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Suitability of Different Navigation Technologies of AGV for Specific Implementations in Logistics

Diploma Thesis

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Content areas:

1. Conduct a literature research in the field of logistics, automated guided vehicles and their navigation technologies.
2. Analyse existing implementations of AGVs in logistics and create set of best practices.
3. Evaluate and compare different navigation technologies of AGVs in relation to various specific implementations in logistics.

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Recommended literature:

1. BAKER, P. – CROUCHER, P. – RUSHTON, A. *The Handbook of Logistics & Distribution Management.* Velká Británie: Kogan Page Ltd, 2017. 912 p. ISBN 978-0-7494-7677-9.
2. *The concept industry 4.0: an empirical analysis of technologies and applications in production logistics*. Springer Gabler, 2017. 150 p. BestMasters. ISBN 978-3-658-16501-7.
3. GÜNTER, U. – ALBRECHT, T. *Automated Guided Vehicle Systems.* Wiesbaden: Springer, 2022. 300 p.

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Contents

Introduction

The aim of the work is to analyze the current state of the art in the field of navigation technologies of AGVs, analyze existing implementations of AGVs in logistics and to present classification and recommendation for selection of different navigation technologies for specific logistics use cases. The work also analyze existing implementations of AGVs in logistics and create a set of best practices. We will also evaluate and compare different navigation technologies of AGVs in relation to various specific implementations in logistics.

The relevance of the topic of the dissertation is because logistics plays a leading role in the world economy. A digital revolution is taking place in logistics, the speed of which is increasing due to the COVID-19 pandemic that has arisen in the world.

The thesis is divided into two main parts. One is a theoretical review and the other is practical. In the first chapter of the theoretical part, logistics concepts and related knowledge, including the latest digitalization trends and advanced technology applications in the field are introduced. In the following chapter, AGVs and the different types of AGVs are introduced. Different kinds of navigation technologies of AGVs, from the original type of application to the most advanced version and technologies knowledge are covered.

Next, the third chapter is about different examples in logistics fields where the AGV is implemented and the chapter is going to analyze, evaluate different navigation utilization in the company to provide the reader with basic understanding.

Last but not the least, the fourth chapter aims to create a basic solution model by applying decision tree method to provide general steps and guidance for the readers to choose suitable navigation methods based on the individual needs and conditions.

1 Logistics

Logistics is a part of the chain that plans, implements, and manages forward and return products and materials and information to meet the customer’s requirements (Gros et al., 2016). The chapter introduces the current logistics situation around the world and the future development and combination of Intelligence technology with logistics.

1.1 Logistics (From Current Situation to Futural Development)

Today, peace comes in a crisis. Practically all spheres of life are in a difficult position and suffer huge financial losses, logistics is no exception. Countries have closed their borders to each other, exporters and importers are in a very tense situation.

For the first time, the coronavirus (COVID-19) was discovered at the end of 2019 in China. An outbreak of disease in the city of Wuhan forced many foreign guests to leave the country urgently, soon the city was closed for quarantine, after which China was completely isolated from all countries (Illah et al., 2021). This problem resulted in the delay of production of many factories and organizations, as deliveries from China were suspended. The heads of the organizations had to make decisions to replace suppliers of raw materials and components, and some of them went bankrupt due to growing expenses. Few could boast of changing the direction of production to medical needs, which is very important to this day. This led to problems of a global scale, which include difficulties with the transportation of goods, interruptions in supplies, huge debts of organizations, downtime of transport and problems with customs clearance. The listed global problems are united by one main one - this is the economic crisis. It will take a lot of time to get out of it, and many organizations will never be able to work as before, since some of them will simply cease to exist.

The role of logistics in the world is difficult to overestimate. Considering the modern world, there is such a trend as the development of logistics systems, it directly relates to the management of supply chains. International trade is directly related to logistics systems (Illah et al., 2021).

Technological innovation is playing an increasingly important role in all sectors of the economy, and logistics and supply chain management also cannot stay away from this process. And since in the field of logistics large amounts of data are actively used, which are stored separately and in different programs, and are very often entered manually, it is perhaps logistics that benefits more from the introduction of new innovative ways of working (Illah et al., 2021).

Innovations in the logistics sector are associated not only with the desire of logistics companies to introduce new technologies in order to keep up with the development of the industry – to a large extent this is required by the clients of logisticians – representatives of the trading business and large industrial enterprises, who require that their goods or services come to the customer more quickly and at lower costs (Habl et al., 2017).

1.2 Real-time Supply Chain Management

The real-time supply chain has ceased to be a "technological highlight" or "curiosity" in logistics. In 2019, many companies began to implement it, and in the future, it will become necessary almost everywhere. Real-time data is becoming increasingly in demand among customers, and this means that businesses in the logistics industry will need to focus on it. Currently, many startups have emerged whose solutions provide transparency in the supply chain, provide technology that facilitates rapid response to changes, allowing companies to use real-time data. Such data includes transport movement patterns, weather conditions in a particular area, the condition of roads or access roads to ports, which allows you to optimize delivery routes (Ullrich, 2015). In 2019, studies were conducted that showed that logistics companies using fully integrated supply chains are 20% more efficient than their competitors. It is unlikely to consider the current supply chain management without mentioning the Internet of Things (IoT) technology, which is the most important asset for tracking supplies (Hoa et al., 2022). IoT device connections at different sites allow workers to track the movement of equipment, vehicles, and goods through cloud services. At the same time, IoT-based container management is also simplified through real-time monitoring, improved fuel efficiency, preventative maintenance, and enhanced container operations. Due to this, another trend is likely to be closer collaboration between IoT startups and logistics companies (Corsi et al., 2006).

1.3 The Growing Importance of New Models in the Market of Logistics

It should be noted that the future of logistics is formed not only by new technologies. The equally important role of new business models and new players in the industry. Often, startups create new systems that include elements of the sharing economy, which are quickly gaining popularity. Without much experience with logistics assets, startups tend to focus on the "light" parts of the supply chain, turning, for example, into digital freight forwarders. Thanks to more flexible operations, they can offer more attractive prices, while ensuring transparency of the logistics process. This also applies to Uber, which launched its Uber Freight feature in the United States in 2017 and expanded to Europe and Canada last year, aiming for a more efficient global trucking market. Even the industry's own customers see potential in freight forwarding: Amazon plans to expand its own warehousing and transportation expertise to develop its own delivery capabilities. The company has already made great strides thanks to the development of Prime Air, an unmanned aerial vehicle service it is building to build all-electric drones capable of flying up to 15 miles and delivering packages weighing less than five pounds to customers in less than 30 minutes (Lou, 2018).

In addition, the company announced the Amazon Flex platform, which uses on-demand contract drivers to accelerate the expansion of its Prime One Day delivery program. Amazon also announced its new robotic products heading to hundreds of service centers around the world. One such product is the Pegasus sorting system, which to date has covered two million miles and has already reduced the number of incorrectly sorted goods by 50%, while maintaining the safety features of the existing drive system. In addition, the e-commerce giant is testing Amazon Scout, which is designed to securely deliver parcels to customers who use small autonomous delivery vehicles. In 2020, Amazon CEO Jeff Bezos said the company had invested $700 million in Rivian, an electric vehicle startup that could make it possible to produce 100 thousand electric vans to deliver Amazon goods. Another great example of the company's impact on the industry is Flexport, a dedicated cloud-based freight forwarding software and data analytics platform. Amazon plans to launch an operating system for global trade that incorporates a strategic operating model for global freight forwarding and combines the best of all supply chain technologies. With so many future technological advances being developed, it becomes clear that this is one of the trends in logistics technologies that need to be monitored (Lou, 2018).

1.4 Robotization of Warehouse Operations

It is obvious that warehouse operations have undergone significant changes in recent years – and with the gradual integration of technology – this is one of the trends in logistics technology that is likely to continue. One of the obvious innovations is warehouse robotics, which is developing rapidly. According to a global report, testing of robotics in stock increased significantly annually. The Boston Dynamics mobile robot called Handle is one of the clearest examples: the company has developed a fully autonomous compact device that can access any hard-to-reach places, and at the same time has an extended viewing area. Thanks to this, the robot can quickly unload trucks, fold pallets, and move boxes throughout the warehouse. Technologies such as driverless vehicles or multifunctional work can also increase the efficiency and speed of warehouse processes. For example, GreyOrange and Locus Robotics are already using robots that move independently around the warehouse. Thanks to machine learning technologies and sensors that provide the utmost accuracy and ease of tracking, many autonomous robots will appear in modern warehouses in the future (Mikušova et al., 2017).

1.5 Artificial Intelligence

Over the past few years, the logistics industry has begun to integrate artificial intelligence (AI) solutions into its operations, including intelligent transportation, route planning and demand planning, and this is just the beginning. Shippers, carriers, suppliers and consumers can be expected to benefit from these logistics technology development trends that continue into 2020. Along with artificial intelligence, augmented reality and advanced intelligence will certainly be used no less actively. Advanced intelligence combines human intelligence with automated artificial intelligence processes. For example, in planning logistics, the use of advanced intelligence may even surpass the use of artificial intelligence only, since it combines the capabilities of people (experience, responsibility, customer service, flexibility, common sense, etc.). According to Gartner experts, advanced intelligence will create $ 2,9 trillion in business value and lead to a 6,2 billion hours increase in labor productivity globally by 2021. Logistics companies can be expected to implement more intelligence-enhancing solutions that will eventually allow logistics professionals to do their jobs faster, reducing mistakes and saving money (Woschank et al., 2020).

1.6 Digital Twins

Digital twins (digital copies of a physical object or process) are arguably one of the most exciting trends in logistics technology to follow in the future (Kannan et al., 2018). Many logisticians know that products will never be the same as their computer models.

Modeling in its current state does not consider how parts wear out and replace, how owners make changes according to their needs. However, the technology of digital twins' changes this once and for all: now the physical and digital worlds can be combined into one, allowing us to interact for the first time with a digital model of a physical object or part in the same way as with their physical counterparts (Lou, 2018). The potential for using digital twins in logistics is enormous. In the transportation sector, digital twins can be used to collect product and packaging data and use this information to identify potential shortcomings and recurring trends to improve future operations. Warehouses and businesses can also use this technology to create accurate 3D models of their centers and experiment with layout changes or the introduction of new equipment to see their impact. In addition, logistics centers can create digital twins and use them to test different scenarios and increase efficiency. In addition to this, delivery networks could use this technology to provide real-time information that would improve delivery times and further assist autonomous vehicles on their routes (Batty, 2018).
The digital revolution today, just like its predecessors – agrarian and industrial – is changing a huge number of aspects of modern life. The new transformative era of total digitalization, i.e., the use of digital technologies to change the business model and provide opportunities for the growth of added value, requires the use of new work methods and analysis tools (Hoa et al., 2022). Artificial intelligence, as a field of computer science that focuses on creating intelligent mechanisms that will work and react in the same way as a person, is increasingly going beyond purely laboratory research and penetrating almost all areas of human life. Artificial intelligence is created as a set of algorithms that can make complex decisions based on input data. For example, the company has its own source of information, from shipment data to video and audio content from the driverless car; in this case, artificial intelligence uses multi-component blocks in the decision-making process, processes huge volumes of both structured and unstructured data and offers the best option at the output (Hoa et al., 2022). As digitization is constantly gaining momentum in the professional world, more and more companies are starting to introduce artificial intelligence technologies into their supply chain to maximize profits by reducing financial resources and time needed to determine the optimal option for building their own business processes (Batty, 2018). The networked nature of logistics, both in the physical and digital dimensions, creates a natural basis for the implementation and scaling of artificial intelligence, which can multiply the human components in highly organized global supply chains. The

implementation of innovative technologies opens opportunities in the logistics industry for rethinking modern practice, transitioning actions from reactive to proactive, planning from forecasts to prediction, processes from managed to autonomous, services from standard to personalized (Lou, 2018).

The range of possible uses of artificial intelligence technologies expands practically every day with each new successful start-up, so let's consider the main areas of potential use, planning and forecasting (Kannan et al., 2018). The application of elements of artificial intelligence significantly increases the efficiency of the company in the field of predictive demand and/or network planning. By understanding what to expect, they can reduce the number of vehicles needed on a given route for transportation and direct them to locations where demand is only expected, which in turn will lead to significant reductions in operating costs (Lou, 2018). Technology uses data in its entirety to more accurately predict events, avoid risks, and create new solutions. For example, DHL analyzes 58 different internal data parameters to create a machine learning model for air transport. Unlike previous subjective estimates, the new method allows shippers to predict an increase or decrease in average daily transit time a week ahead. In addition, other factors that may affect shipment delays, such as climatic and operational variables, are identified. Such an approach is extremely valuable in the air transport industry, which accounts for only 1% of world trade in terms of tonnage, but 35% in terms of value. Robotics used to be perceived as a futuristic concept, but now it is becoming an integral part of supply chains. Thus, according to the report of the Tractica company, which specializes in human and technology interaction research, the supply of warehouse and logistics robots is forecast to grow over the next five years (Lou, 2018). It is noted that the growth rate will begin to decline in 2021, as key market players will fully adapt robotics to their chains by then. Global revenues in this area will grow. Big data has changed the traditional view of how information is generated and transmitted. First, the latter is perceived as structured data recorded in databases, analyzed in reports, and presented in familiar formats, for example, spreadsheets. Big data contains both structured and unstructured data (for example, social) of enormous variety and volume. Conclusions built on unstructured data analytics are impressive in their performance. For example, the company has incomplete shipment data. Artificial intelligence can process data in the system of all information, including past deliveries, and form accurate conclusions about a given batch. A similar algorithm requires the correctness of only 5-10% of the data to create a training one (Batty, 2018).

1.7 International Logistics

The following describes how goods from one continent get to another without organization of transportation. Nowadays, most of the carriers and operators organizing the entire transportation process are private companies that have no relation to America. But despite all the factors, America plays a huge role in this process, since it is impossible to solve a number of issues related to the organization of transportation without the intervention of state structures (Zhu et al., 2007).

The logistics development market is one of the most active in the world today. The average share of GDP in developed countries is approximately 13-14 %. It is possible to see that transport companies and transport logistics bring more profit to the US (Zong, 2013).

Logistics is the main connection and channel in international trade. Strictly speaking, logistics is a huge number of companies that undertake the transportation of goods from one point to another. Or it is organizations for the production of certain products that have their own logistics departments.For example, logistics plays an irreplaceable role in global corporations, known throughout the world for their products. Usually, the development of their product takes place in one country, the production is delivered in a second country, and the third country is responsible for bringing this product to the whole world. Such an example makes it clear that it is necessary to constantly manage the global supply chain for international business chains. The global supply chain in this case is included in various countries and elements of the process into a single whole, which can be constantly monitored in real time. Simply put, the pre-assembled part must be transported on time to the manufacturer, in turn, the manufacturer collects the product to the end and sends it to the consumer. Logistics covers the entire production process, starting with raw materials, from which parts for construction will be made, ending with finished products, and many businessmen treat logistics with misunderstanding, but not a single global production and not a single international business can do without logistics. It is impossible to organize production that does not require additional materials. (Lin, 2019)

1.8 Global Production

Global production means that the organization acquires and uses resources regardless of the country in which they are located. Such an approach allows companies to save financial resources on the supply of raw materials from another country, producing everything locally, or on the costs of exporting products, both of which show that production is best organized locally. But this does not apply to all organizations, there are also those who find profitable solutions for themselves in companies acting as suppliers for them. Each organization makes an analytical calculation that allows it to draw up a strategy that is best suited for its activities and saves the maximum number of financial resources (Zhao, 2020).

Usually, large international organizations have "back-up routes" in case something happens to the supplier, in such cases, they turn to the "backup plan" and work with it further. Such a solution is often available to many, but more often than not, the second supplier may offer a product that will not be ideal in terms of its characteristics or will not be profitable in terms of certain parameters. Therefore, companies try to work only with verified organizations and try to maintain good conditions in order not to incur losses. Logistics can suffer big setback, but from a global perspective, they are not fatal. During the pandemic, entire sectors switched to manufacturing medical equipment. This meant that not all factories closed due to the crisis, many suffered losses, but remain on the market, since their production is either vital, or they do not have stops in the supply of raw materials, which allows them to continue economically valuable the production (Zhao, 2020).

2 Automated Guided Vehicles (AGV)

The chapter starts with the development of AGV from first era to the current stage. Next, the chapter introduces AGV related information, such as common types of models, systems and motion controls, navigation methods and software, etc.

2.1 Development of AGV

According to the American Material Handling Association, the definition of Handling AGV is the abbreviation of Automated Guided Vehicle. AGV is a kind of unmanned automatic vehicle powered by rechargeable battery and automatically guided. It can walk accurately according to path planning and operation requirements under the monitoring of a computer. And stops at the designated place to complete a series of tasks such as picking up, delivering, charging, etc (Ullrich, 2015).

AGV is an important branch of mobile robots. AGVs for industrial applications are also known as autonomous unmanned vehicles. Its research focus is on the problems that may be faced in its application in industrial production, such as: the design of the combined structure of the AGV controller, the collision avoidance scheduling of the AGV running route based on high-speed wireless communication technology and electronic map, and the application of task scheduling, etc. In recent years, more and more attention has been paid to the research of AGV. This paper focuses on the discussion of mobile robot AGV for industrial application (Ullrich, 2015).

Application of AGV technology at home and abroad are numerous. It is used in the assembly of automobile chassis, which reflects the advantages of using unmanned trucks. But it was track-guided at the time (now called RGV). In the mid-1950s, the British first removed the guide track on the ground and used buried wires under the floor to form an AGVS guided by electromagnetic induction. In 1959, AGV was used in warehousing automation and enterprise production operations (Wang, 2019).

In the 1960s, computer technology began to be applied to the management and control system of AGV systems. AGV has developed rapidly, although AGV first appeared in the United States. It has rapidly developed and popularized in Europe and has become a popular material handling equipment in manufacturing and assembly operations (Wang, 2019). Since AGV has the advantages of high efficiency and flexibility, AGV system has been widely used in various industrial advanced countries. Sweden used AGVs for the first time in manufacturing and assembly operations in 1969. In 1973, Sweden VOLVO used many AGVs on the assembly line of the KALMAR car factory for automated assembly operations (ENGSTRÖM at al., 2018). By 1985, there were a total of 1250 AGVs in Sweden. Running in the AGV system; there are 360 AGV systems in Europe with a total of 3900 AGVs in operation, and the total number of AGVs produced in 1985 exceeded 10,000; in 1985, the United States had 2100 AGV systems, a total of 8199 AGVs, a total of more than 30 AGVs AGV manufacturer; Japan first introduced one AGV in 1963, and dozens of AGV systems have been added every year since 1976. At present, there are dozens of AGV systems produced by 27 major manufacturers such as Kobelco Electric, Hirata Electric, and Sumitomo Heavy Machinery. For different types of AGVs, sales reached 6 billion yen in 1981, increased to 15 billion yen in 1984, and rose to 20 billion yen in 1985. The average annual growth rate is 20% (Wang, 2019).

In China, the Beijing Institute of Hoisting and Transportation Machinery developed the first ADB-type AGV in 1976. Two AGVs, WZC and WZC-1, were researched and trial-produced by the Beijing Postal Science and Technology Research Institute of the Ministry of Posts and Telecommunications for the Shanghai New Railway Station Postal Hub and the Jinan Military Region Warehouse (Wang, 2019). They were put into operation in 1991. With the support of the national "863" plan, where Shenyang Automation of the Chinese Academy of Sciences is located, several basic research and application technology development projects for mobile robot applications have been completed. And developed a more mature AGV (electromagnetic guidance) and its system technology applied to practice (Wang, 2019).

First Era

The first period began with the invention of AGVs in America in 1953. A few years later, he appeared in Europe. Technologically, the first machines were marked by their simple systems with track guidance and tactile "sensors" such as bumpers and emergency stop handling with mechanical switches. The AGV now monitored the electrically conductive strip mounted on the floor. This principle is called induction track routing. The stations in which the cargo was to be transported were encoded by magnets embedded in the floor, which were detected by sensors in the vehicles. At that time, a simple guidance system consisted of vacuum tubes that had limited potential for development (Ullrich, 2015).

Second Era

The second period covered the 70s and 80s and ended in the early 90s. Electronics were introduced in the form of simple on-board computers, support for micro-technologies and huge control cabinets for controlling block sections. As a result of the development of micro technologies and the on-board computer, AGV technology has boomed. Shortly after the beginning of this era, China also became involved in the development of AGVs.

Third Era

The third period lasted from the mid-90s. years until about 2010, when the technological standards were set. The devices have electronic guidance and proximity sensors, as seen in Figure 1.2, which shows VW's automobile production in 1986. It is controlled by a standard PC and AGV contains a microprocessor. Classic navigation technologies are magnetic and laser navigation (See Fig .1).

Fig. 1 VW automobile production using AGVs in 1986

Source: GÜNTER, Ullrich: Automated Guided Vehicle Systems

Fourth Era

The fourth period is still ongoing, starting in 2010, and it is quite certain that it is not the last period. There are more and more companies in the world that offer AGV systems, which primarily have a more self-sufficient control system. The fourth period deals mainly with the topic of guidance autonomy (Bechtsis et al., 2017).

2.2 Types of AGV

The following briefly introduces three typical types of AGV. Each type of AGV has its specific application and suitable environment.

AGV Forklift

This is the most used type of AGV. Due to its ability to lift material, it has a wide range of usage, and it is usually used in transport areas and pallet space as well as other transport units. It can remove transport units from the floor to a certain level of height (See Fig .2).

Fig. 2 AGV Forklift

Source: Agvnetwork

AGV Unit Load

It is highly used top carriers. It is widely used and ideally suited for raw materials carrying and work-in-process, and end-of-line movement. In addition, it is also common for pallet and roll handling (See Fig .3).

Fig. 3 AGV Unit Load

Source: Agvrobotor

AGV Tugger

The Tugger AGV or AMR is a self-driving locomotive designed for trailers. Basically, it's a robotic tractor. Tugger robots can use different navigation methods:
Magnetic navigation (tape or dot) is widely used on tractors, especially low-cost tractors. Magnetic navigation is reliable and easy to install and modify but can be costly if the circuit is long. On the other hand, magnetic navigation is simple and not expensive to implement in an AGV, so vehicles with magnetic navigation are cheaper. LGV Navigation is a great solution for Tugger trains. The AGV chassis allows for tall masts where navigation sensors can be installed.
Laser navigation is not intrusive as it only requires some reflectors to be placed in the work area for position triangulation. If the circuit is long and/or complicated, then laser navigation is worth it. The cost of the vehicle will increase, but you will save on tape and installation time. Free or natural AGV navigation means no need for rigid infrastructure such as wires, tape or laser reflectors. The robot maps the environment and uses that environment as a reference to navigate (See Fig. 4).

Fig. 4 AGV Tugger
Source: Agvrobotor

2.3 AGV System

Several key technologies of AGV in China and abroad are well developed. The AGV system mainly includes: AGV ground management system, AGV vehicle-mounted control system, AGV autonomous positioning and guidance system, AGV motion control drive system, AGV energy system, AGV wireless communication system, etc. The following introduces the domestic and foreign development status of related technologies of each subsystem (Li et al., 2018).

The main functions of the AGV management and monitoring system are management and monitoring and schedule AGV to perform handling tasks. On the one hand, the AGV management and monitoring computer communicates with the host of the upper-level information management system (SAP/ERP/WMS/MES, etc.) to generate, send and feedback handling tasks, and on the other hand, communicates with the AGV through the wireless network system. Send material handling tasks according to certain rules, and carry out intelligent traffic management, automatically schedule the corresponding AGV to complete the material handling task, and at the same time accept the status information fed back by the AGV, monitor the task execution of the system, and report the task to the upper-level information management system host implementation (Ullrich, 2015).

The AGV management and monitoring system is a complex software and hardware system. At present, the middle and high-end AGV systems at home and abroad all have AGV management and monitoring systems. The hardware consists of servers, management and monitoring computers, network communication systems and related interfaces. The software consists of related databases. Management system, management monitoring and scheduling software, etc.

2.4 AGV Software

AGV management monitoring and scheduling software is an important core of the AGV system. The maturity of system software restricts the development and promotion of AGV, and the non-opening of foreign software technology also restricts the development and promotion of domestic AGV (Hou, 2017). In recent years, the research and development of management monitoring and dispatching software has received attention. Domestic AGV manufacturers have established their own AGV management monitoring and dispatching software system research and development platforms and developed their own AGV management monitoring and dispatching software products.

2.5 AGV Vehicle Controller

AGV vehicle controller The AGV vehicle controller is the core of the AGV control system. Responsible for human-computer interaction, path planning, task execution, positioning and navigation control, power management, autonomous obstacle avoidance, safety information prompts, and communication with the AGV management and monitoring computer, feedback the status of the AGV, and accept the AGV management and monitoring system. Tasks such as scheduling and work orders. The performance and reliability of AGV on-board controllers directly affect the performance and reliability of AGV products. The early AGV vehicle controller hardware usually uses industrial computer or general-purpose PLC as the main control unit, through more complex control software and various A/D, D/A interfaces to complete human-computer interaction, path setting, task scheduling, positioning and Navigation control, motion control, power management, autonomous obstacle avoidance, safety information prompt, communication with the management and monitoring computer, feedback of the current state of the AGV, acceptance of scheduling and work orders and other tasks (Li et al., 2018).

In recent years, with the rapid development of computer technology, the software and hardware levels of embedded computers have been greatly improved, which can already meet the various needs of AGV products. In addition, compared with industrial computers, embedded computer systems have obvious advantages such as compact structure, low cost, and low power consumption, which are especially important for AGV products that must use their own power supply. Therefore, the use of embedded computer systems for AGV vehicle controller hardware will be the future technology development trend (Li et al., 2018).

AGV Autonomous Positioning and Navigation System Although there are many types of AGV navigation methods, currently

The AGV guidance methods that are applied or have application prospects mainly include the following types:

2.6 AGV Navigation

The subchapter covers different types of navigation methods and introduces from the basic guidance to the advanced intelligent utility.

2.6.1 Electromagnetic Induction Guidance

The basic working principle of this guidance method is as follows: bury a metal wire on the driving path of the AGV and load a low-frequency and low-voltage current to generate a magnetic field around the wire. The induction coil on the AGV can identify and track the strength of the navigation magnetic field. Guidance of AGV. At present, electromagnetic induction guidance technology is relatively mature and widely used.

The main advantages of this navigation method are that the lead wire is hidden, not easy to be polluted and damaged, the navigation principle is simple and reliable, no sound and light interference, and the manufacturing cost is low; while the main disadvantage is that the flexibility of the path change is poor, the adjustment is troublesome, and the induction coil has no effect on the surrounding Ferromagnetic
It is sensitive to quality. For some simple routes that require 24-hour continuous operation (such as engine and other assembly production lines), there are still many applications in foreign countries that cooperate with non-contact power supply systems (Ullrich, 2015) (See Fig .5) (See Fig .6)**.**

Fig. 5 Electromagnetic induction guidance

Source: (Ullrich, 2015)

Fig. 6 Electromagnetic induction guidance

Source: Agvnetwork

2.6.2 Tape, Magnetic Point Guide

The basic working principle of this guidance method is as follows: paste tapes or magnetic points on the travel path of the AGV and realize guidance through magnetic induction signals. At present, tape and magnetic point guidance technologies are mature and widely used.

The main advantage of this guidance method is that it is easier to change or expand the path, and the installation of tapes and magnetic points is simple; while the main disadvantage is that it is easily disturbed by metal substances around the AGV's walking path. In addition, because the tape is exposed, it is vulnerable to mechanical damage and pollution, and the stability of navigation is greatly affected by the environment. Therefore, in recent years, such AGVs mostly use the magnetic point method (Ullrich, 2015). (See Fig. 7)

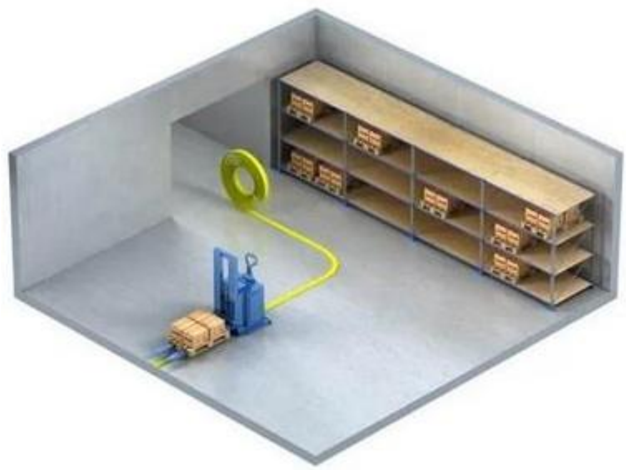

Fig. 7 Magnetic tape navigation

Source: ŠKODA AUTO a.s. Internal documentation

Magnetic markers work on the same principle as magnetic tape. The difference is only in the fact that individual marks are installed under the floor. (See Fig. 8)

Fig. 8 Navigation using magnetic markers

Source: ŠKODA AUTO a.s. Internal documentation

2.6.3 Optical Guidance

The basic working principle of this guidance method is as follows: paint or stick a ribbon on the travel path of the AGV and realize guidance by recognizing the ribbon image signal collected by the optical sensor. In addition, replacing ordinary optical sensors with CCD cameras and image processing systems can effectively improve the reliability of the guidance system. At present, the optical guidance technology is mature and widely used.

This guiding method is like the tape guiding method. Its main advantages are that it is more flexible, and the ground route setting is very simple; while the main disadvantage is that it is easily affected by the contamination and wear of the ribbon and has higher environmental requirements. Reliability is subject to ground conditions, and the parking accuracy is relatively low. (Ullrich, 2015) (See Fig. 9)

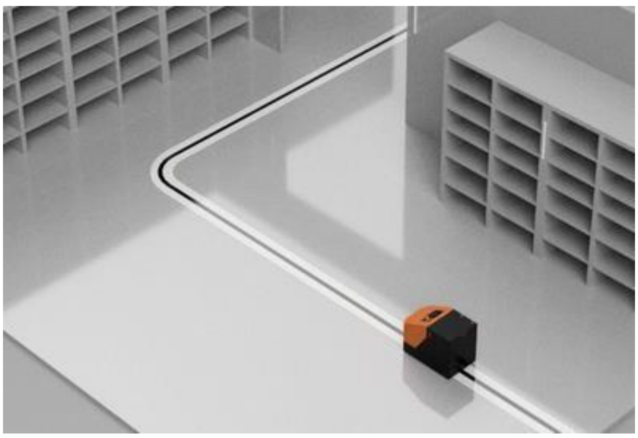

Fig. 9 Optical navigation

Source: ŠKODA AUTO a.s. Internal documentation

2.6.4 Inertial Guidance

The basic working principle of the inertial guidance method is to install a gyroscope on the AGV and install a positioning block on the ground in the driving area, and the AGV determines its own position and direction by calculating the gyroscope deviation signal and collecting the signal of the ground positioning block to realize the automatic guidance of AGV.

Inertial guidance technology is an emerging guidance technology in the AGV field. Its main advantages are advanced technology, high positioning accuracy and strong flexibility. With the development of inertial sensitive components and the reduction of cost, inertial guidance technology will also become the most promising AGV guidance technology (Ullrich, 2015).

2.6.5 Laser Guidance

The basic working principle of this guiding method is as follows: a laser reflector with a precise position is installed around the AGV's travel path, and the laser positioning device installed on the AGV emits a laser beam and collects the signals reflected by the reflectors at different angles. Geometric operations are used to determine its current position and orientation to achieve AGV guidance. At present, the laser guidance technology is relatively mature and widely used.

The main advantages of this guidance method are accurate positioning, can adapt to complex path conditions and working environment, and can quickly change the travel path and modify operating parameters; the main disadvantage is the high cost of the laser positioning device (Demuth, 2013) (See Fig.10).

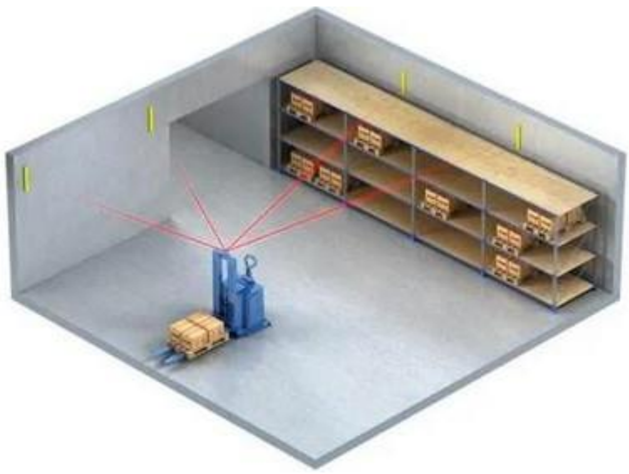

Fig. 10 Laser navigation

Source: ŠKODA Internal documentation

2.6.6 Visual Guidance

The basic working principle of this guidance method is as follows: a CCD camera is installed on the AGV, the AGV collects image information through the visual sensor during the driving process and determines the current position of the AGV (identifies a given road sign) by processing the image information.

The visual guidance method has flexible route setting and scope of application.

The advantages of wide range and low cost are also the future development direction of the AGV guidance method. However, since the technical bottleneck of realizing road sign recognition quickly and accurately by the vehicle-mounted vision system has not been broken through, the method has not yet entered the practical stage. The technology will become the most promising AGV guidance technology (Ullrich, 2015).

2.7 Motion Control System

AGV motion control system as a branch of mobile robot, AGV is driven by It mainly includes four modes: single steering wheel drive, differential drive, dual steering wheel drive, and multi-steering wheel drive: multi-steering wheel drive is generally used for heavy-duty AGVs with a load of more than 10T. Single steering wheel drive, differential drive and dual steering wheel drive are usually used for AGVs with a load of less than 10 tons (Walenta et al., 2017). Single steering wheel drive is used for three-wheeled models: one steering wheel, two fixed driven wheels (distributed on both sides of the body axis). The advantage of this structure is that it is widely used and does not require a high ground surface, while the disadvantage is that the structure is relatively complex, and the stability is poor when turning (especially when making high-speed turns). Differential drive for three-wheel or four-wheel models: two fixed driving wheels (distributed on both sides of the body axis), one (three-wheel models) or two (four-wheel models) driven free wheels, relying on two driving wheels. The differential drive between enables cornering. Compared with the single drive method, the differential drive method can make the structure of the AGV simpler, but it has higher requirements on the control performance of the motor drive assembly and the ability to eliminate errors based on external sensors, otherwise it is difficult to ensure that the AGV runs along a given path. Likewise, a three-wheeled vehicle with differential drive has poor stability when cornering, while a four-wheeled vehicle requires a higher level of ground surface (Zhang et al., 2018).

Dual steering wheel drive for four-wheel models: two steering wheels, two driven freewheels. The outstanding advantage of this model is that it can achieve omnidirectional (universal) driving, which is especially suitable for narrow passages or environments and occasions with special requirements for the working direction, while the disadvantage is that the structure of the AGV is relatively complex, and the flatness of the ground surface is higher requirements (Mohan et al.,1994).
Multi-drive for multi-wheel models: multi-steering wheel drive refers to 4 upper steering wheels, which are generally used for heavy-duty AGVs with a load of more than 10T, and the motion model is more complicated. The motor drive assembly of the AGV consists of a servo motor and a deceleration mechanism (Sabanovic, Ohnishi, 2011). It is used for the drive of the AGV body and the drive of the loading and unloading mechanism. It is the core component of the AGV and has a great impact on the cost and performance of the AGV. At present, there is still a big gap between domestic motor drive assemblies and foreign countries. Most of the domestic AGV products use imported motor drive assemblies and driver products, which are costly (Sabanovic, Ohnishi, 2011).
At present, in foreign countries, AC motor drive assemblies with low-voltage AC motors as the core are widely used in heavy-duty AGV drive systems because of their high efficiency and low maintenance costs. Foreign AGV product suppliers are competing to launch AGVs driven by AC motors with better performance, taking the new AGVs driven by AC motors as a winning weight to compete in the global market. To enrich its own products, meet user needs and win market share (Zhang et al., 2018).
At present, domestic AGV manufacturers mainly use DC drive technology, and the biggest drawbacks of DC motors in DC drive systems are excessive noise, brush ignition, rotor pollution, and high motor temperature. The DC motor has higher efficiency, the sealing performance of the AC motor is much better than that of the DC motor, and the protection level is much higher. There is no need to replace the brushes regularly, which brings a lot of convenience to the users in the future. The application of low-voltage AC drive control technology in AGV has just started, and the market prospect will be very broad. Therefore, it is imperative to develop AC motor driven AGVs (especially heavy-duty AGVs) (Goehner, 2019).
AGV energy system: The AGV energy system is one of the key systems of the AGV system. It includes a battery intelligent charge management system, intelligent battery charger, battery level detection and battery.

The characteristics of AGV batteries have a great influence on the design of a single AGV. At present, the batteries used by domestic and foreign manufacturers are mainly divided into two categories: lead-acid batteries and cadmium-nickel batteries. The lead-acid battery has a low charge and discharge rate, suitable for slow charging and slow discharge, long charging time and long continuous working time; while the nickel-cadmium battery has a higher charging and discharging rate, adapts to fast charging and fast discharging, has a short charging time, and has a longer continuous working time than lead-acid batteries. The acid battery is short; generally, the appropriate battery for AGV is selected according to the operational characteristics of the AGV, such as the intermittent production, the working shift, and the running time of the AGV (Zhang et al., 2018).

In some applications, if the AGV travel path is a fixed path, the battery power supply can be replaced by non-contact inductive power supply. In the non-contact inductive power supply mode, the on-board controller obtains electric energy from the high-frequency constant current line laid underground through the coupling power-taking board and passes the on-board power supply (Walenta et al., 2017). After AC-DC conversion, it is supplied to the on-board components, thus realizing the non-contact induction power supply of the AGV in motion, replacing the battery power supply system of the traditional AGV (Zhang et al., 2018). There are four main characteristics:

- It solves the capacity limitation problem of battery power supply, can solve the continuous demand for electric energy in logistics handling, and ensure the continuity and reliability of AGV power supply.
- It avoids the waste of time caused by battery charging, can achieve 100% maintenance-free, and improve production efficiency.
- It reduces many environmental problems caused by using a battery power supply and can work in a dust-free clean environment or a harsh and humid working environment with very strict environmental requirements.
- Calculated based on the use of the equipment for more than 5 years, the non-contact inductive power supply system has lower investment and use costs than the battery power supply system

At present, the battery power supply method is commonly used in China. The non-contact inductive power supply method has been used in batches in foreign automobile and other manufacturing industries. In the past 1-2 years, there have also been some applications in China where AGVs need continuous operation, but they are all used abroad. For some products and technologies, domestic research on this technology is still limited to some universities and colleges, and there is no mature product (Zhang et al., 2018).

AGV wireless communication system There are multiple AGVs working at the same time in the AGV system. Command each AGV to work in coordination with the tasks accepted by the AGV management system, (i.e., assign tasks to the AGV, manage traffic, etc.), and all AGVs and other automated logistics equipment in the system are controlled by the AGV management and monitoring computer. The AGV needs to report the status to the AGV management monitoring computer and the data exchange between the AGV needs to be completed through the communication system (Burganova et al., 2021).

The AGV with fixed operating lines can conduct inductive communication through the wires embedded in the operating lines, while the omnidirectional operation Since AGV does not have a fixed operating line, it generally uses wireless communication to exchange data with the host. When there are many sources of interference in the workshop, the communication system must have high reliability, otherwise it will cause the AGV system to malfunction. At present, at home and abroad Most of the AGV wireless communication systems use the general wireless system of the wireless Ethernet standard protocol 802.11b/g. The improvement of wireless communication system technology and the reduction of hardware cost can promote the development of AGV. 4 Suggestions on the research work of AGV technology. At present, China is faced with the impending loss of demographic dividend, the sharp rise in labor costs, the lack of well-trained industrial workers, and these problems have created a strong driving force for the rapid growth of the demand for robots (Fang et al.,2018). The demand for industrial robots from domestic enterprises is unprecedentedly high. How to provide enterprises with cost-effective industrial robots is an important issue faced by robot R&D and production enterprises (Zhang et al., 2018).

According to the current international AGV development trend, the following three principles should be implemented in the research work of interested AGV technology: Drive technical research with product development and market demand; Encourage the technical research work of key components of AGV and promote the improvement of the technical level of AGV products with the improvement of the technical level of key components; According to the diversification of market demand, carry out research and development of AGV products with different costs.

In some studies, the following result of research work (Hou, 2017) on AGV key technologies should be carried out:

The AGV management monitoring and dispatching system is one of the important core technologies of the AGV system. The development of the management and dispatching system based on more than 50 AGVs should be developed, and special research on human-computer interaction technology, remote monitoring technology, and remote fault diagnosis technology should be carried out to improve my country's The software development level of independent intellectual property rights is to meet the domestic market demand of AGV in recent years (Zhang et al., 2018).

The AGV on-board controller is the core of the AGV control system, and a dedicated AGV on-board controller based on an embedded computer system is developed to replace the one that uses an industrial computer or a general-purpose PLC as the main control unit and Robotic Arm.

2.8 Vehicle-Mounted Controller

AGV vehicle-mounted controllers are the future technology development trend and the focus of future research and development.

With the increase in the demand for AGVs in the manufacturing industry, the demand for heavy-duty AGVs with loads above 20 tons will grow rapidly. The research and development of multi-steering wheel-driven AGV is particularly important, and the kinematics research of multi-steering wheel-driven AGV and the research of multi-steering wheel motion control algorithm should be carried out.

Motor drive assembly is one of the important basic components of AGV, and motor drive assembly products with independent intellectual property rights should be developed. Research work and product development work on low-voltage AC motor drive technology should be carried out as soon as possible. Research and develop DSP-based AC and DC servo drive controller products (Liu et al., 2016).

Visual guidance technology will become the most promising AGV guidance technology, carry out research work on key technologies of fast image processing, carry out research work on the adaptability of image processing technology in AGV guidance technology, and realize visual guidance technology as soon as possible.

3 Analysis and Evaluation of AGV Implementation

The chapter introduces four cases of implementation of AGV in China to analyze the utility and efficiency of the technology. Each case includes the innovation and benefit of implementation and the difficulties and impacts afterwards so as to evaluate the result of implementation.

3.1 Cases Study Backgrounds (China)

In 2020, under the haze of the new crown pneumonia epidemic, infrastructure has once again become a weapon for stable growth. Infrastructure investment has become one of the few favorable sectors. Benefiting from the demand for infrastructure investment, the construction machinery industry is in the best period in history, and the rise in demand for construction machinery and equipment has also driven the demand for related production equipment (Baidu, 2022).

With the further development of China's construction machinery manufacturing industry, its production mode has gradually changed from labor-intensive to technology-intensive, from high consumption and high pollution to energy saving, consumption reduction and environmental protection. Therefore, many automated logistics transportation complete sets of equipment and systems, such as mobile robots, have become an inevitable choice for enterprises in China's construction machinery manufacturing industry. Since general construction machinery belongs to large-scale equipment, the current application of mobile robots in the construction machinery industry is also dominated by heavy load and heavy load products (ZhiHu,2022).

The intelligent transformation of the construction machinery industry has become a general trend, and the leading enterprises in the industry have begun to transform the relevant aspects, and the following lists some representative cases of mobile robots in the application of mobile robots in the construction machinery industry.

3.2 Case 1: CSG HuaXiao - whole plant flexible AGV project

The project is from a well-known construction machinery company applied 91 AGVs customized by CSG. The main line is equipped with 43 large-scale custom-assembled

AGVs, with a single load bearing of more than 10T, which can achieve stepless speed change of 1m/min~30m/min. Compared to conventional e-chains assembly lines, it is highly flexible and is the basis for automation of assembly. There are 37 sets of SPS latent traction AGVs, 5 sets of balanced suspension and front middle and rear axle lifting and carrying AGVs, 7 sets of engine traction AGVs after sub-assembly, and 24 sets of latent traction AGVs in the cab, realizing unmanned logistics transfer in the whole plant (See Fig .11).

Fig. 11 AGV HuaXiao application

Source: HuaXiao CSG official website

Difficulties and innovations

The first automated production line in China that realizes the magnetic stripe navigation of heavy-duty truck AGV stand-alone machines, adopts a low body structure design, which is convenient for operators to get on and off the vehicle and assemble with AGV. Realize the assembly flexibility of the whole machine, better adapt to the layout of the plant, and have a demonstration role in the field of commercial vehicles/buses/rail transit (Baidu, 2022).

The production line uses AGV transportation, which can effectively and economically reduce the demand for civil engineering and steel structure, reduce the initial investment, and be more suitable for the construction of new plants for commercial vehicles/buses/rail transit. When upgrading products or optimizing processes, such as increasing stations, modifying beats, etc., only need to adjust the AGV path or quantity, without re-doing foundation and steel structure construction, the production line can be adjusted more flexibly and conveniently, and the secondary investment is smaller (ZhiHu,2022).

Advanced: The innovative use of heavy-duty differential drive suspension technology can realize the forward, backward and traverse of AGV, and at the same time, the car body can be moved out in time when the production line fails, ensuring the production timeliness of the entire line.

Benefits or impacts

A well-known construction machinery company "Super Pilot Factory" has been put into production, which is also the first factory to comprehensively apply AGV to various civil truck manufacturing fields and is the first factory in the heavy truck industry to realize unmanned logistics transshipment in the whole process and whole factory area. As a leader in the heavy industry, under its demonstration and leadership, the domestic heavy-duty truck manufacturing field will usher in an industry change, promote the industry to improve the level of intelligent manufacturing, and help industrial transformation and upgrading (Baidu, 2022).

3.3 Case 2: AGV handling project - Guozi Robot

The project customer belongs to the leading enterprise of construction machinery, at present, the company mainly produces large, medium, and small micro excavators, and the products are widely used in the field of construction machinery. A total of 2 production lines were renovated in the workshop, and the original old-fashioned track RGV on the frame line of the excavator was updated and upgraded with a fully flexible AGV loop line to realize the flexible station and automatic and manual parallel upgrades. The original old-fashioned conductor RGV of the excavator unloading line was changed to a battery-type maintenance-free lifting RGV to meet the upgrade of the dismounting process (See Fig .12)**.**

Fig. 12 AGV application GuoZi Robot

Source: GuoZi Robot Official website

Difficulty and the innovations

There are many transformation points, low degree of automation, and unsmooth information flow, such as large-scale upgrading and transformation, and it is difficult to meet the timeliness requirements (Baidu, 2022). Lack of comprehensive information tracking function, information cannot be comprehensive, timely collection, resulting in many information islands, only rely on personnel collection input, easy to produce errors and low efficiency, quality problems cannot be timely feedback and traceability, easy to cause quality accidents. Guozi Robot provides customers with overall solutions through the following aspects of research and exploration:

The use of fully flexible intelligent AGV solves the problems of singleness, non-universality, and inflexibility of the original RGV on the boarding line; Use maintenance-free batteries to solve the cumbersome maintenance of RGV of the conductor conductor under the car; Increase real-time global monitoring on large screens, and interconnect and visualize all intelligent devices. Through the AGV system, the tracking of the material frame circulation process is realized, which makes up for the gap of comprehensive informatization and makes the circulation process of raw materials and semi-products traceable. Innovative heavy-duty 20-ton flexible AGV production assembly line, upgrading the traditional RGV method to an automated handling robot AGV (ZhiHu,2022).

Benefits and impacts

After the adoption of the AGV system, the workshop realizes the orderly transfer of goods, transports according to the shortest route, supplies according to the beat, locates and stores goods, etc., greatly reduces the turnover, and automatically transmits the information to the upper computer, reducing the error rate and improving efficiency. After the automation transformation, the project creates an annual increase of 150% in benefits and becomes the first fully automatic workshop for template production in China, meeting the requirements of systematic logistics, automation, intelligence, green energy saving, and technical specialization of workshop logistics (Baidu, 2022).

3.4 Case 3: Tangshan - 20T heavy-duty AGV system project

Description of the project

The heavy-duty AGV system provided by Mechanical Development Technology Co., Ltd. in this project is mainly composed of AMB04200 heavy-duty AGV vehicle, AGV control system and charging system. This system can realize the excavator's boom, small arm, slewing, lower frame, side frame and other materials in the automatic and semi-automatic transfer and transportation between each station, heavy-duty AGV using four steering wheels for power drive, the maximum carrying capacity is 20 tons, all wheel trains are installed with buffer mechanisms, to ensure that the heavy-duty AGV is evenly loaded in each wheel during operation. Heavy-duty AGV bodies are required to be strong, beautiful, and durable, and the battery and other electrical components are installed in a position that is convenient for future maintenance operations (Baidu, 2022).

The system sets the semi-automatic/automatic mode switching button, the automatic mode refers to the automatic delivery of AGV tasks through the call button set at the operation site or the central control upper computer, and the semi-automatic mode refers to the issuance of AGV tasks can be realized by the workstation call button set on the side operation panel of the heavy-duty AGV car body. When the heavy-duty AGV receives the handling task, it will automatically move to the designated station, after the manual completion of material loading, the heavy-duty AGV will automatically run to the next station, after the material operation is completed, if there is no material operation task, the heavy-duty AGV will automatically return to the waiting position (charging point) of the feeding station to perform the charging task, if there is a material operation task, continue to execute the task(See Fig .13).

Fig. 13 AGV application TangShan

Source: TangShan mechanic official website

Difficulties and innovations

This project has a large load capacity of the heavy-duty mobile robot AGV, and the situation of eccentricity of the vehicle body is caused by the characteristics of the cargo itself when carrying goods, which has a certain impact on the motion control of the heavy-duty mobile robot AGV, and at the same time, according to the characteristics of heavy load and long length of the vehicle body, the body chassis has more bearing wheels, and the special shock absorption mechanism of the rudder wheel and load-bearing wheel on the chassis is designed, so that the mobile robot AGV chassis meets the control requirements during operation;

The body of the heavy-duty mobile robot AGV is 12m long, and the drive form of four steering wheels is adopted, which puts forward higher requirements for the precise navigation motion control of the heavy-duty mobile robot AGV due to the navigation mode of magnetic dots (ZhiHu,2022).

Benefits or Impacts

By using the heavy-duty mobile robot AGV to handle materials, it solves the situation that the enterprise used two manual forklifts to drag and transport material flatbed trucks, which not only saves manpower and material resources, but also ensures the safety of products and materials during transportation.

3.5 Case 4: Kaiyunlai robot handling type AGV - assembly line application

Implementation project started by Undertaking the AGV system equipment (including scheduling system) of the off-road scissor aerial work platform and the straight curved arm climbing platform assembly production line of a machinery company in Zhejiang. The product has a load capacity of 10t, which is used in the transfer buffer and assembly work after the paint workshop of the construction machinery industry comes off the line, and the heavy-duty AGV realizes the assembly of the lifting arm between stations and the transfer with the cache station through the piggyback jacking mechanism (Baidu, 2022) (See Fig .14).

Fig. 14 AGV application KaiYunLai

Source: KaiYunLai official website

Difficulties and innovations

Heavy-duty AGV has many technical difficulties and is very different from the design structure of light-duty AGV, and the parts purchase criteria are also different, and heavy-duty AGV will have a very large performance test in terms of stability, flexibility, and durability. KaiYun comes from the main research and development of multi-wheel group ultra-low omnidirectional double differential drive assembly, through the floating damping system between multiple wheelsets to make up for the unevenness of the ground, to ensure that multiple sets of wheel trains are in contact with the ground, and the bearing and driving capacity are greatly enhanced. AGV drive wheel set has a lifting system: when a wheel set fails, the wheel set is manually / automatically lifted, while other follower wheel sets continue to operate, so that the AGV can smoothly drive away from the current task line without affecting the operation of other AGVs, so that the entire AGV system can continue the current task smoothly. KaiYun comes from the main research and development of a synchronous hydraulic jacking device and adopts electromagnetic encoder coaxial control principle between multiple groups of jacking units to ensure a smooth and safe jacking process. The single hydraulic unit also adds the function of preventing the instant drop of the oil pipe burst and preventing stall.

In addition, KaiYun adopts the innovative AGV segment self-navigation mode to overcome the estimation error of the scheduling system, so that the AGV is always in the safe operation range, and effectively alleviates the impact caused by network delay. The innovative "preemption" scheduling algorithm is adopted to allocate road resources and maximize the utilization of dispatching resources as a whole; The innovative "segment self-identification" road mode is adopted to make the road paving pattern and standardization, and effectively reduce the complexity, cost, and later maintenance workload of road construction (Baidu, 2022).

Benefits or impacts

This product adopts mature AGV navigation system and is equipped with the latest power drive system to meet the full circulation function of factory automation; The logistics path of semi-finished products and finished products is clear, and the handling tasks are carried out flexibly and efficiently, and the efficiency of the production line is improved by more than 40%; The rapid deployment of logistics handling system realizes the closed loop of intelligent information in the whole field, which is conducive to enterprises to achieve efficient unmanned production and save more than 50% of manpower. This heavy-duty AGV product can meet the functions of forward, backward, left and right turning, side shifting, omnidirectional movement, and realize the assembly of the lifting arm between stations and the transfer of the cache station through the piggyback jacking mechanism, and the load performance, the complexity and diversity of tooling have strong demonstration significance, which can be promoted and copied to other large-scale equipment manufacturing fields, and strongly empower large-scale equipment manufacturing enterprises to achieve Industry 4.0 and intelligent manufacturing. At the same time, it has rich application scenarios and example experience of heavy-duty AGVs, which lays a solid foundation for higher load design.

4 Selection of navigation method to implement AGV technology

The chapter is going to introduce a simple selection method to determine the suitable navigation method by decision-tree approach (Myles et al.,2004). “A decision tree is a flowchart structure in which each internal node represents a “test” on an attribute (e.g., whether a coin comes up heads or tails), each branch represents the outcome of the test, and each leaf node represents a class label (decision taken after computing attributes) (Song et al., 2015). The paths from root to leaf represent classification rules.” The sample format can be seen as the following graph (See Fig .15).

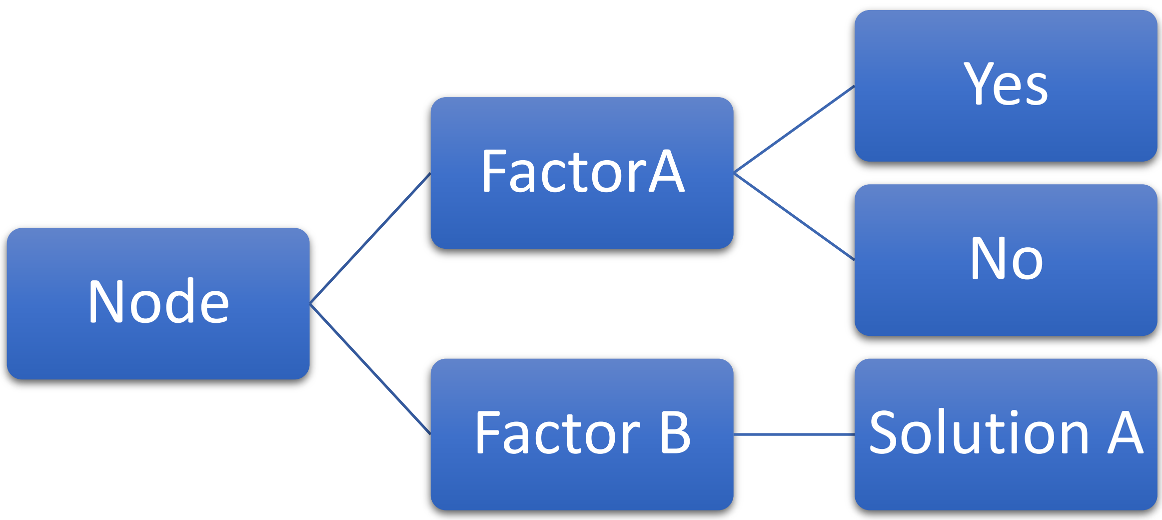

Fig. 15 Decision tree sample 1

Source: Huang,2022

Each node contains a determinant. The determinant needs to be evaluated and judged whether it is the direction of emphasis. Regardless of whether it is emphatic and adopted, it will be extended to the next layer of nodes and in the next layer of determinants, repeated evaluation and judgment whether it is emphatic and adopted (See Fig. 16).

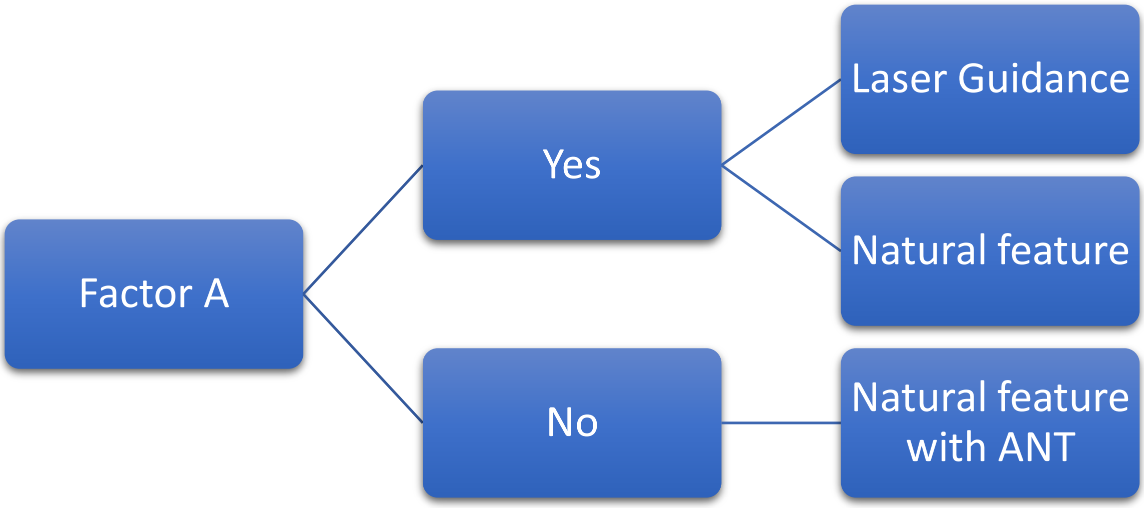

Fig. 16 Decision three sample 2

Source: Huang,2022

4.1 Step 1 Analyze the characteristics of different navigation of AGV

An AGV's navigation system is heavily related to its operational performance. It decides how the vehicles move around, how it interacts with obstacles, and how easily it can be installed. Each type of the systems has its own advantages and disadvantages. The following is the analysis of different navigation system.

4.1.1 Physical paths: following installed lines and tags

The first type of AGV runs on rails. They can either follow lines or tags. Line-following AGVs are combined with special sensors capable of following a physical line on or under the ground. This line could be magnetic tapes, painted on the floor, or inductive wires physically embedded in the floor itself. Also, tag following vehicles are equipped with a sensor (such as a camera or code reader) that allows them to follow a route that is defined by tags. These tags might be magnetic points embedded in the floor, or QR codes and other types.

The pros of this type of navigation are reliability and accuracy. They are not affected by active modification or changes in the environment, such as the appearance or removal of pallets, materials, racking systems or other vehicles. However, the cons of this type of navigation are time-consumption and high-cost installation (embedding a physical line in the floor is especially disruptive), and this process will be repeated if routes need to change. Besides, magnetic tapes, paint, and tags or codes can be also torn and worn over a period, leading to the risk of broken routes and therefore vehicle errors. Fleet management with line and tag following vehicles is challenging: a single AGV following physical lines or tags may work well but getting multiple vehicles to work seamlessly together- for instance, at crossings or intersections- can be highly problematic.

4.1.2 Virtual paths: laser and visual guidance

Laser-guided vehicles calculate their position with the help of laser beams. These are radiated around the environment using LiDAR laser scanners positioned on the vehicle and reflected from carefully installed reflective targets. So long as a minimum of three targets can be seen at any one time, the vehicles can calculate their position accurately and reliably. Therefore, the careful design of reflector location is highly important. The laser guidance is reliable and highly accurate. Since a central server is used to manage vehicles following virtual routes, managing a fleet of multiple automated vehicles is efficient and effective. Besides, the routes are digital, modifying these routes when an operation evolves is quick and simple. Unless that is, the locations of reflector installation need to be changed, which can be time consuming and expensive, since reflectors must be installed first by a technician and then their positions measured by a professional surveyor. The disadvantages of such guidance are time-consuming and expensive. The process of installing LGVs (including designing reflector layouts, installing reflectors, and then validating their position). In addition, a vehicle's laser is generally installed on top-to maximize the number of wall-based targets it can see which means there are fewer types of LGVs available. Although natural navigation can use the machine's ankle-height safety laser scanners to navigate, LGVs need that higher position to work effectively.

AGVs operating with visual guidance navigation are quick and simple to install and there is no need to change infrastructure. However, the accuracy and reliability of such navigation methods can be affected by changes in the environment and lighting conditions. The latter could be a particular concern if the site has inconsistent light conditions, or the vehicles are moving towards a lights-out operation.

Natural navigation is also called free, or contour navigation featured with reliability, accuracy, and its vehicles quick to install and modify. This approach uses permanent, static 'features' (or references) in the environment - such as walls, columns, and fixed machinery- to calculate the vehicle's position. This navigation method can be further divided into two types. One is scan matching (SLAM navigation) and the other is feature matching (natural feature navigation).

Scan matching vehicles are quick to install and modify. Since vehicle paths are virtual, fleet management via a central server is efficient. Besides, it is not required to change permanent infrastructure. Occasionally, reflective stickers might need to be added - in areas with few visible natural features. Yet, they do not need to be validated by a professional surveyor. Vehicles that use scan matching often require an additional laser scanner to be installed high on the vehicles, to maximize the visibility of permanent features. This limits the number of vehicle types that are available based on this technology, in addition to raising costs.

To simplify the above characteristics, the following table includes comparison of different navigation methods and the rank of cost and the ease of implementation. The higher the number in the following factors: cost of infrastructure, installation time, cost of maintenance and cost of modification, the more expensive the number symbolizes. By contrast, the higher the number in the remaining factors: accuracy, reliability, environmental change, vehicle speed and fleet management, the better the performance it is. (See table1, table 1-2)

Table 1 Navigation method by different factors

	Infrastructure cost	Installation time	Accuracy	Reliability	Environment change
Line following	3	2	3	3	3
Tags	3	3	2	3	3
Laser Triangulation	3	2	3	3	3
Visual Guidance	1	2	1	1	1
Natural Feature	1	2	2	2	1
Natural feature with ANT	1	3	3	3	2

Source: Huang,2022

Table 1-2 Navigation method by different factors part 2

	Vehicle Speed	Cost of maintenance	Cost of modification	Fleet management
Line following	1	2	3	1
Tags	2	2	3	2
Laser Triangulation	3	1	2	3
Visual Guidance	2	1	2	2
Natural Feature	2	1	2	2
Natural feature with ANT	3	1	1	3

Source: Huang,2022

This study mainly divides the navigation patterns into six categories, and selects nine common consideration factors, and each factor is rated from 1 to 3. Among some factors, the higher the number, the better the performance. However, in some factors Among them, higher scores indicate higher costs and poorer performance.

The higher the score, the higher the cost and the lower performance factors include infrastructure cost, installation time, cost of modification and cost of maintenance Conversely, the higher the score, the better the performance factors include accuracy, reliability, environment change, vehicle speed and fleet management.

4.2 Step 2 Decide factors in nodes and select suitable navigation method

First, it is necessary to separate all navigation types to two categories: with physical rails and without physical rails (virtual rails) (See Fig .17) (See Fig .18).

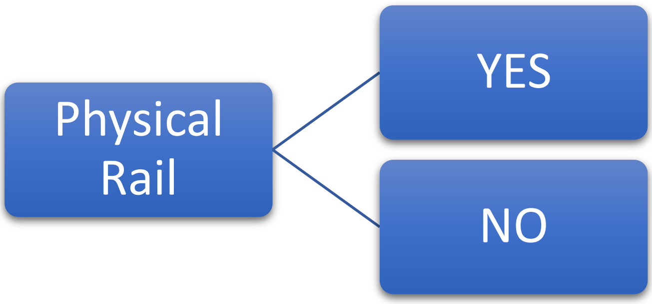

Fig. 17 Physical Rail first step

Source: Huang,2022

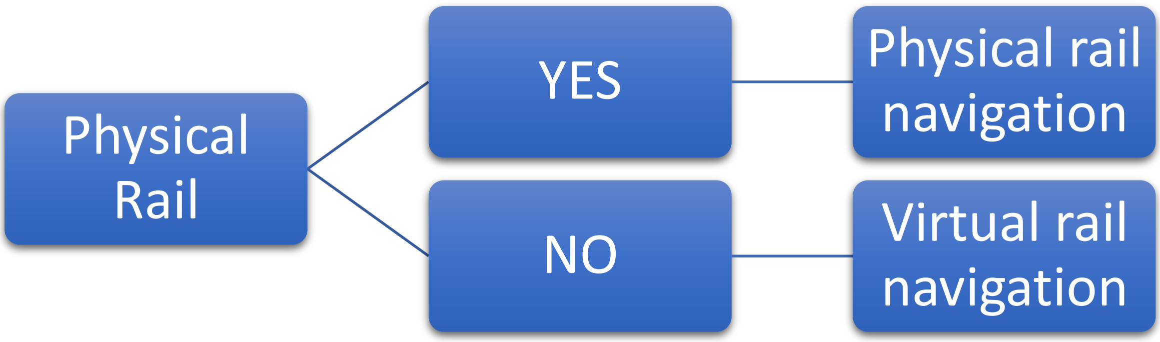

Fig. 18 Physical Rail to navigation method

Source: Huang,2022

If the condition of the environment allows change of floor and the cost of infrastructure, maintenance and modification are acceptable and well-affordable, the implementation of physical navigation can be considered and utilized. By contrast, if the companies are concerned with the cost of installation and modification of routes and the infrastructure of the implemented environment is uneasy or impossible to change the embedded routes on floor from time to time in a certain scale, virtual navigation methods are preferable and suggested. Physical rail method includes two possible navigation methods- line-following method and tag method while virtual rail method contains four different navigation methods- laser triangulation, vision guidance, natural feature, and natural feature with ANT.

4.2.1 Physical rail

Next, according to the graph above, there are four differing factors between the line following and the tags method- installation time, accuracy, vehicle speed and fleet management. They can be categorized into two subgroups (emphasis on initial cost of time and management over operational performance) which can be preferred and focused by interested companies. The first group contains installation time and fleet management, and the group is suitable for the navigation method by embedded tags, referred to as group A. The second group is the opposite situation where the fleet management and initial installation cost of time are not primarily emphasized, and the group is named B and the suggested navigation method belongs to the line following navigation. Therefore, the nodes on the physical rail branch can be extended to the next level as the graph below (See Fig .19).

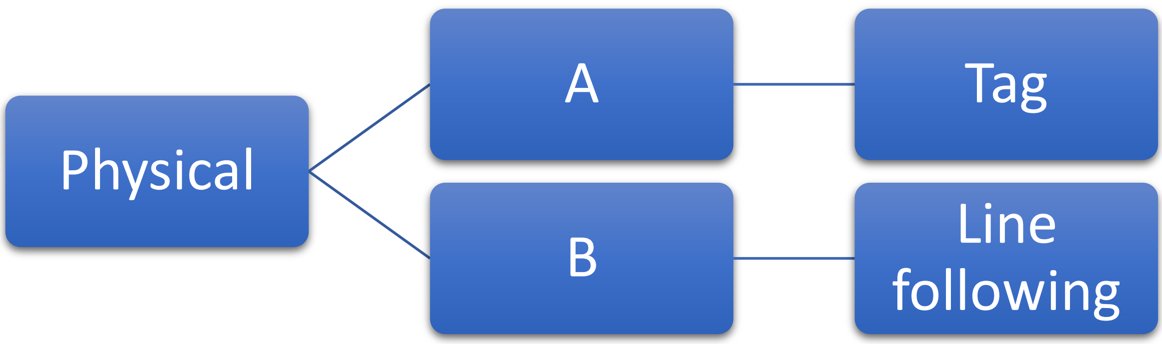

Fig. 19 Physical Rail to navigation method final

Source: Huang,2022

4.2.2 Virtual rail

As for the virtual rail branch, these four navigation methods can be divided into two groups by the focus on three performance factors which are accuracy, reliability, and vehicle speed. If the interested companies emphasize on performance factors, then Laser triangulation and natural feature with ANT are the preferred options so these two navigation methods can be put together as group C. However, if the interested companies do not emphasize on performance factors (accuracy, reliability, vehicle speed), then there are two navigation methods-vision guidance and natural feature to be considered and categorized as group D. Therefore, the virtual rail branch can be extended one more level and two nodes as the following graph (See Fig .20) (See Fig .21).

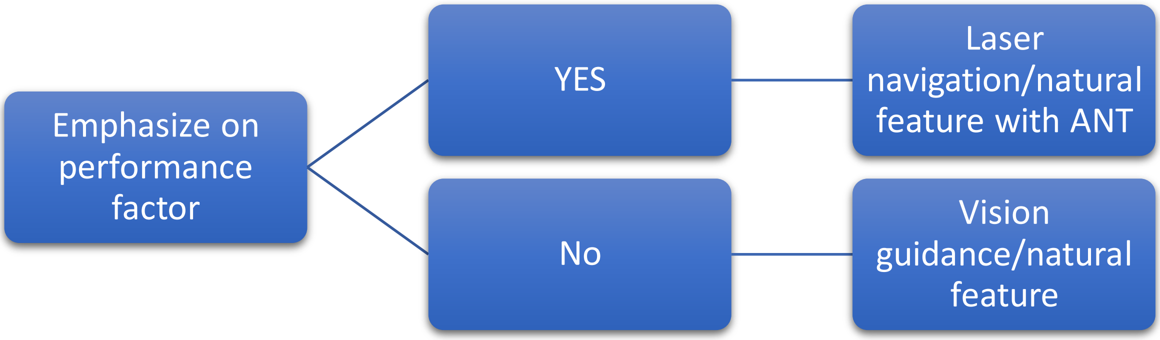

Fig. 20 Emphasis on performance factor

Source: Huang,2022

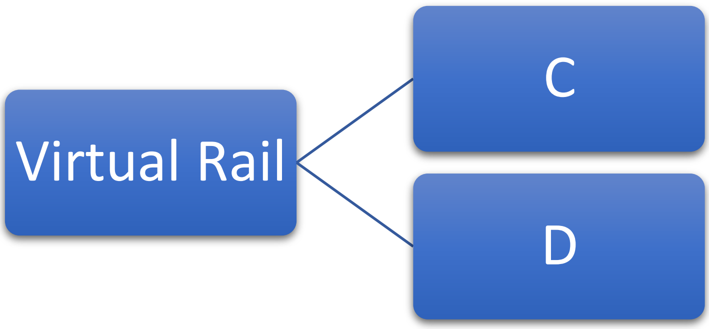

Fig. 21 Virtual Rail categorization

Source: Huang,2022

Next, we need to extend node C to the next level. In node C, there are two navigation options to choose from and they are laser triangulation and natural feature with ANT. The laser triangulation method has better environmental adaptation than the natural feature with ANT so if the interested company prefers this feature more than the rest factors which are the cost of the modification and the cost of infrastructure, then the laser triangulation navigation is the ideal solution.

However, if the company focuses on the cost of modification and the cost of infrastructure, in other words, the economic factors are more primary than the adaptability of the navigation method, then the natural feature with ANT is the suggested option. The graph below illustrates the conditions and the extension of the node C (See Fig .22) (See Fig .23).

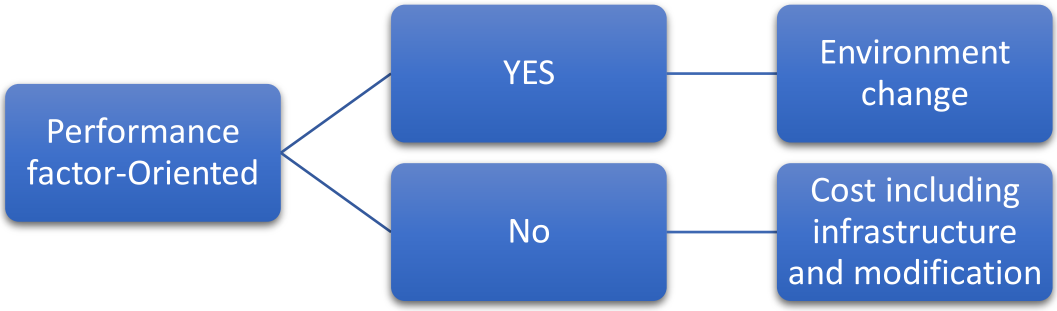

Fig. 22 Performance factor orientation

Source: Huang,2022

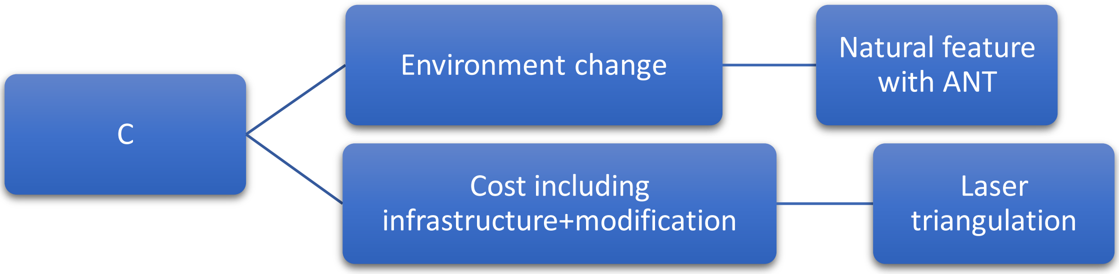

Fig. 23 Separation to Laser triangulation

Source: Huang,2022

Next, in node D, there are two navigation methods which are visual guidance and natural feature. To compare and provide the guidance to select the suitable navigation method, it is suggested that the difference between these two navigation methods should be evaluated. The laser guidance has limited types of models and can be a harder challenge in the future to manage or grow the fleet in the organization, so it is a factor to determine if the fleet is expected to grow in the future or to be unified. In other words, natural feature navigation method is better for futural fleet unified expansion and management (See Fig .24).

After the above steps are completed, various navigation methods are classified and completed. By selecting different paths from the initial node according to the needs and factors, it is possible to select and judge further considerations layer by layer to the next layer of nodes. In the nodes of each level, repeat the dichotomy judgment. Finally, the most suitable navigation mode is obtained (See Fig .25).

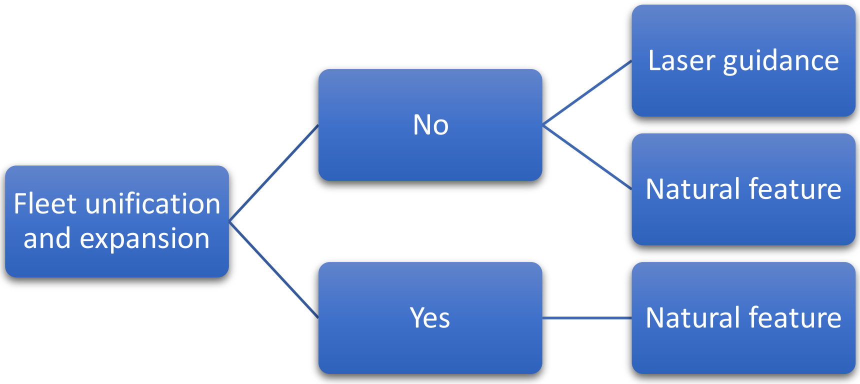

Fig. 24 Fleet unification and expansion

Source: Huang,2022

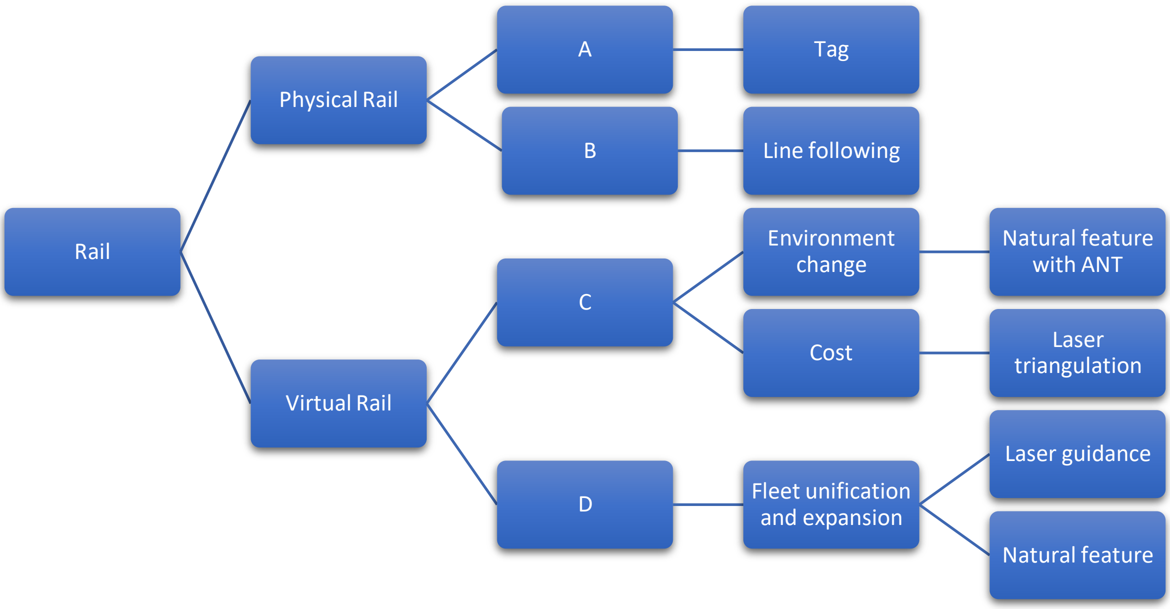

Fig. 25 Whole decision tree process

Source: Huang,2022

Conclusion

The result of the work created a basic method to select and evaluate the AGV navigation methods by categorizing and considering multiple decisional factors by the adoption of decision tree making. A simple guidance for those who are interested in implementing AGV and considering the difference of navigation methods as a different approach firstly instead of selecting based on merely cost factor was organized. Each navigation method has different advantages and disadvantages, and it is rare that there is a perfect navigation method which can be dominating and well adapted in all environments and conditions under various requirements or features of individual location and space. Therefore, the further research and study will be focused on evaluating relation between different factors and coefficiency to provide a more sophisticated categorization. Besides, some features occurred the situation that they contradict to each other, or they share the same level of importance of the factors. It is necessary to take into consideration of the thorough planning and future potentisal expansion and management cost and hidden implicit factors should be discovered and studied in the future research.

This article evaluated and analyzed four actual cases of introducing AGVs in Chinese companies and introduced various types of navigation systems in detail. It also provided simple instructions and descriptions for the mobile system and control system of unmanned vans. The article also provided Common AGV types which can be served as inspiration for those who aim to innovate different modes and create more adaptative models to improve the usage of AGV. The article provided a simple reference for those who are interested in introducing unmanned vans to enterprises, factories, logistics industries or various industries in the future.

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ANNOTATION

AUTHOR	**Ting Chun Huang**		
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THESIS TITLE	**Suitability of Different Navigation Technologies of AGV for Specific Implementations in Logistics**		
SUPERVISOR	**Tomáš Malčic, Ph.D.**		
DEPARTMENT	**KRVLK - Department of Production, Logistics and Quality Management**	**YEAR**	**2022**
NUMBER OF PAGES	**58**		
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NUMBER OF APPENDICES	**0**		
SUMMARY	**This paper starts from the theoretical part to introduce the development of the future logistics field and the relevant common sense of today's unmanned vans, as well as the advantages, disadvantages, and characteristics of different navigation types, to provide industry practice examples to analyze and evaluate the breadth and validity of unmanned vans. In the actual application part of this article, industry implemented cases are provided as an analysis and evaluation of the application of unmanned guided vehicles in a specific environment. A simple decision tree method is provided to help distinguish and choose a suitable unmanned guided vehicle navigation method.**		
KEY WORDS	**Unmanned, Autonomous vehicle, AGV, logistics, Navigation**		
