

Development of Low-cost Automated Guided Vehicle (AGV) to Step towards Industry 4.0

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Abstract

The primary elements largely related to the cost of material handling, which accounts for an average of around 20 to 25 percent of overall production costs, are lost time and labor costs. This report aims to inform readers about a substitute material handling technique called an automated guided vehicle (AGV). It is an innovative programmable vehicle that can automate transportation activities at a reasonable price. In other places, such as warehouses, container terminals, and exterior (underground) transit networks, AGVs are now employed for continuous transport systems. By making route selection judgments utilizing a variety of ways, such as vision-based mode, frequency-selected mode, path-selected mode, and so on, AGV automates the system. The map is stored in the AGV memory and monitored by the stationary control unit of the warehouse for the pre-defined industrial setting. The traffic management system, floor control, guiding path system, and vehicle peripheral on-site component are the four critical parts of the AGV system. This study recommends adding new functionalities to the AGV in accordance with the industry's escalating need for more multifunctional machinery aspects.

Keywords

Automation, material handling, line follower AGV, intralogistics, robot vehicle and IoT.

1 Introduction

Highly developed machines called Automated Guided Vehicles are frequently employed in big industries to carry products from one location to another. In many situations, this has eliminated the need for a human labor force to do certain jobs. AGV demand has significantly increased over the past 10 years since they are now employed in a variety of industries in addition to manufacturing and distribution, including healthcare, farming, commerce, and defense (Li et al. 2011). AGVs have proven to be quite helpful and provide a lot of benefits for numerous sectors. AGVs are designed to work around the clock. They are the ideal alternative for physical work and will lead to reduced expenditures for overtime, paid vacations, and other expenses. Human error is avoided by using an Automated Guided Vehicle in place of a person. This lessens distributing center goods and equipment losses as well (Kumar Das 2016). Error reduction boosts production, which boosts the bottom line. Despite having a lot of initial investment, with several shifts, uniform pick-up and drop-off locations, and unit load product volume, AGV offers a straightforward and cost-effective return on investment (De Ryck, Versteijhe, and Debrouwere 2020).

1.1 The Novelty of the Product

AGVs should be easy to learn, use or deal with so that workers can quickly get familiar with it. The performance of AGVs should be as efficient and effective as possible. It should minimize current costs and maximize operational capabilities. The design of AGV should be focused on people and how they might interact with. It must fit the workplace to the employees' needs. While designing an AGV, a holistic approach should be taken to keep different ergonomic aspects in mind. AGVs should require very little time, and effort to look after them. It should not tend to cause problems or demand attention. AGVs need to be purchased or acquired at a relatively low cost compared to the other means of automation technologies.

1.2 Application of the Product

The most important aspect of employing AVG in many domains is autonomy. It will attain a high level of precision and clarity, which will reduce overall system error and decrease lead time. The main factor that will make AGV popular compared to other material handling techniques is adaptability. The AGV is employed outside of the production facility as well as in new locations in various service industries. It is utilized in technically advanced and electrical industries for loading and unloading stations and implemented in warehouses to move products (Mehami, Nawî, and Zhong 2018). AGVs are required for unappealing activities including washing warehouses, floor cleaning, and luggage transfer inside airports, supermarkets, and shopping malls. They are also used for dispatching materials to inaccessible locations for humans, locating and disposing of bombs and mines, and investigating nuclear plants, steam generators, and pipelines. Providing food, drink, and medications; submitting procedural reports, handling toxic substances, dumping biological matter and offering support to the disabled, and prompt assistance with personal hygiene, AGVs can be used (Le-Anh, De Koster, and Koster 2004).

2 Literature Review

AGVs are utilized in industrial applications to transport products within a production facility. By making the choice about the path, AGV can automate the system. This is accomplished using a variety of techniques, including frequency-chosen mode, path-selected mode, vision-based mode, etc. The steering command and speed command are sent by the AGV's central processing system. The map is kept in the AGV memory and controlled by the stationary control unit of the warehouse for the predefined industrial environment (Rehman, Asif, and Ahmad 2018). A primer on the design and operation of automated guided vehicle systems. can be given by addressing the majority of important related issues, such as the design of the guide path, figuring out the needs of the vehicles, scheduling, positioning of idle vehicles, battery management, routing, and deadlock resolution (Li et al. 2011). Because it offers visibility and control, automated guided vehicles (AGV) are frequently used in automatic logistics systems. Logistics systems for container terminals can incorporate the Multi AGV System (MAGS) and its coordination control. In order to coordinate many AGVs, monitoring control and electric AGV design are crucial (Saputra and Rijanto 2021). The most significant differences between conventional and emerging areas of application are the quantity of AGVs used, the number of shipping requests, the utilization level of AGVs, the distances to be traveled, and the number of pick-up and delivery positions where transportation demands are accessible. Many different choice factors appear in design challenges. Decisions may have an unpredictable effect on how people connect and perform. Making a choice without taking into account other factors in the decision could be challenging (Mehami, Nawî, and Zhong 2018). The majority of currently in-use AGV systems utilise some type of centralized control, which is in charge of the whole network of AGVs. Decentralized systems, where AGVs decide on their own, are becoming more popular. These systems promote the adaptability, reliability, and capacity of transportation (De Ryck, Versteijhe, and Debrouwere 2020). An important aspect of optimizing intralogistics is the automation of transportation in the industrial, commerce, and service sectors. Automated guided vehicle systems (AGVS) offer particular advantages for this purpose. The automated guided vehicles that are centrally controlled are these systems' main features (AGV). The cars were first directed by optical or inductive rules. The primary drawbacks of guidelines are their rigidity with regard to routing modification and change, as well as the requirement for installations on or in the ground. New innovations lead to systems without rules. The laser navigation for the AGV serves as an illustration of this progress. The AGVs are very distinctive. They are often created and built to meet the requirements of a particular application, making them exceptional (Le-Anh, De Koster, and Koster 2004). An important factor in the optimization of logistics is the automation of transportation in the industrial, commercial, and service sectors. For this job, Automated Guided Vehicle Systems (AGVS) provides a number of advantages. AGVS technology, current technical advancements, and research findings from the Planning and Controlling of Warehouse and Transport Systems (PSLT) Department are very important in this regard (Ricciardi et al. 2020). Material handling systems (MHSs) based on AGVs, which are extensively used in flexible manufacturing system (FMS) installations, automate transportation, which needs several considerations. These include the necessary number of vehicles, the shape of the track, the flow of traffic around the AGVs, and resolving traffic management issues. Analytical and simulation models can be used to analyze the issues with multi-vehicle systems and look at potential solutions (Babi et al. 2012). Increasing the load capacity at first can raise the AGV system's efficiency, but after the load capacity rises over a certain point, the efficiency of this strategy will decline. It is discovered that employing a multi-load AGV can improve the performance of a system with variable loading and unloading sites. But there must be an ideal load capacity for a particular AGV system for an AGV system to operate better after employing a bigger capacity of multi-load AGV (Yan, Jackson, and Dunnett 2020). AGVs are being incorporated into current production systems because they provide several advantages in terms of social, environmental, and economic sustainability. AGVs have a higher economic potential since they require less maintenance than traditional vehicles and can run continuously with less need

for human assistance or labor. Utilizing AGVs effectively and efficiently boosts productivity in logistics operations and raises the level of service throughout the whole supply chain. AGVs' effects on environmental sustainability in supply chain activities are more pronounced and mostly relate to decreased energy usage, particularly in the case of AGVs powered by electricity (Bechtsis et al. 2017).

3 Data collection and customer survey

A Pareto Chart is a graph that depicts the frequency of defects as well as their total impact. Pareto charts can be used to highlight the counts that must be addressed first to see the greatest overall improvement.

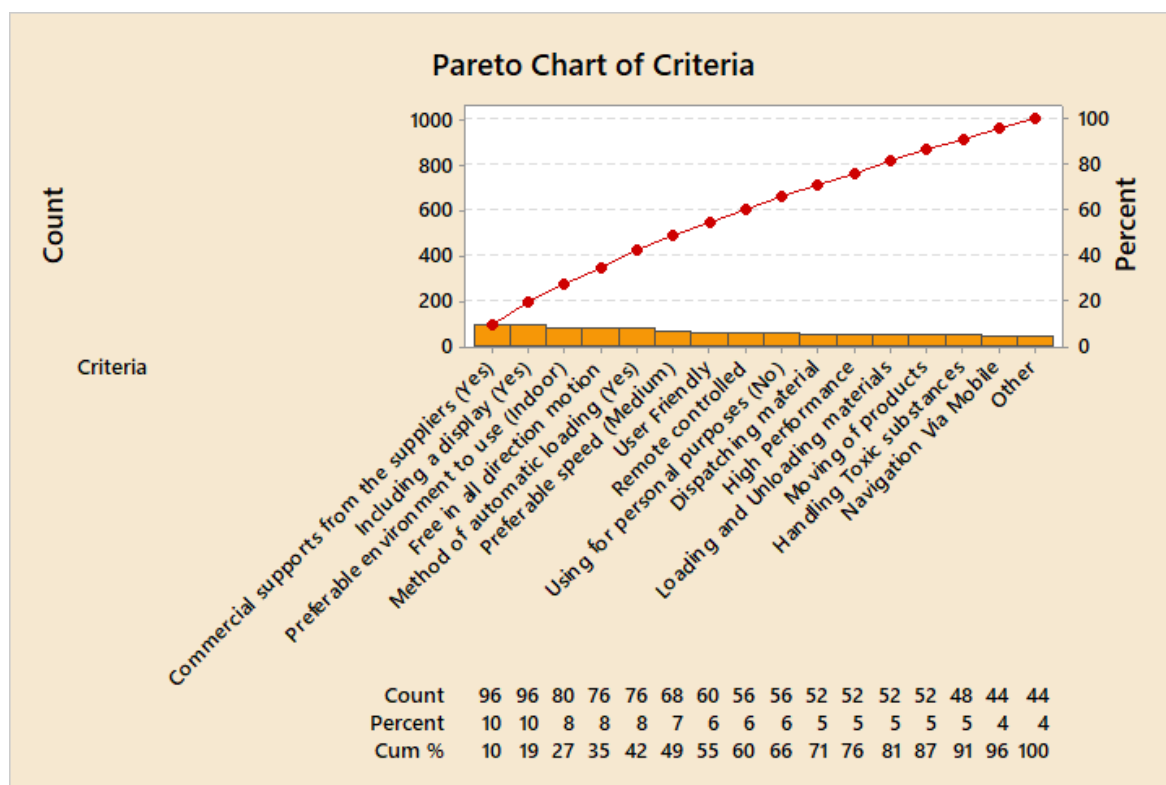


Figure 1. Utilizing the Pareto chart to prioritize criteria

From the chart above in Figure 1, we can see that by ensuring commercial support, adding some features like display, free motion in all directions, automatic loading system, remote controlling, etc, and designing the AGV for indoor environment mostly, we can fulfill the customers' satisfaction up to 66%. To ensure that the majority of our customers are satisfied, we must place more emphasis on this criterion.

4 Methodology

4.1 QFD

Quality Function Deployment (QFD) is a constructive, targeted strategy used to consider the Voice of the Customer (VOC) and then implement efficient feedback to customer expectations and demands during the design and manufacturing stages. QFD, which was first thought of as a type of cause-and-effect analysis, is a crucial tool for planning as well as quality control. QFD aims to develop a methodology that incorporates customer happiness into a product before commencing its production process. Compared to other quality control techniques that concentrate on resolving consumer complaints during or after manufacture, this one takes a more practical approach.

The House of Quality (HOQ), also known as the product planning matrix, is the most important step of the QFD. At this point, every detail must be evaluated because it will impact how quickly the succeeding phases of the QFD will proceed. HOQ is also the primary graphical representation of the product planning and development process.

The House of Quality for our Automated Guided Vehicle is given below in Figure 2:

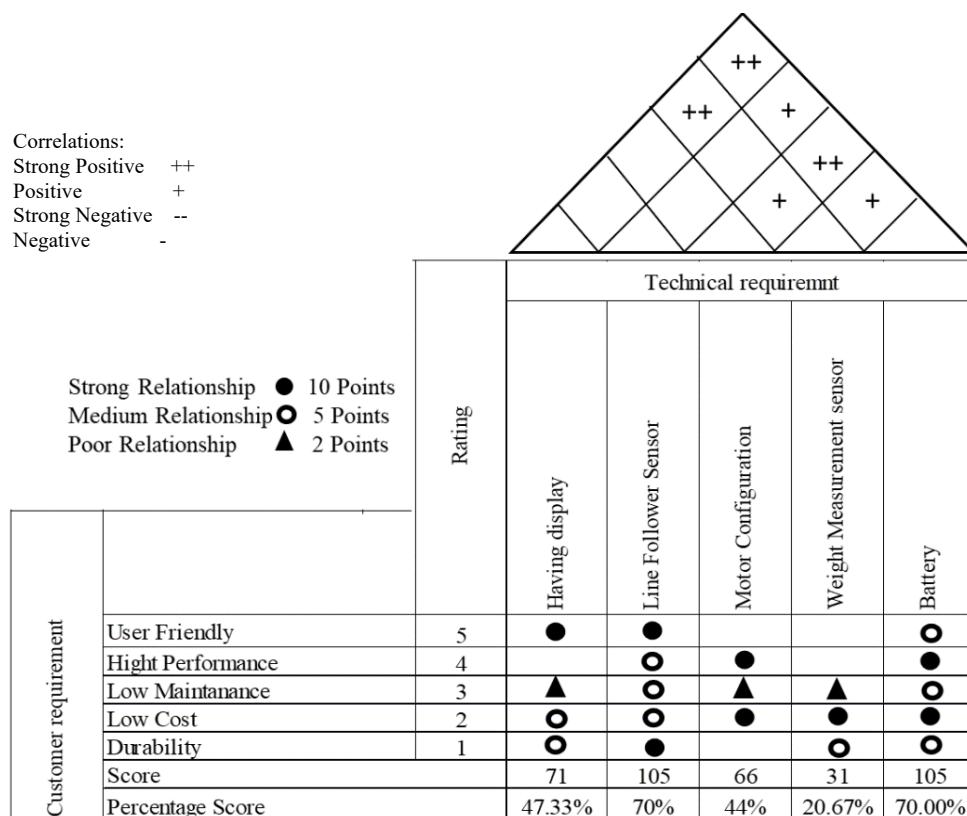


Figure 2. QFD Chart analysis for automated guided vehicles

4.2 Functional Decomposition

A functional decomposition diagram is a common visual representation of the separate process components and their hierarchical relationships to one another. The functional decomposition diagram of AGV is given below which includes both the main function or task and the essential supporting functions or tasks that must be completed to complete the main function or task.

The parts of AGV are separated into four basic components.

Base: The base of AGV is made of basically three parts- four wheels, one power switch, and two motors. The 3 axial wheels are used for 360-degree angle rotation. The front-side wheels can move along with rotary motion and the back-side wheels can give axial motion. A power switch is used for supplying power from the battery to the motor to the wheels. Here the DC motor is used as the torque can be maintained according to the customer's need.

Main Body or Chassis: Stainless steel rollers are used on the surface for thoroughly lifting the materials on the vehicle. Rubber coating has been used on the surface of the rollers for better grabbing of materials. The whole body is made with stainless steel sheet metal for reducing cost. Speaker is used beside the sonar sensor to give a sound signal in response to detecting obstacles. An LCD is used to measure how much weight it carries.

Operating System: Operating system assembles the input and logical parts. The operating system is made of two components- A microcontroller and sensors. An Arduino-based microcontroller is used here. Three types of sensors are used for different purposes-

Line follower: Used to follow a definite path drawn from the materials receiving zone to the delivery zone.

Sonar: Used to identify obstacles (human or object) in front of it.

Weight measurement: A definite range of weight it can take which can be measured by this sensor.

Driven Unit: Total unit which is giving motion to the vehicle. The motor will rotate the shafts via the motor driver, the shaft will transfer rotary motion to the bearing and wheel which is illustrated in figure-3.

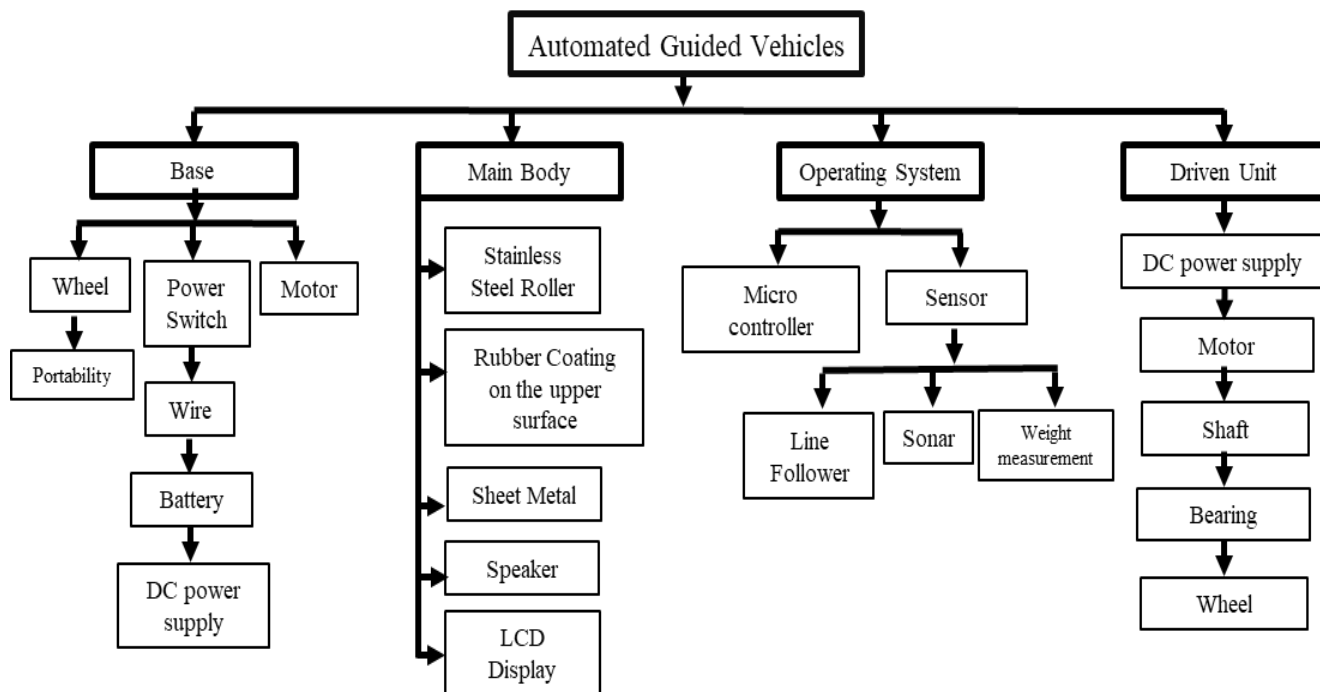


Figure 3. Decomposing Functions for Automated Guided Vehicles

4.3 Black Box

Black box is a model that receives input and produces output without revealing any information about its internal workings. The black box of AGV is given below where we can see that AGV receives energy and different information to produce results accordingly.

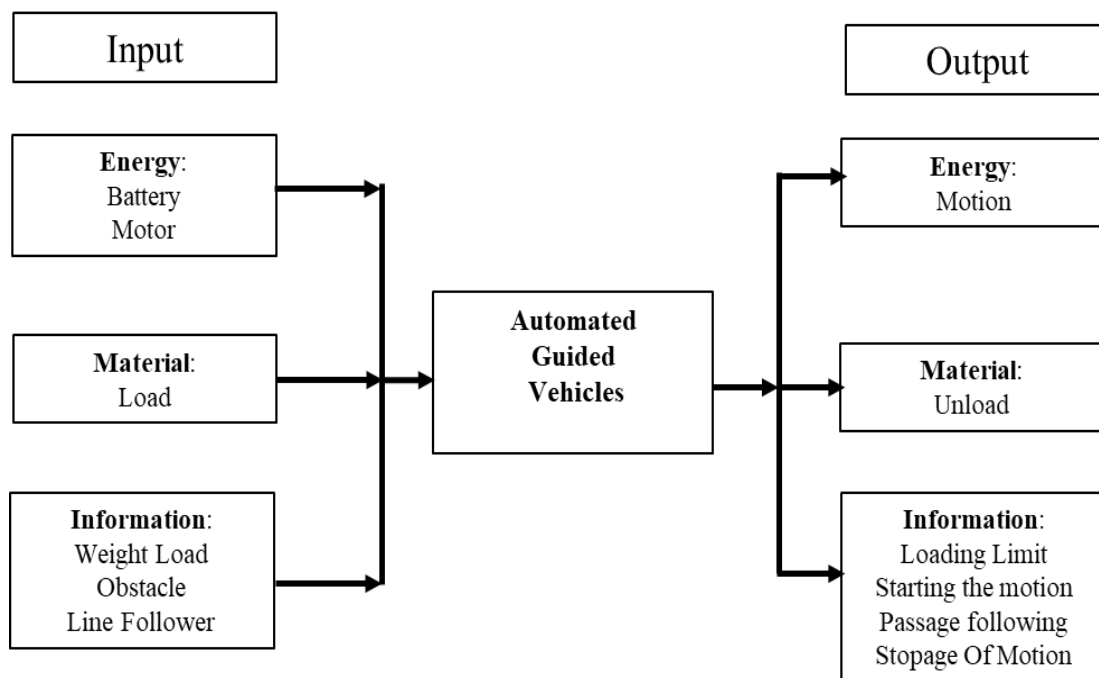


Figure 4. Black Box for automated guided vehicles

The input can be defined as three things– Energy, materials, and information. Energy will come basically from the battery to the motor and then to the wheels and LCD panel. The input material is load. The input information

that the sensors will receive is that weight range, obstacle detection, and line sensing. Output energy can be received in motion (linear or rotary), and material unloading and the output information can be gained are- if AGV is following the path properly, if the AGV can respond to obstacles and if the AGV can show loading limit.

4.4 Cluster Diagram

A Cluster diagram helps organize the idea-generating process through information organization. The cluster diagram of AGV shows the overview of the flow of energy and signal through the whole system till converting to the final output. The overall input of our AGV is two things- Electrical signal and electrical energy. Electrical energy will come from the battery and be transmitted through the motor and wheel, giving kinetic energy. The electrical signal coming from the sonar IR sensor, weight measurement sensor, and line follower sensor will be transmitted into the microcontroller. Line follower sensors will control the movement resulting in kinetic energy. Weight measurement sensor will show weight range via LCD panel resulting in optical energy. Sonar IR sensors will detect obstacles and give sound signals. This will result in sound energy. The other abstract input is material that will be transferred to the right destination via our AGV. The whole process is illustrated in figure 5

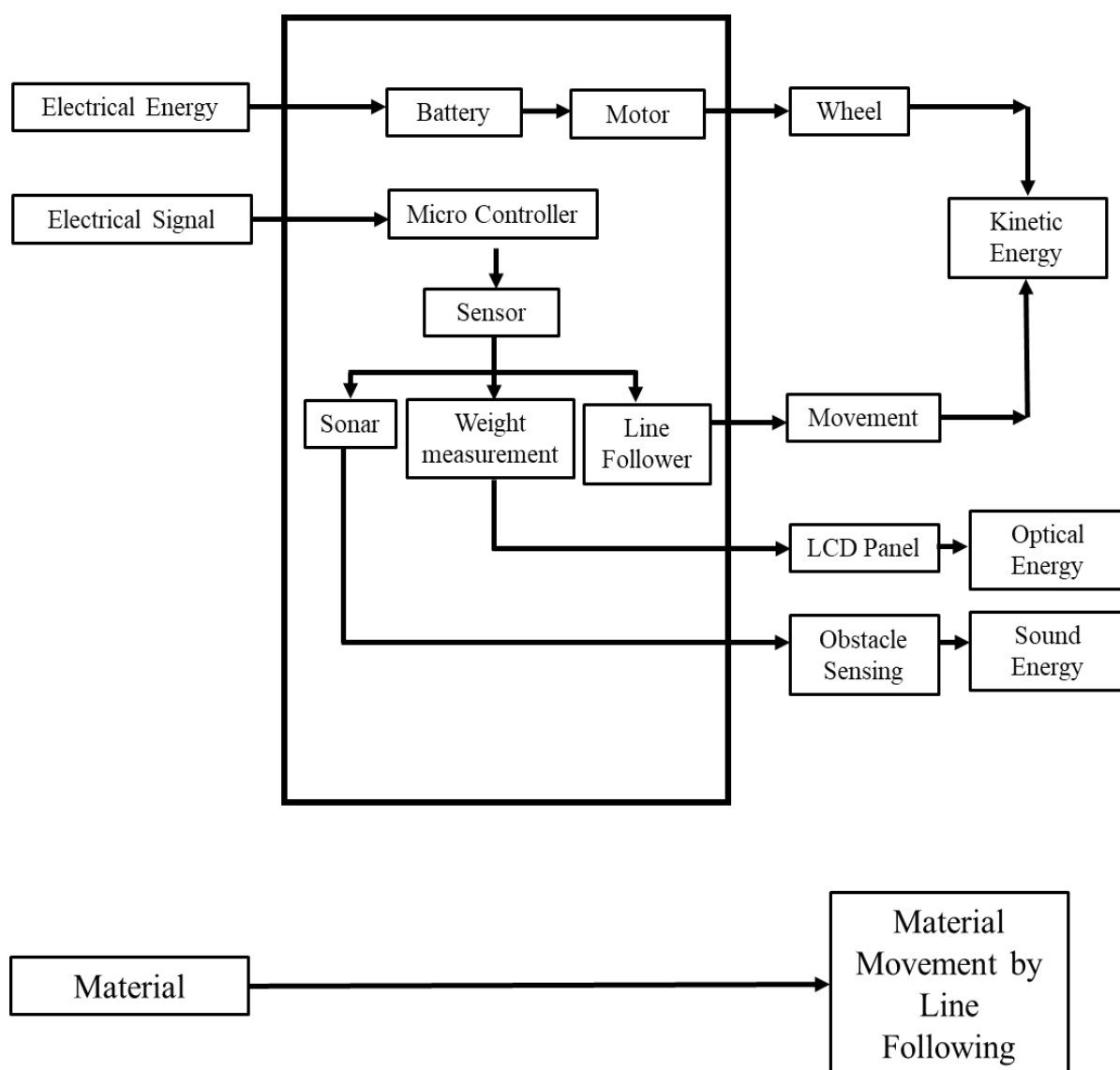


Figure 5. Cluster Diagram for automated guided vehicles

4.5 Material Selection

4.5.1 Wheel

Based on the comparison of the characteristics, the following Table 1 shows their relative importance. According to the table, the "load-bearing" capability of the AGV is the most impactful, because the main objective of the project is to efficiently transport products. Several other important criteria are also compared with each other, and a relative importance coefficient is calculated.

Table 1. Determination of Relative Importance of Goals Using Digital Logic Method

Selection Criteria (Goals)	The number of positive decisions: $5(5-1)/2=10$										Positive Decisions	Relative emphasis coefficient α
	1	2	3	4	5	6	7	8	9	10		
High speed	0	0	1	1							2	0.2
Maintaining grip	1				0	0	1				2	0.2
Load-bearing		1			1			1	1		4	0.4
Force absorption			0			1		0		0	1	0.1
Surface protection				0			0		0	1	1	0.1
The total number of possible decisions (N) = 10											$\sum \alpha = 1$	

The following Table 2. consists of some numbers (1-5) to rank the importance of the mentioned criteria. The highest important one will be rated as 5 and the lowest one will be rated as 1.

Table 2. Numerical Value (Rating)

Very High	5
High	4
Medium	3
Low	2
Very Low	1

The following Table 3 lists the major selection criteria. By using the previous ranking system from table 2, they are compared in the context of polyurethane caster and cast-iron caster

Table 3. Preferred material's properties and selection criteria of the product.

Selection Criteria	Polyurethane Caster	Cast Iron Caster
High speed	4	3
Maintaining grip	5	3
Load-bearing	3	5
Force absorption	3	5
Surface protection	5	3

The Material Performance index has been calculated based on scaled properties and weighted properties. This was done with the help of a weighted factor. For example, the weighted factor of high-speed criteria is 0.2 taken from table 1. Table 3 shows that polyurethane caster has a rating of 4 and cast iron caster has a rating of 3 in high-speed criteria. So, the scaled property for polyurethane caster is taken 100 and the weighted property is 100 multiplied by 0.2 equals 20. On the other hand, the scaled property for cast iron caster is 100 multiplied by three-fourths ($\frac{3}{4}$) equaling 75 and the weighted property is 75 multiplied by 0.2 equaling 15.

Results: Cast iron caster and polyurethane caster have material performance indexes of 83 and 80, respectively. With a value of 83, cast iron caster is the most effective material component for wheels

Table 4. Calculation of the Material Performance Index

Table 5: election Criteria	Weighted Factor, α	Polyurethane Caster		Cast Iron Caster	
		Scaled Property, β	Weighted property, $\alpha\beta$	Scaled Property, β	Weighted property, $\alpha\beta$
High speed	0.2	1005	20	75	15
Maintaining grip	0.2	100	20	60	12
Load-bearing	0.4	60	24	100	40
Force absorption	0.1	60	6	100	10
Surface protection	0.1	100	10	60	6
Material Performance Index, $\Upsilon = \sum \alpha\beta$			80		83

4.5.2 Chassis

Based on the comparison of the characteristics, the following Table 5 shows their relative importance. According to the table, the "safety" capability of the AGV is the most impactful, because an important objective of the project is to safely transport products. Several other important criteria are also compared with each other, and a relative importance coefficient is calculated.

Table 5. Determination of Relative Importance of Goals Using Digital Logic Method

Selection Criteria (Goals)	The number of positive decisions: $4(4-1)/2=6$						Positive Decisions	Relative emphasis co-efficient α
	1	2	3	4	5	6		
Lightweight	0	0	1				1	0.167
Economic	1			0	0		1	0.167
Safety		1		1		1	3	0.5
Recyclability			0		1	0	1	0.167
The total number of possible decisions (N) = 6								$\sum\alpha=1$

The following Table 6 consists of some numbers (1-5) to rank the importance of the mentioned criteria. The highest important one will be rated as 5 and the lowest one will be rated as 1.

Table 6. Numerical Value (Rating)

Very High	5
High	4
Medium	3
Low	2
Very Low	1

The following Table 7 lists the major selection criteria. By using the previous ranking system from table 2, they are compared in the context of steel and aluminum.

Table 7. Preferred material's properties and selection criteria of the product.

Selection Criteria	Steel	Aluminum
Lightweight	2	4
Economic	4	2
Safety	4	3
Recyclability	4	3

The Material Performance index has been calculated based on scaled properties and weighted properties. This was done with the help of a weighted factor. For example, the weighted factor of lightweight criteria is 0.167

taken from table 5. Table 7 shows that steel has a rating of 2 and aluminum has a rating of 4 in lightweight criteria. So, the scaled property for aluminum is taken 100 and the weighted property is 100 multiplied by 0.167 equals 16.7. On the other hand, the scaled property for steel is 100 multiplied by two-fourths (2/4) equaling 50 and the weighted property is 50 multiplied by 0.167 equaling 8.35.

Results: Steel and aluminum have material performance indexes of 91.75 and 75.075, respectively. With a value of 91.75, steel is the most effective material component for chassis.

Table 8. Calculation of the Material Performance Index

Selection Criteria	Weighted Factor, α	Steel		Aluminum	
		Scaled Property, β	Weighted property, $\alpha\beta$	Scaled Property, β	Weighted property, $\alpha\beta$
Lightweight	0.167	50	8.35	100	16.7
Economic	0.167	100	16.7	50	8.35
Safety	0.5	100	50	75	37.5
Recyclability	0.167	100	16.7	75	12.525
Material Performance Index, $\Upsilon = \sum \alpha\beta$			91.75		75.075

5 Design Guidelines

It is important to consider how to avoid AGV collisions and deadlocks while creating and controlling AGV systems. Physical collisions can be prevented by fitting AGVs with sensors. AGVs ought to be able to avoid obstructions and return to their original paths without running into anything. Locations for pick-up and delivery terminals must be chosen while designing the AGV system's configuration. The AGV system must be constructed with the fewest number of vehicles possible since having too many vehicles in the loop increases complexity. Above all, it is important to design the flow path layout carefully since AGVs can travel along fixed guide paths.

6 Result and Discussion

AGVs are not suitable for everyone, but they may be helpful instruments that boost productivity and profitability in many order fulfillment businesses.

The advantages and disadvantages of automated guided vehicle use must be assessed to decide whether they are appropriate for the business. Also, it must be considered whether they would help or hurt the operations. A different form of automation technology could be better suited to handle the company's demands depending on the particulars of its operation. Consequently, it might be a good idea to speak with a warehouse design consultant before implementing AGVs.

Once a product is loaded into an AGV, it offers superior accountability, which reduces lost products. An AGV automated guided vehicle system's costs may be very predictable and its course adjusted as production and handling demands vary, unlike labor costs, which tend to rise and fluctuate fast based on a variety of factors. Automated Guided Vehicles (AGVs) can be added to increase capacity and efficiency in any assembly, manufacturing, or warehousing operation. Because of their accuracy, AGVs improve scheduling capabilities and operational efficiency. They also have smooth acceleration and deceleration, handle products delicately, reduce product damage, and perform repetitive movement tasks reliably.

7 Cost Estimation and Breakeven analysis

A breakeven analysis is done to find out after how many sales the company will have profit.

Table 6. Production of automated guided vehicles cost estimate.

Variable cost	\$205.00 per unit
Fixed cost	\$79500.00
Expected sales	350 units
Price	\$650.00 per unit
Total revenue	\$2275000.00
Total variable cost	\$71750.00
profit	\$76250.00

After conducting numerous surveys among the sectors that have been utilizing AGV, we have come to the conclusion that the variable cost and fixed cost can be reduced to \$205 and \$79500, respectively. If we sell them for \$650.00 per unit and sell 350 units, we can make \$227500 in profit.

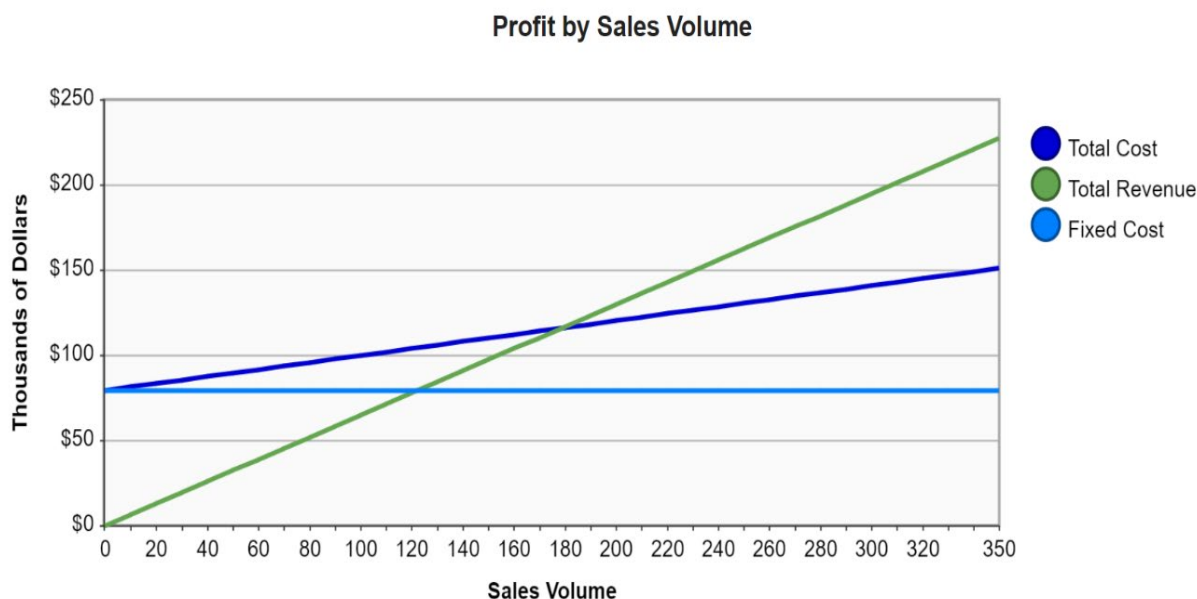


Figure 6. the analysis of the automated guided vehicles production breakeven point.

Figure 6 shows total costs, total receipts, fixed costs & sales volume. After selling 179 units, we have reached the breakeven point from here.

8 Conclusion

The aim of this paper is to provide readers with a detailed overview of manufacturing AGVs considering the point of view of customers or users. We divided the overall AGV control into many fundamental tasks and examined the available approaches for each of those tasks. With the expanding use of many AGVs in new fields of application, studies on AGV systems are entering a new era. AGVs are now employed in the distribution, transshipment, and (external) transport sectors for repetitive transportation activities. Although AGVs have significant up-front costs, their efficiency benefits can lead to a sizable return on investment, frequently in as little as one or two years. An effective approach to future-proofing a business is to switch to automated guided vehicles, which may increase capacity, raise productivity, and enhance site safety all at once. As a result, the market for automated guided vehicles is expected to grow rapidly.

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Biographies

Asif Iqbal is currently pursuing his BSc in Textile Engineering (specializing in Industrial and Production Engineering) from the Bangladesh University of Textiles. He is a certified NLP (Neuro-Linguistic Programming) practitioner and one of the first internationally acclaimed values-based leadership facilitators from Bangladesh. Being an undergraduate student, his research interests include the area of data analysis, operations management and research, project management, ergonomics and safety management. He is actively involved with the activities of different professional organizations like CKH Network, Sensei-Wisdom, Jump Movement, The John Maxwell Team, etc.

Saib Khan Sami at the Bangladesh University of Textiles is presently pursuing a Bachelor of Science in Industrial and Production Engineering (IPE) (BUTEX). IoT, IIoT, Data Analysis, Process Improvement, and Quality management are some of his current areas of research interest. He had gone to seminars on IoT implementation in the textile sector. Additionally, he completed an Udemy online course on "Ultimate Digital Transformation & Industry 4.0." Software for 3D modeling, such as Solidworks and Ansys Discovery, interest him.

HomayraAnjumi Hoque is a student of the Department of Industrial and Production Engineering at Bangladesh University of Textiles. She has done her HSC in 2018. Her area of interest is operation research, automation, ergonomics, Industrial usage of IoT, supply chain management, industrial safety and rescue management. She is doing a research work on implementing automation in industry. She has expertise in mechanical designing (solidworks, grabcad, AutoCAD), engineering graphics, manufacturing processes etc. She is actively involved with some organizations working on both textile technology and industrial engineering.

Md. Abu Saleh Shafil is currently pursuing his BSC in Textile Engineering (specializing in Industrial and Production Engineering) from the Bangladesh University of Textiles. Being an undergraduate student, his research interests include the area of Autocad Analysis, Solidworks, Supply Chain management, Robotics, Data science and technology and Machine learning. He is vastly involved with some co- curricular activities like Business and communicative English, Autocad designing both in 2D and 3D view including building designing also.

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