crossing each other's path, then they are automated to sense the obstacle on its path, putting it to a stop. In most cases they move back to the optimum position, waiting for the new pre-defined instructions to be received from the On-site engineer to load the next set of instructions, to access the goods.
- The analysis is done for the area of the part of the warehouse which is marked in red path, and we concentrate on this same part for the AGV movement also and use the parameters time and space to do an analysis, to find out which one can be more efficient.
- The dimensions of the AGV, specified above is the main point of focus, which uses less space to access the same goods in the same warehouse conditions.

3.5 Space Analysis for AGV in Warehouse

The space analysis is done by calculating the area of AGV movement, along the 4 outer sides of the columns with 2m width of AGV path, on all sides. This area added to the area of the AGV operation between the columns, along the isles. The total area will give us the total AGV movement space.

Here there is an optimum position, which is the middle of the column length which is 89m. The space analysis in forklift usage includes the area that the forklift uses also to go back to the parking space. But in this case it goes back to the optimum position. However the area of the docking station for recharging the AGV is a small space on the left wall of the warehouse which consumes only $1m^2$. The charging dock area is a sufficient space that has been assumed to dock/mount an AGV to recharge its battery.

Area of the charging dock of the AGV = 1m x 1m = $\mathbf{1m^2}$ *('x')* (3.5.1)

Area of Movement of AGV above and below with 2m path each.

Length of the Movement of AGV = 89m

Width of the Movement of AGV = 2m

Area of movement of AGV = 89m x 2m = $178m^2$

This is for above only, and for both above and below we calculate as shown below,

Total area of the Movement = $178m^2$ x 2(above and below) = $\mathbf{356m^2}$

Area of movement of AGV on both sides with 2m path each

Length of the Movement of AGV = 89m + 2m +2m = 93m

Width of the Movement of AGV = 2m

Area of movement along one side of the columns = 93m x 2m = $186m^2$

Therefore, Total area of the AGV movement along both sides = $186m^2$ x 2 = $\mathbf{372m^2}$

Total Area of Outer movement of the AGV = $372m^2 + 356m^2$ = $\mathbf{728m^2}$ *('y')* (3.5.2)

Calculation of Area between 13 columns (isles)

Distance between columns = 2m

Length of the columns = 60m

Area of each aisle = 60m x 2m = $\mathbf{120m^2}$ *('z')* (3.5.3)

No. of isles between 13 columns = 12

Area of 12 isles = $120m^2$ x 12 = $\mathbf{1440m^2}$

Area of between 13 columns = $\mathbf{1440m^2}$

From the equations (3.5.1), (3.5.2) and (3.5.3), we can calculate the total area of movement that AGV uses in this warehouse for these 13 columns installed, which is as given below.

Total Area of Movement of the AGV = $x + y + 12z$ (3.5.4)

Total Area of the movement of AGV = 356m^2 + 372m^2 +1m^2 + 1440m^2 = **2169m^2** (3.5.5)

Thus the area of movement of the AGV usage is 2169m^2 which is the space that the AGV utilizes in this warehouse. Space analysis of AGV is complete.

3.6 Time Analysis for AGV in Warehouse

As we did for the forklift, the basic assumption of range of speed of the AGV will be **(0-1.5m/s)**, but the situation is different here, and we don't need to fix an optimum speed, as AGVs are automated and they can move in full speed, along the path defined.

The time analysis is done on a defined path, which is divided here into three sections which is shown below in the diagram. This is done purely based on the assumption to bring out the result of time that the AGV travels, with the respective distances calculated at the given assumed speed.

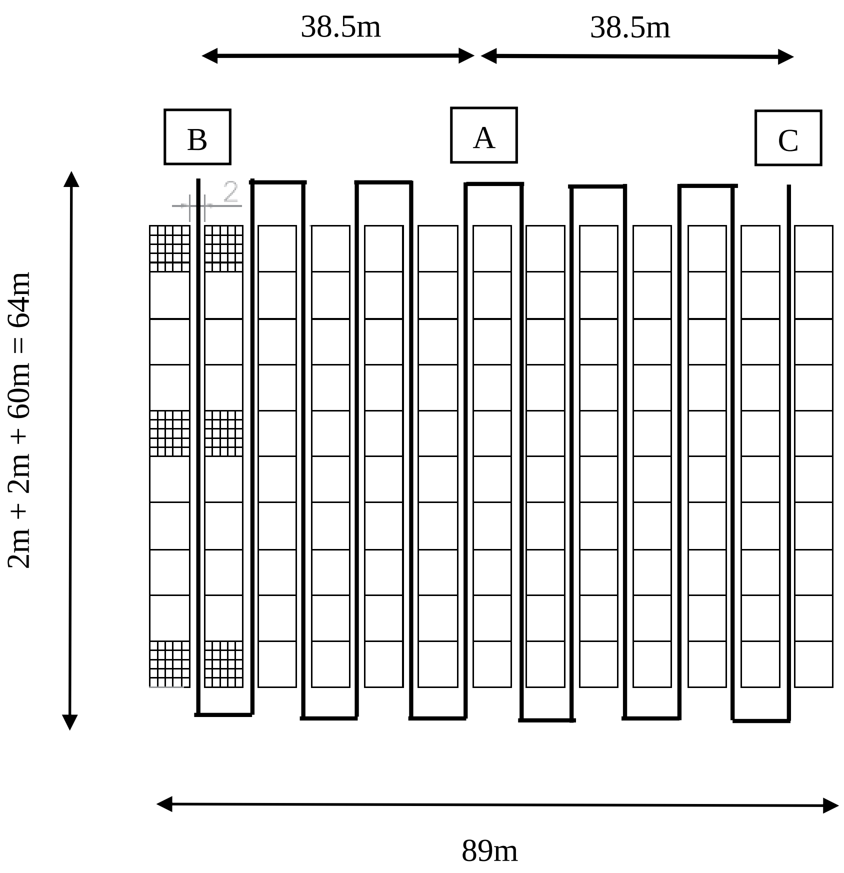

Figure 3.6.1 Time analysis for AGV path plan

The above diagram shows the path in which how AGV moves, and the defined path that we are giving as our assumption. Here the AGV moves from the optimum position A to the position B. The AGV then, moves along the path from B to C, to access the goods between the columns through the aisles. Finally after it has accessed the commodity, it moves back to the optimum position A from C.

The optimum position is the position that the AGV are placed to access the goods at a quicker pace, as it is the middle point of the columns, and they can quickly move through the path based on which columns they are assigned to access. The isle no. and the product column are programmed into the AGV, so that it accesses it with ease. The exact position of access, is determined by the column number, block number and the designated isle from B to C.

The distance calculation of the pre-defined path which is from A to B, B to C and from C to A with pre-defined speed of 1.5m/s of the AGV, can give us the time that it takes to cover one complete cycle in this path.

Calculation of Time for AGV from A to B

The AGV is at the optimum position, which is the mid point of the Length of the columns (89m).

Hence the distance from A to B,

Distance from A to B = ½ of 89m – [5m(Width of the Isle) + 1m (½ of 2m)] = 44.5m – 6m

= **38.5m**

Speed of AGV is 1.5m/s for the Whole process as we mentioned before.

We use the basic formula for calculating time,

Time for movement from A to B = $\frac{Lenth\ of\ AB}{Speed\ from\ A\ to\ B} = \frac{38.5m}{1.5m/s}$

= 0.4278mins (Approx.) (3.6.1)

Calculation of Time for movement from B to C

The length of the path shown below, along the sides of the column is 2m above and below with respect to the columns. The width of the path is the width of the column added to the half of the width between the isles (2m) on both sides. This is done for the AGV to reach exactly in the middle of the isle to access the products.The diagram below shows the path from B to C, where the length along the column is 64m and the width of the path is 7m. How we reached these values is given below.

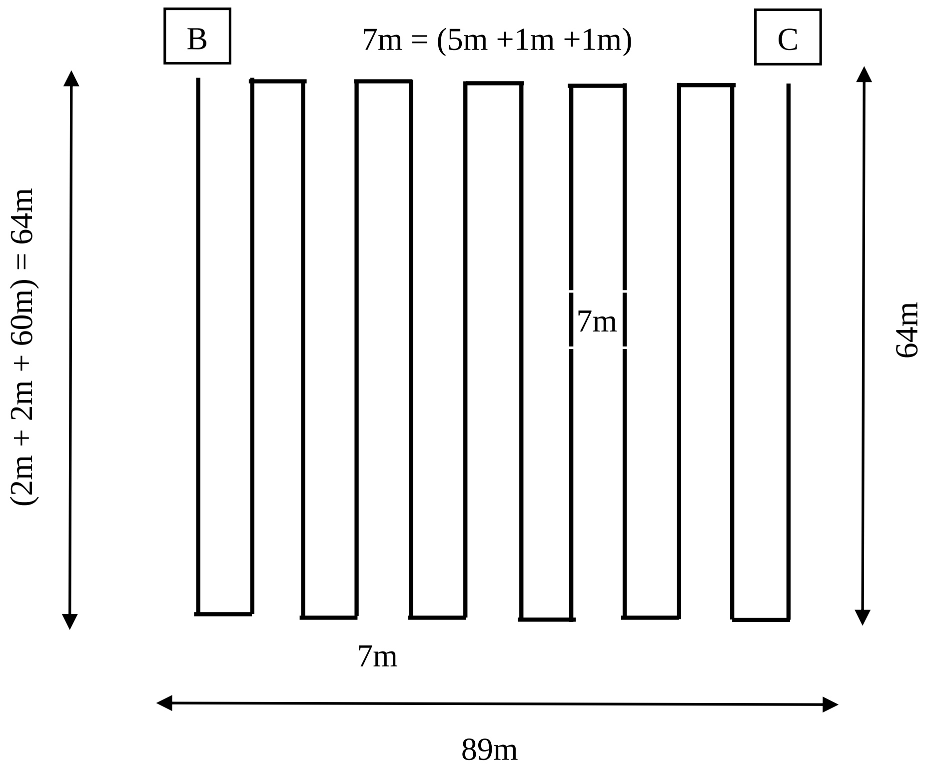

Figure 3.6.2 Path covered by AGV

Total Distance Covered by the AGV from B to C = 12(64m) + 11 (7m) = 845 m

Speed throughout the pre-defined path is set to 1.5m/s for the AGV,

We use the basic formula for calculating time,

Time for movement from B to C = $\frac{Lenth\ of\ BC}{Speed\ from\ B\ to\ C} = \frac{845m}{1.5m/s}$

= 563.33secs,

= 9.3888 mins (Approx.) (3.6.2)

Calculation of Time for AGV from C to A

The time for this section of the path is the same distance as that of from A to B.

The speed for this pre-defined path is also 1.5m/s

We use the basic formula for calculating time,

Time for movement from C to A = $\frac{Lenth\ of\ CA}{Speed\ from\ C\ to\ A}$ = $\frac{38.5m}{1.5m/s}$ = **25.67secs = 0.4278mins (Approx.)** (3.6.3)

Therefore, from (3.6.1), (3.6.2) and (3.6.3), we can calculate the time taken for entire AGV path,

Total Time taken by the AGV in a defined path from A to B, B to C and C to A

= 25.67 secs + 563.33 secs + 25.67secs = **614. 67 Secs** = **10.2445 mins, (Approx.)**

Hence we obtain the total time taken for the AGV to move from the optimum position A to the position B, and then to C, which returns back to A. The optimum position to access the goods in an orderly manner, as the beginning of the charging dock and the corners of the columns, will not be the perfect position to access the goods from the other end, hence the middle of the columns as the optimum position.

The time and space analysis of AGV has been calculated and there is a clear comparison on what an AGV can achieve under the same conditions in which the forklift operates. The time and space gives us the idea of how bulkier, expensive and tedious it is to maintain a forklift in a facility, which we are trying to eliminate.

4. Cost efficiency analysis

The fuel cost for forklift was analyzed from a set of observations. Comparing the findings of electricity cost for electric forklifts with power consumption of line tracing robots, the robots seem to be at the vantage point. While calculating the fuel or power cost for the electric fork lift an assumption was made on a peculiar scenario. Assume an electric forklift working in a warehouse for three shifts straight per day. The usage of electricity and the cost is mentioned below [31].

The electric fork lift uses 9KWh per hour. If the forklift runs for 2000 hours on a year then

2000 hours x 9 KWh = 18000 KWh per year.

The current rate of electricity per unit in Europe is 0.09 Euros per KWh, therefore

18000 KWh x 0.60 Euros = **10,800 Euros**

An industry using an electric fork lift for 3 shifts everyday would pay 10800 Euros every year as a fuel cost for the forklift.

The accumulated power required for the robot is calculate below.

No. of motors	= 2
Voltage for each motor	= 12V x 39 amp = 468 Wh
	= 468 x 2 = 936 Wh
Electronic Components	
Motor Controller	= 5.5V
Sensor	= 5V
Micro Controller	= 12V
Total power required for	
the electronic components	= 5.5 + 5 + 12 = 22.5V x 9000mA = 0.19 KWh
Total Power consumption	= 0.19 + 0.93 = 1.12KWh

Taking Line tracing Robots energy cost into account under the same condition (three shifts per day) the required power by the robot is 1.12 KWh which is in the form of direct current. Assuming the charger efficiency to be 75%

1.12 / 0.75 = 1.49 KWh

Which is the real power required by the batteries to get charged above 80% in few hours. Cost for charging one battery for one shift will be

1.49 KWh x 0.60 = 0.90 Euros

If it is applicable for 3 shifts and 365 days,

0.90 X 365 x 3 = **985.50 Euros**

Compared to an electric forklift the line tracing robots have better cost efficiency since the annual electricity cost for line tracing robots is ten times lesser than the electric forklifts [32].

The labor wage for operating the fork lift will also be compromised since their operations are automated. If an industry uses five fork lift they have to use five labors to operate these fork lifts and there would a maintenance charge and wage which accounts as overhead expense. IF they are replaced with AGVs then the overhead expenses would be minimized and the profit can be increased accordingly. There are few warehouses where the operation is seasonal, in those places it is highly preferable to use AGVs rather than fork lifts which requires less maintenance and one person to supervise the entire operation. Instead of paying wages for five different employee the industry can pay wages for one supervisor which makes the logistics cost efficient [43].

5. Manufacturing Cost

The robot manufacturing cost can be determined from the two sides, one being the electronic components being used and the other being the machining process of chassis. The electronic components have a stable price sheet but the machining process of the chassis keeps varying based on the place it is being manufactured. The manufacturing cost plays a major role in finding the efficiency since the user needs to know how much he is investing to increase the efficiency of his work and how much he will be saving in a year. The return on investment can be calculated using the cost of robot.

The manufacturing cost is calculated in Indian rupees but will be converted to euros since the assumption made is that the robots are manufactured in India. The conversion rate from Indian rupees to euro is done at the current day. Since manufacturing of the chassis covers the major manufacturing part and the electronic components will be part of assembly work. Assembly and programming are the major part of the robot but the coding of the microcontroller will be standardized based on the requirement. The below table will contain the price of the electronic components required to provide the major functions of the robot.

Table 5.1 Electronic component pricing table

Components	Quantity	Price (EUR)
Arduino UNO	1	23
Arduino MEGA	1	43
Load Cell	1	6.50
Magnetic Line sensor	1	400
Voltage Sensor	1	10
LCD Display	1	21
RF Transceiver	1	21
IR Distance Sensor	1	11
24V DC Motor	2	250
Motor Driver Control	1	7
Batteries 12V DC	2	104
Aluminum Chassis	1	150
Magnetic strip	1	125
Magnetic Marker	30	50
Solar Charge Controller	1	66
Total Cost		1287

The component prices are obtained from Spark fun which is an online marketing platform for electronic components based in United States of America. Assembling and programming of micro controllers will be the major part of manufacturing the robot, since fabricating the chassis can be outsourced to a third party industry. The chassis will cost 150 EUR for one robot since it involves only few processes like cutting, bending and polishing. The prices for extra additional parts like robot arms and rollers will be separate. The magnetic strip that has to be laid on the floor depends on the length of the path. Each magnetic roll is 45.72m long and it depends on the total length of the path used on the shop floor. The magnetic markers are also included in the list which is 1.60 EUR per piece and depending on the number of operations, appropriate number of markers will be installed along with the magnetic path.

5.1 Cost Comparison

In order to arrive at the final verdict the AGV has to be compared with the existing forklifts based on their specification to analyze whether the AGV is more efficient than the existing forklift. The following table will provide the comparison between the AGV and the forklift. During comparison the features of the forklifts will be highlighted which can also be compared to the AGV. The AGV can be integrated in an automated warehouse where the transfer of good is completely automated with the concept of Internet of Things which enables the owner to use less human labor and more electronic vehicles keeping the efficiency the same but reducing the expense for logistics. The cost of forklift was obtained from a forklift seller which was stated in US dollars but it was converted to Euros since all the price values are in Euros.

Table 5.1.1 Cost comparison between forklifts and AGV

Features	AGV	Fork Lift
Cost (Eur)	1300	10470
Uses	Storing Stacking Moving Loading	Storing Stacking Moving Loading
Training	Automated	Operator

AGV seems to be more efficient in some places where they have load capacity below 1000 kg. Places where they have to carry beyond 1000 kg pounds will be substituted by five more AGV still the total cost of one forklifts can be compromised.

The AGV ownership is expensive compared to the fork lift ownership but the graph below will explain what will be the maintenance cost in the next 5 years. The graph is formulated with the following assumption in an industry. Assume there is an operation carried by two forklifts with operators. The forklifts move at a speed of 6 km/h, these forklifts are replaced with five AGVs that move at a speed of 2 km/h. The daily work hour is 8. These data are calculated for a period of five years.

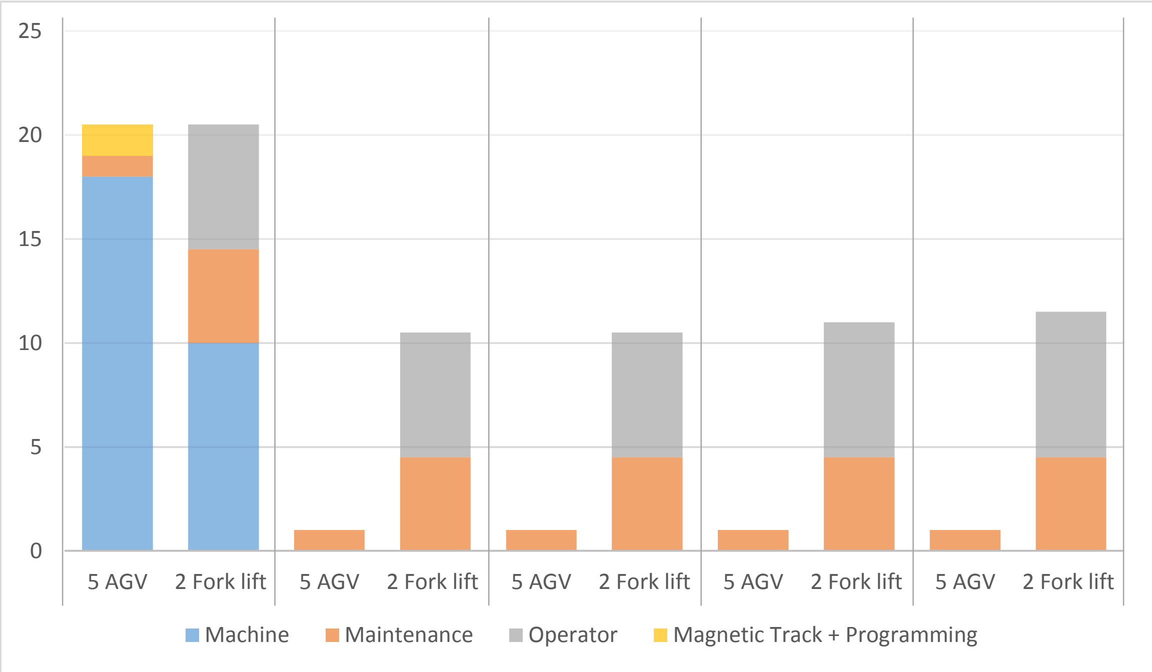

Figure 5.1.1 Ownership Cost Analysis

If the values of the total sum of expense made in five years for fork lift and AGV the following graph will show the clear picture of which one is the more efficient.

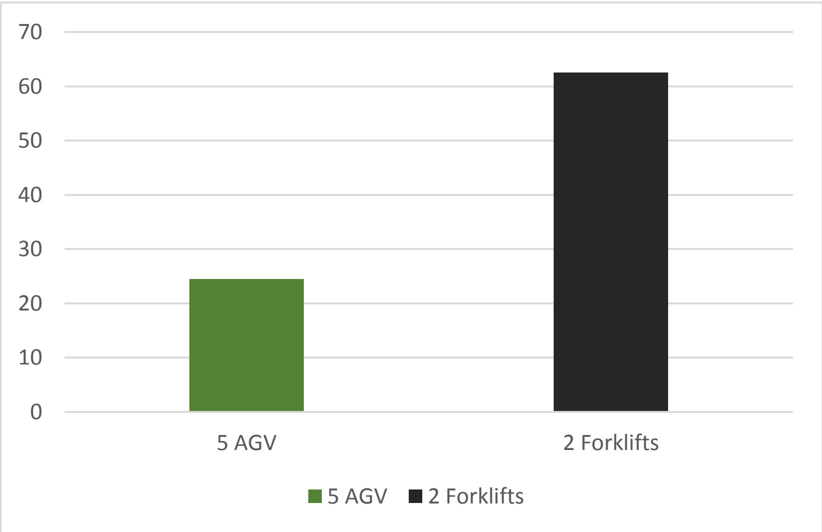

Figure 5.1.2 Cost comparison of AGV and forklift for 5 years

The average cost over a period of five years for 5 AGVs is 60% compared to the average cost of two forklifts for the same period of time.

6. Market Research

As students of Industrial Engineering and Management, we were doing a survey on AGV (Automatic Guided Vehicle) will influence the future of the warehouses in the long run, and how they can reduce the expenses, while taking care of the mobility of goods in a facility to enhance the process of logistics. In the appendix, we can see the questionnaire that was send to different employees in companies, who have replied to the same, with their valuable feedback on how they think, usage of forklift will affect their logistics, how much expenses they incur based on this, in comparison to how an AGV, in an automated set up can improve the conditions in the storage facility. The survey has detailed questions which an engineer would face in a facility, and how our product can improve the status, when compared to using an AGV.

Our product is an AGV, which can sense obstacles on the way, helping to move faster and safer for commodities. The whole set up runs on DC current and it has a charging dock, which it automatically by default, programmed to go back to the charging dock, recharge and then go back to the task at hand. The cost efficiency is quite evident from its specs, time and space analysis, which can be preferred over bulky forklifts, in a given warehousing condition.

The questionnaire that we sent to different employees working in different fields of engineering, which employs commodity storage, have responded positively on automating their warehousing facilities , than wasting fuel, which the forklifts use in the current scenario, and also the energy used, by conveyors and electric forklifts. The result of this feedback from our questionnaire shows to how we analyzed the market, and how we could implement this for a particularly long period of time. The market demands a replacement for something new to cut down on the use of manual labor and heavy machinery to move goods from outside to inside, and vice versa. This made us think of how an AGV can work in a warehouse or any given facility, may it be automobile, bottling etc. We have thought of a design which suits all the above industry, utilizing less area to operate, saves the energy bill at the end of the month and employs less workers on salary to handle goods to be dispatched. Market research feedback given in the next section will talk about the choice of professional/non-professionals as an overview in general on how they feel to, the approach of an AGV operating under only 3-4 engineers in the unit/floor to completely control the actions/tasks given to the vehicle, programmed appropriately to perform tasks in sequential manner to achieve faster movement of inbound and outbound goods.

Feedback Analysis from the Questionnaire

Let us see how the employee have responded to the questionnaire, how the structure of the form send to them, help us analyze the market that is existing now, and what we can do to improve the conditions. The following are the points that we noticed:

1. More than 83% of the responses agree to the use of forklifts in their facility, which means they are using forklifts to move goods, and a surprising 100% use the conveyor belts in their go downs to store and move goods. Since these are 2 separate methods, and one of them involves human labor and risks of human lives, if there is a mishap, on the contrary, conveyors are really difficult to maintain and the energy used by this method is considerably high which increases the electricity constraints for the warehouse. The third method is the traditional one which is manual labor. In spite of using the forklifts and conveyors, manual labor is still required to safeguard the goods while they are moved. Almost 66% and more, of the responses state the use of manual labor in their companies. Other than this, the forklifts and the conveyors need like technicians to check and maintain these machines. However, the maintenance is quite high when we employees to work on the conveyors, forklifts and manual labor, including separate technicians to maintain it. We learn from this that our AGV, can minimize the capital investment of purchasing and using bulkier, expensive machines. The risk of humans being employed in this setup, is less and also prevents the accidents that normally occurs in a flow process of the facility.
2. Next we go into the working days of the companies, 50% says that they have 6 working days, as these facilities will have non-stop business, so the traffic of goods is faster, and more efficient time, leaving on one day shutdown. On a six working day with 2 shifts, means continuous running and usage, which will be easier with DC current than actual fuel and electricity. AGV is self-sufficient, as it can recharge from the charging dock and then go back to the pre-set task. When asked to rate on a scale of 1-5, on the fuel usage of forklifts, we had different replies. Some employed the usage of electric/diesel forklifts, so we learn that the forklifts that people used have both 50% of both electric and diesel forklifts. Continuous usage of electric energy and fuel, will increase expenditure of the maintenance and handling of materials in the warehouse.
3. Conveyor belts are used for a flow process type of industry and it can also be employed in a warehouse. The responses said that more 83% working 24 hrs with 2 shifts. When asked about the fuel consumption, the answers were mixed, which kind of makes us

still confused with the dilemma of the firms to eliminate the use of conveyor belts, but slowly they will be replaced by AGVs.

4. About 66%, and more of manual labor is employed, a group of 50 workers is still preferred by the 60% of the companies need these workers to monitor and handle material inside the facility. Each of the workers earn, nonetheless 3 Euros per hour. Now when we calculate in general, an employ earns minimum, 576 Euros which is a saving of investment, per employee and sums up to a huge sum when it comes to 50 workers.
5. For the 15th question, which is the main part of the survey was to automate the logistics in a facility, to which the response was favoring a big YES to automation of warehouses.
6. The observation made that most of the companies showed a safe interest in it, by agreeing that they choose to invest a range of 6000-12000 Euros to automating logistics processes for a long term solution. This makes us understand that the existing systems are being over used and they get deprived of their efficiency in performance.
7. The engineers and other professionals who responded, was in a general manner, but still we could understand what we workers choose for and prefer. A strong 66% or more, selected the middle range.

7. Conclusion

1. A literature survey on logistics and automatic guided vehicle was conducted and the findings led to the understanding of logistic operations in warehouses and industries.
2. An analysis was made on the existing forklifts that are used in industries. Their features were studied carefully. The design was created keeping the lacking features in mind.
3. Using Solidworks and google sketch up a 3D model was developed. A 24V DC motor was selected with the help of motor torque calculation. As the calculations were done it was seen that the wheel motor torque was 291.4 kg-cm and the maximum tractive torque was 450 kg-cm which should be greater than the wheel motor torque to achieve stability and avoid slippage.
4. Path planning is one of the essential step for an automatic guided vehicle since it is not operated by human. Multiple path planning method were used for black lines and magnetic strips as well. The programming of microcontrollers will change based on the medium of line whether black line or magnetic strips. Compared to black lines and magnetic strips, magnetic strips are more efficient since the programs can be integrated in the magnetic strip and it is less time consuming.
5. Based on the path plans created for the AGV with magnetic strip there was an analysis made from the aspect of time and space by creating a warehouse floor plan and analyzing time and space consumed by both AGV and forklifts. This comparison proved that AGV is better than fork lift.
6. The energy consumption plays a major role in every industry which when focused on reduces the yearly expense for the industry. If the forklifts are replaced by AGV the industry can reduce its energy consumption and save up 60% of the expense involved in logistics. The forklift requires 10,800 EUR for powering the device and the AGV requires 985 EUR. The AGV’s assembling cost sums up to 1300 EUR whereas the forklift’s market price is 10470 EUR. Manufacturing the AGV is cheaper but programming the AGV is a bit expensive when compared to buying a forklift. The return on investment will be obtained in 3 years approximately since once the AGV is installed there would less maintenance and low wage for human labor.
7. From the above analysis we can conclude that automating a warehousing facility is the demand in the interest of the engineers in a firm, to quicken the process of mobility of commodity. The percentage of responses favoring the use of forklifts in a facility is considerably less. Hence, having our AGV in this facility saves a lot of time lag, space and capital investment, with less human labor.

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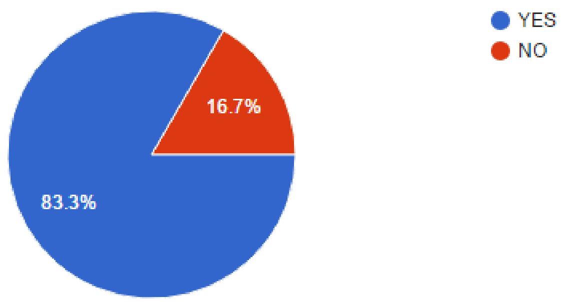
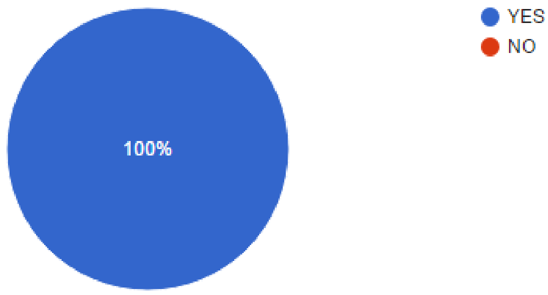
Appendix

1. Market Survey Questionnaire (Responses)

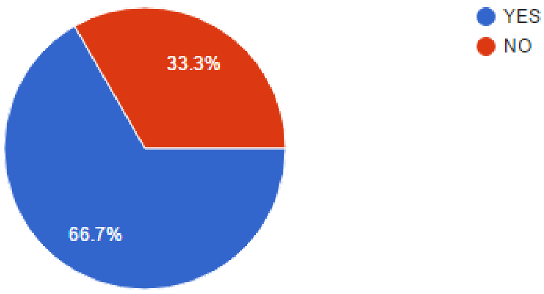
1. In your company facility, are forklifts being employed to move commodity?



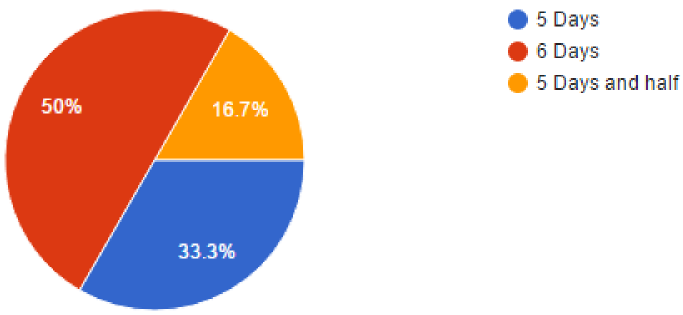
2. In your facility, are conveyor belts being used for moving commodities?



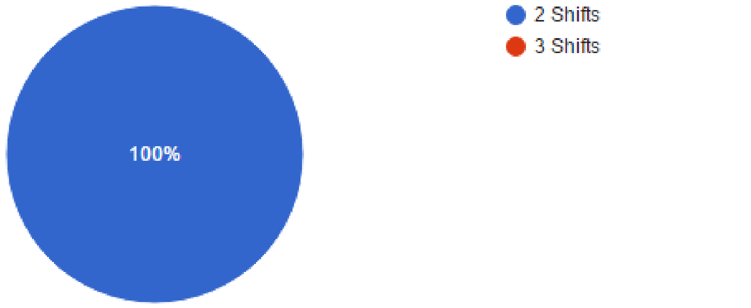
3. In your facility, is manual labor being employed to move commodity?



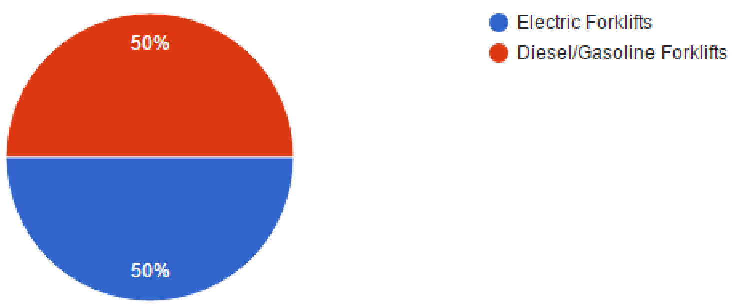
4. What is the number of working days in your organization in a week?



5. If forklifts are being employed in a day, how many shifts of work cycle does it operate?



6. What kind of forklifts do you use?



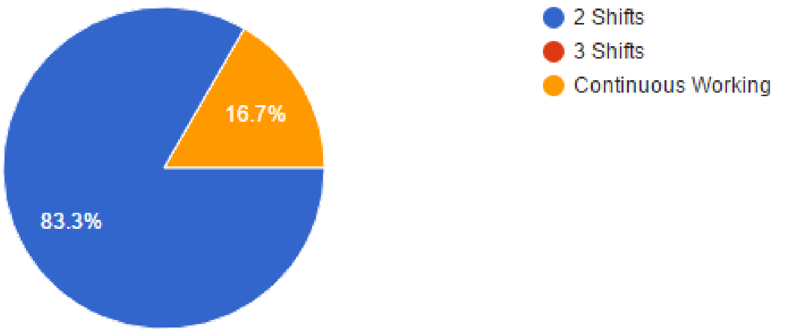
7. On a scale of 1-5, how much fuel is utilized for the mobility of commodities in your facility using forklifts? (1,2,3,4,5)

   3 (4/6 Responses)

   4(1/6)

   2(1/6)

8. If conveyor belts are being employed in your facility, how many work cycles does it operate? If conveyor belts are being employed in your facility, how many work cycles does it operate?



9. On scale of 1-5, how much fuel is utilized for the mobility of commodities using conveyor belts?

5 (1/6 Responses)

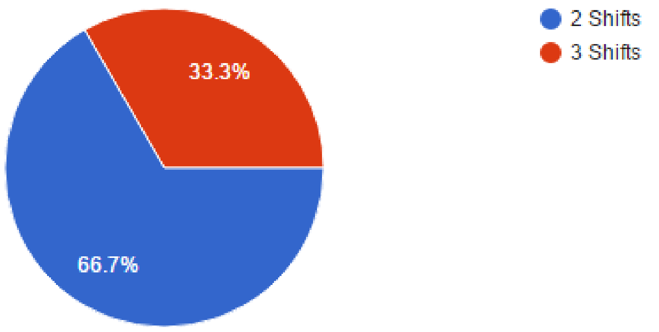
2 (2/6)

1 (1/6)

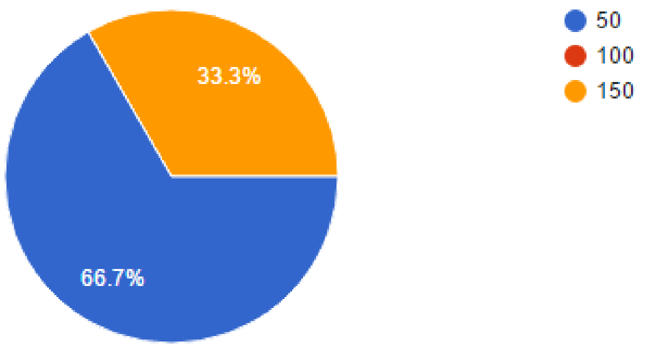
4 (1/6)

3 (1/6)

10. If manual labor is being employed in your facility, how many work shifts are they employed?



11. If manual labor is employed, how many laborers have been employed during a shift?



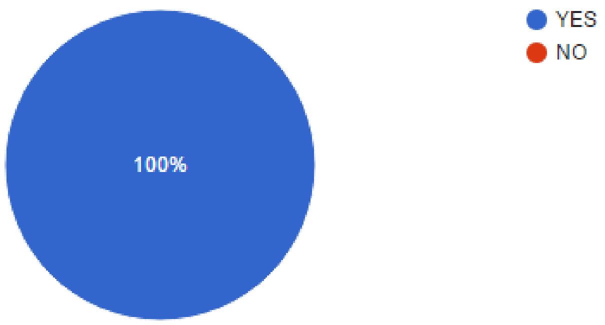
12. On a scale of (1-5 euros/hour), what is the salary paid per hour for their labour charges?(If above 5 Euros, please mention)

4 (2/6 Responses)

3 (2/6)

5 (1/6)

13. Will automating your logistics process increase your efficiency?



14. How much would invest in automating your logistics processes, for a long-term solution?(Euros)