Günter Ullrich

Automated Guided Vehicle Systems

A Primer with Practical Applications

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Second revised and expanded edition with 154 illustrations and numerous tables

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Preface

Automated Guided Vehicle Systems (AGVS) were invented in the 1950s, and have since developed into a tested means for organizing modern intralogistics. Although the automotive industry was initially the leader in adopting them, almost all industries have come to use AGVS to optimize material flows. This manual documents the variety of uses and the technological standards that are available without claiming to be authoritative. In addition, it documents the new developments – which will hopefully continue – in both technology and applications. The future has long since begun with the advent of the fourth era of AGVS.

Another key point is the integrated planning of such systems, which is thoroughly described along with all necessary planning stages. Here the reader will not only find a guideline through the planning process, but also valuable advice.

For 28 years, the VDI Automated Guided Vehicle Systems panel has been accompanying the industry. It currently unites some 40 member companies – this strong network has given rise to the European AGVS community, the AGVS Forum, which is actively involved in publicity work (seminars, presentations, and initial consulting). At this point, I would like to offer thanks to all members of the AGVS Forum, without whose contributions this manual would not have been possible. In addition, I would like to thank the Mechanical Engineering Editor's office of Springer Vieweg publishers for their friendly and understanding assistance.

This handbook is directed at specialists and practitioners in intralogistics who are concerned with optimizing material flows. They are found in almost all branches of industry, in certain service companies or in research and development at universities and technical colleges. From our experience as planners and consultants, we are aware that there is a practical and theoretical need for a comprehensive presentation of this topic. We have tried to take an objective approach with a moderate degree of specialization using clear and concise language. This second edition was entirely revised, slightly restructured, and takes into account recent developments in technology and the markets. We hope that this revised handbook will contribute to more automated guided transport systems being used and their future performance enhanced.

Voerde, September 2014 Günter Ullrich

Contents

Chapter 1
The History of Automated Guided Vehicle Systems

Automated guided vehicle systems (AGVSs) have become a key component of today's intralogistics. The technological standard and the current level of experience with this automation technology have led to AGVS being introduced in almost all branches of industry and areas of production. The history of AGVS began around sixty years ago in the home of so many of today's innovations – in America.

As production facilities started up again after the Second World War and the world economy was booming, self-driving robots were part of the dream that humanity had realized of letting machines do our work for us. The rapid development of sensory and regulatory technology as well as early developments in microelectronics paved the way for AGVS.

At this point we would like to pay a brief tribute to the invention of AGVS in America, but then turn our full attention to the European market. Up to now, America has not been successful at entering the European market. But there has been a great deal more success in the opposite direction: right now there are several European AGVS manufacturers working on projects in America. In the past, the Asian market had almost no overlap with Europe, either in one direction or the other.

The sixty-year history of AGVS can be divided into four eras. These eras can be distinguished by the state of the technology available and the emotional attitude towards the systems. They can also be seen as evolutionary stages during which there were only limited technical advancements, but which rather abruptly segued into the next era (Fig. 1.1).

G. Ullrich, *Automated Guided Vehicle Systems*,
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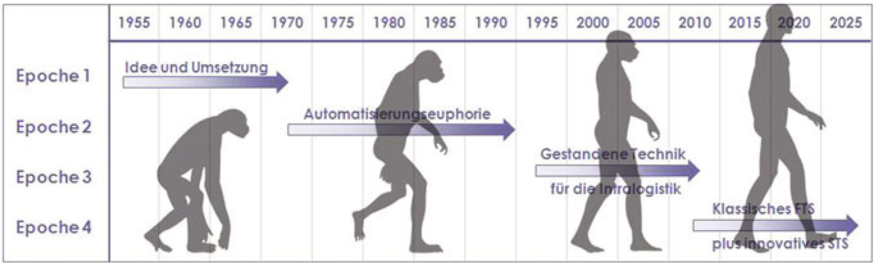

Fig. 1.1 Automated guided vehicle systems develop within and into the next stage of evolution (eras)

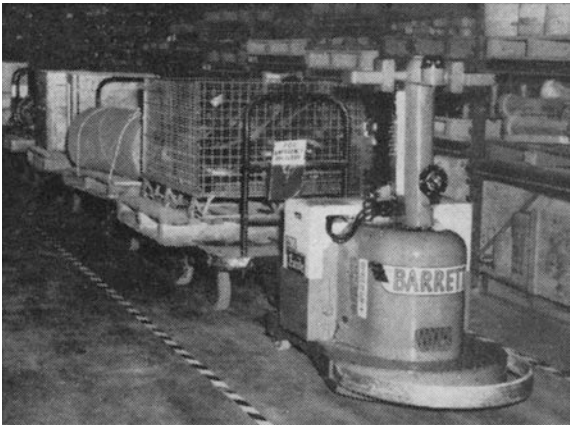

Fig. 1.2 One of the first American AGVS, built starting in 1954 as tractor for five trailers (*Source* Barrett-Cravens/Savant Automation (1958))

1.1 The First Era of AGVS – Idea and Implementation

The initial era of AGVS began in America in 1953 with its invention, followed by Europe a few years later. It lasted nearly twenty years. Technologically, the first machines were marked by their simple track-guided systems and tactile "sensors" such as bumpers and emergency arrest handles with mechanical switches.

In the early 1950s, an American inventor had had the idea of replacing the drivers of a tractor trailer for transporting goods using automation.

This idea was implemented by Barrett-Cravens of Northbrook, Illinois (currently Savant Automation Inc., Michigan). The first automated guided vehicle system (AGVS) was installed as a tractor-trailer in 1954 at Mercury Motor Freight Company in Columbia, South Carolina, for long-distance round-trip consignment shipping (Fig. 1.2).

The previously track-guided vehicles now followed an electrically conductive strip which was mounted on the floor. This principle is now known as inductive track guidance. This means that the first automated guided vehicle oriented itself while driving along the induced magnetic field. The stations at which loads (goods)

Fig. 1.3 Ameise/Teletrak (*Source* E&K (1965))

were to be transferred were coded with magnets sunk into the floor which were detected by sensors in the vehicles. The coding itself was based on a specific alignment of positively/negatively oriented magnets.

At this time, the simple guidance system consisted of vacuum tubes, which had only limited potential for development.

1.1.1 The First European Companies

In England, EMI entered the market in 1956. Their vehicles followed a colored strip on the floor which was recognized by an optical sensor, which sent out the corresponding signals. Starting in the 1960s, the first transistor-based electronics came into use, increasing flexibility in steering and guidance.

In Germany the companies Jungheinrich in Hamburg and Wagner in Reutlingen started developing AGVS in the early 1960s. They initially started automating the manually operated forklift and platform vehicles.

The mechanical engineering firm Jungheinrich was founded in 1953 and entered the market with its electric four-wheel "ant" lifter: the "Ameise 55". Then shortly thereafter, in 1962, it introduced the first automatically guided, induction-controlled "Teletrak" lifter. This also used optical track guidance (Fig. 1.3).

Wagner Fördertechnik started marketing automated guided vehicle systems starting in 1963 for use in automotive production and commercial trade.

1.1.2 Early Equipment and Tasks

From the very start, the first systems developed and built in the USA, England, Germany and other countries displayed basic characteristics that are still part of any AGVS: the guidance system, the vehicle with steering and personnel protection, the track guidance system.

The environment in which the first automated guided vehicle systems were employed consisted of regular factories or warehouses. Wherever workers transported goods with their vehicles and/or trailers throughout the factory and warehouse floors, the environment was adapted step by step to meet the demands of a system which no longer relied on human accompaniment. Markings, free lanes, passive and active protection measures were put in place to reduce risks. In the USA there were even reports of resistance to the new technology. The unions feared the loss of jobs. But who back then could have anticipated the creation of new jobs in the developing market for manufacturers and suppliers?

Starting in the mid-1960s the first systems for individual transportation were employed as part of the "interlinking" of workplaces, and finally the first systems were installed in goods commissioning in the food industry. The range of vehicles was restricted to towing vehicles, forklift and platform vehicles (Fig. 1.4).

The guidance system was simple: the vehicles followed predetermined paths from station to station, started on command and halted when they recognized the

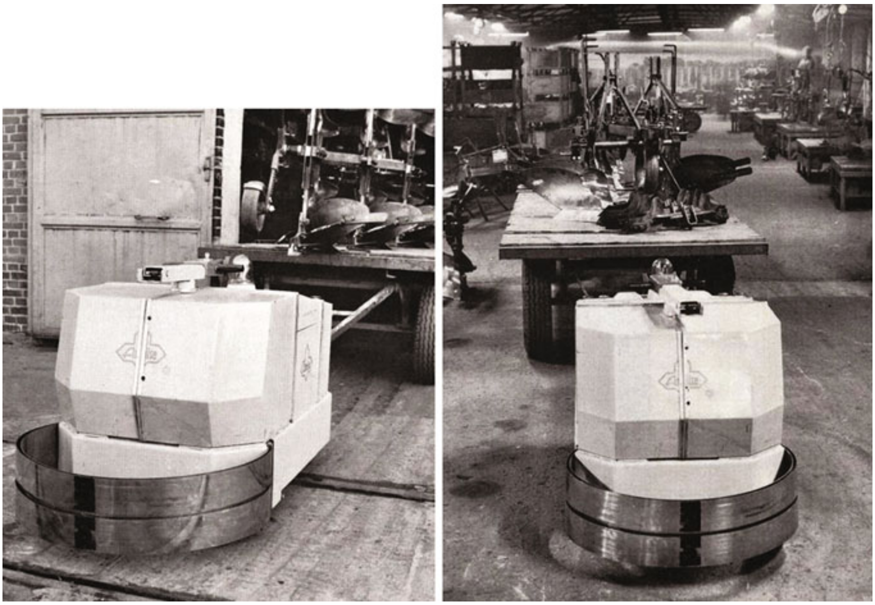

Fig. 1.4 Ameise/Teletrak with trailers (*Source* E&K)

stop marker. Simple electric and magnetic sensor systems were sufficient. Operations allowed for no flexibility, transportation covered greater distances, the stops were visited in succession, there was practically only one possible direction – forwards.

The automated guided vehicle (AGV) was developed from the manned tractor, in that it was a normal vehicle with steering, a drive and safety features. Its size was determined by the tasks it was to perform. With the driver removed, a combination of mechanical, electrical and "electronic" intelligence was to assume his role. Human perception – the driver's eyes – was thus replaced by sensory technology, if only in rudimentary form. In order to guarantee safety in working operations, not only the installation had to be protected, but the employees themselves.

Vehicle guidance was initially still based on vacuum tubes, then there were models with relays and "step-by-steps", and starting in the late 1960s with semiconductor technology (TTL logic).

Personnel protection for forward motion was provided with the aid of a bumper or safety bar, in any case equipped with a "tactile sensor".

Track guidance was based on electrified conductors on the hall floor or optical guiding strips.

Fig. 1.5 AGV as tractor (*Source* E&K ca. (1970))

At the end of the 1960s the first tractors with automatic tow hitches were designed, they were able to drive in reverse and drop off the trailers wherever they were needed. Figure 1.5 shows one such tractor being used in a French paper mill. It is interesting to note how unprotected the towed trailer was.

1.2 The Second Era – Euphoria about Automation

The second era spanned the 1970s and 1980s, ending with the early 1990s. Electronics were introduced in the form of simple on-board computers and enormous control cabinets for block section control. Active induction track guidance using a wire on the floor became the norm and data transfer followed either the same wire, used infrared or even radio signals.

The classic AGVS was finally developed in the 1970s. Through a combination of the ever-increasing productivity and the use of manned transport systems, there developed a demand for an even higher degree of automation in order to reduce production costs over the long term.

1.2.1 Technological Advances

Market demand, driven by user expectations, could only be satisfied by constantly improving technology.

A growing number of manufacturers and component developers increased the flexibility of the range of uses and improved system capabilities. Even at this stage, manufacturers recognized that they could above all take advantage of the rapid developments in electronics and sensory technology. But this did not lead to the development of a dedicated supplier market, as the overall market volume was still too small. Developers and manufacturers of components were driven by other markets, such as demand from manufacturers of traditional manned transportation vehicles.

The experience of the AGVS manufacturers was increasingly directed towards improved control systems. But the pool of suppliers was still based in the mechanical engineering sector.

Technical innovations freed manufacturers from previous limitations, a series of new developments appeared on the market in the 1970s:

- High-performance electronics and microprocessors allowed for quicker computing and thus for more complex use scenarios and equipment design. Programmable logic controllers (PLC) came into use. Improved, more affordable sensory technology improved precision during driving, navigation (positioning and position recognition) and at the goods transfer station.

- Batteries grew more powerful, although in retrospect, it must be admitted that the problem was never completely mastered. But automatic battery charging was introduced.
- One navigation process also became the standard: active inductive track guidance. An AC-charged conductor in the floor generated a concentric magnetic field, inducing a current in two coils attached beneath the vehicle. The differential current in each of the coils was then used to control the steering motor. The vehicle control was based on the block section control system used in railroads. Large control cabinets with relay equipment provided the necessary process control and ensured that vehicles did not collide or block each other.
- Handling of loads took place more intelligently and grew increasingly more automated. The vehicles' range of movement expanded (reversing and unloading, moving over predetermined areas); the first external applications were realized.
- Automated guided vehicles were fully integrated into production processes; this made it possible to use the vehicles as mobile workbenches (assembly lines).
- Infrared and radio signals were used for data transfer.

1.2.2 *Large-Scale Projects in the Automotive Industry*

Market demand was driven primarily by the automotive industry. Especially for the large German auto manufacturers there seemed to be no limits to modernization and automation. AGVS was part of it, it was the "in" thing to do, especially in the following areas of application:

- Taxi operators for "pit-stop field assembly"
- AGVs as mobile workplaces in pre-assembly
- Interlinking of production machines in component manufacturing
- Tractors, piggyback and forklift vehicles to supply production lines
- In the warehouse, for commissioning and delivering materials to the lines
- Special equipment for integration into manufacturing systems.

Many of the major FML[1] partners in the automotive industry deliver large volumes of equipment, often using hundreds of vehicles. The equipment is used in pre-assembly (cockpit, front-end, doors, motors, gears, drivetrains), in final assembly, in vehicle assembly and also for logistics tasks (Figs. 1.6, 1.7 and 1.8).

[1] FML – Material Flow and Logistics.

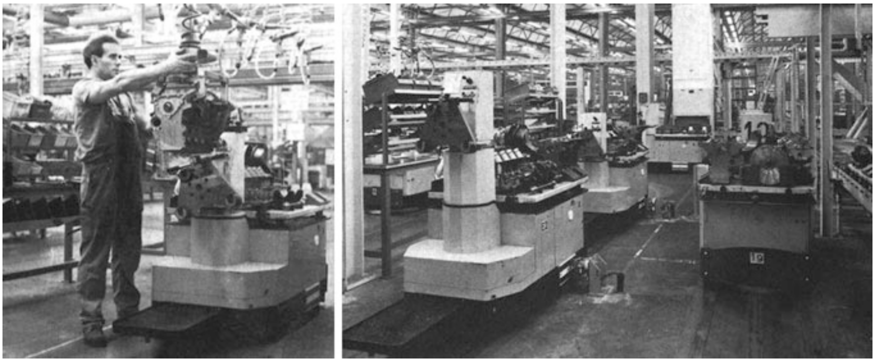

Fig. 1.6 Induction guided assembly platform for motors at VW in Salzgitter (*Source* E&K (1977))

Fig. 1.7 Car manufacture with AGVS: assembling a VW Passat at VW in Emden (*Source* DS (1986))

Fig. 1.8 Engine assembly line at VW in Hannover (*Source* DS (1986))

1.2.3 The Big Bang

At the end of the 1980s a major catastrophe loomed: industry was hit by a recession – money grew scarce. AGVS already had the image of being expensive: the flexibility that the systems advertised themselves with was not achieved in practice.

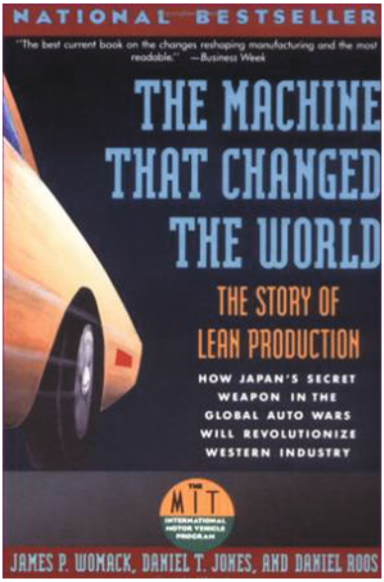

Fig. 1.9 The Machine That changed The World - The Story of Lean Production

Slight variations in the drive path had to be re-programmed by the AGVS suppliers and cost a great deal of money. The reliability and availability of the equipment left a lot to be desired.

The German auto manufacturers Volkswagen, BMW and Mercedes Benz all agreed that something had to be done about the compatibility and economic efficiency of the systems. They initiated the founding of a VDI (Association of German Engineers) specialist panel[2] "Automated Guided Vehicle Systems", which started work in 1987, under the directorship of Prof. Dr.-Ing. Dietrich Elbracht, professor at the University of Duisburg, to develop VDI guidelines for relevant AGVS topics. The author, a founding member, has been director of this panel since 1996.

Four years later, this VDI specialist panel held its first AGVS convention[3] in Duisburg, during which these topics were discussed in great depth. In addition, the AGVS Forum[4] was created in 2006 – the European AGVS Community, in which the key AGVS manufacturers in central Europe (Finland, Belgium, The Netherlands, Germany, Austria, Switzerland) are organized.

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[2] www.vdi.de/fts.

[3] The AGVS convention is held bi-annually, since 2012 at the Fraunhofer Institute IML in Dortmund (www.fts-fachtagung.org), from 2002 to 2010 at the University in Hanover and initially, in the years 1991, 1993, 1995, 1998 and 2000 at the University of Duisburg.

[4] www.forum-fts.com, also contains a list of all of the successfully active AGVS manufacturers in Europe.

Nevertheless, the AGVS industry could not escape the temporary downturn, chiefly caused by an American book (see figure below), which contains an MIT study[5] of productivity for worldwide automotive manufacturers. This study maintained that Japanese auto manufacturers were able to build cars of better quality and with lower manufacturing costs using the simplest means.

This study led to a completely new approach in Europe. It was the end of the line for the largest AGVS equipment (the AGVS recession). Many “large” AGVS manufacturers gave up AGVS activities or went the way of licensing in a more globalized world. But in the end, a new day was dawning with new medium-sized players, new technology and new customers and industries!

1.3 The Third Era – Proven Technology for Intralogistics

The third era lasted from the mid-1990s to around 2010, during which technological standards were set and new markets were established. The devices have electronic guidance and contact-free sensors. They are controlled by a standard PC, the AGV contains either an SPS or a microprocessor. Conductive cable guidance no longer plays a role. The classic “free” navigation technologies are magnetic and laser navigation. WLAN has established itself as a means of data transfer.

This era was noted for the fact that the automotive industry relinquished its dominance to a broad range of the most varied users. There are not as many AGVs per plant as during the second era. And another key trait was first noticed for AGVS: Automated guided vehicle systems of today are reliable, proven means for intralogistics. Manufacturers can choose from a cornucopia of well-tested technologies, combining them to create reliable, powerful and recognized products.

Progress in materials flow and warehouse technology, improved production methods in mechanical engineering and new trends in assembly technology all support developments in AGVS. And improvements in computing and sensory technology bring about further key developments in vehicle and controlling technology and in the following areas of application:

- Higher speeds for vehicles while driving, maneuvering, handling loads thanks to improved sensory technology
- Low-cost vehicles, or better: simple solutions
- Alternative energy concepts with inductive energy transmission
- New navigation processes (magnet point, laser, transponder, building navigation)
- The triumph of the PC – in vehicles, in equipment control and in intelligent sensory technology

[5] James P. Womack, Daniel T. Jones, Daniel Roos: The Machine That Changed the World: The Story of Lean Production. Publisher: Harper Paperbacks; edition: Reprint (November 1, 1991).

Table 1.1 AGVS companies that are mentioned in the following chapters

Abbreviation	Name	Description
CREFORM	CREFORM Technik GmbH, Baunatal, Germany www.creform.de	AGVS manufacturer, AGVS Forum member
Dpm	Daum + Partner Maschinenbau GmbH, Aichstetten, Germany www.daumundpartner.de	AGVS manufacturer
DS	DS Automotion GmbH, Linz, Austria www.ds-automotion.com	AGVS manufacturer, AGVS Forum member
E&K	E&K Automation GmbH, Rosengarten, Germany www.ek-automation.com	AGVS manufacturer, AGVS Forum member
Egemin	Egemin NV, Zwijndrecht, Belgium www.egemin.com	AGVS manufacturer, AGVS Forum member
Fox	Abteilung FOX, Götting KG, Lehrte, Germany www.foxit.de	Department of Götting KG, which automatizes serially-built vehicles
Frog	Frog AGV Systems B.V., Utrecht, The Netherlands www.frog.nl	AGVS manufacturer, AGVS Forum member
Götting	Götting KG, Lehrte, Germany www.gotting.de	Component and systems manufacturer, AGVS Forum member
MLR	MLR System GmbH, Ludwigsburg, Germany www.mlr.de	AGVS manufacturer, AGVS Forum member
MT Robot	MT Robot AG, Zwingen, Switzerland www.mt-robot.com	STS manufacturer, AGVS Forum member
Rocla	Rocla OY, Jarvenpaa, Finland www.rocla.com	AGVS manufacturer, AGVS Forum member
Schabmüller	Schabmüller GmbH, Berching, Germany www.schabmueller.de	Component manufacturer for drive and steering motors
SEW	SEW-Eurodrive GmbH & Co KG, Bruchsal, Germany www.sew-eurodrive.de	Component and systems manufacturer for power and energy equipment
SICK	SICK AG, Waldkirch, Germany www.sick.com	Supplier of safety components and systems, AGVS Forum member
SimPlan	SimPlan Integrations GmbH, Witten, Germany www.simplan.de	Service provider for simulation and emulation
Snox	Snox NV, Aartselaar, Belgium www.snox.com	AGVS manufacturer, AGVS Forum member
Swisslog	Swisslog GmbH, Westerstede, Germany www.swisslog.com	Holding company, Telelift

Table 1.2 Key developments involving current AGVS manufacturers, limited to the European market

Year	AGVS manufacturer	Event/background
1953	All	Barrett begins in America with AGVS
1956	All	EMI produces AGVS in England; 1973 Kalmar begins in Sweden at VOLVO with AGVS
1962	E&K	Jungheinrich, Hamburg begins with AGVS (Teletrak)
1963	E&K	Ernst Wagner KG, Reutlingen starts development of automatically driven vehicles
1969	Egemin	Egemin delivers its first AGVS, but only with vehicles purchased from outside
1970	Swisslog	Telelift starts with its Transcar AGVS. Since 1973 in Puchheim near Munich
1971	MLR	Start of Babcock und Bosch transport- and warehouse systems in Stuttgart, later (1983) in Schwieberdingen. The "Bosch Transport and Warehouse Systems" Division of Robert Bosch GmbH, Stuttgart, serves as nucleus for AGVS components (steering control and guidance signal generators). Wagner initially installed (until 1971) these parts in their vehicles/equipment. The division was later sold to Babcock and then to MLR
1971	E&K	Die Ernst Wagner KG, Reutlingen, founds its "Automated Guided Vehicle Systems" Division
1973	E&K Demag	Mannesmann takes over DEMAG. 1992 Mannesmann Demag Fördertechnik AG, Wetter, is founded. The company history goes back to 1910, when the Deutsche Maschinenfabrik AG (DeMAG) was founded. Parallel to that in 1956, Leo Gottwald KG was founded, producing harbor cranes and later also AGVS for the harbor sector. In 2006 merged with Demag Cranes & Components GmbH and Gottwald Port Technology GmbH (GPT) under the heading Demag Cranes AG, which today still produces AGVs for use in container harbors
1974	MLR	Name change from Babcock and Bosch Transport and Warehouse Systems to Babcock Transport and Warehouse Systems, as Babcock assumes 100 % of the company shares
1980	MLR	Pohling-Heckel-Bleichert AG in Cologne takes over the Transport and Warehouse Systems Division from Babcock. Company is thence known as PHB Transport and Warehouse Systems
1980	E&K	Eilers & Kirf found an engineering firm for control technology. Since 1988 system partners for Jungheinrich
1983	Rocla	Rocla begins in Finland with AGVS
1984	FROG	FROG begins in NL; first as Frog Navigation Systems. 2007 then relaunched as FROG AGV Systems
1984	DS	Voest Alpine, Linz (Austria) begins with AGVS. Later spins off TMS Transport and Assembly Systems

(continued)

Table 1.2 (continued)

Year	AGVS manufacturer	Event/background
1985	MLR	PHB Transport and Warehouse Systems takes over MAFI Transport Systems and a year later, Trepel GmbH, Wiesbaden. In addition, formation of the PHB Holding Company for Industrial Holdings; this includes the companies PHB Transport- and Warehouse Systems, Eisgruber, Mafi, Trepel and BBT
1986	E&K	Linde, in two stages (1986 und 1988) acquires shares of Wagner Fördertechnik, with complete takeover in 1991 the "Automated Guided Vehicle Systems" Division is spun off as an independent company, INDUMAT
1989	Swisslog	Thyssen Elevators takes over Telelift
1990	MLR	Noell, Würzburg takes over AGVS activities from the PHB Group. Name: Noell, Schwieberdingen affiliate. Noell belonged to the Preussag-Salzgitter Group
1993	MLR	Noell takes over Autonome Roboter, Hamburg, and in 1994, Schöller Transportautomation, Herzogenrath
1993	E&K	The AGVS activities of Mannesmann Demag and Jungheinrich are transferred to Demag-Jungheinrich AGVS GmbH, Hamburg
1996	E&K	Eilers & Kirf takes over Demag-Jungheinrich AGVS GmbH
1997	MLR	MLR takes over the Automated guided vehicle systems Division from Preussag/Noell
1999	Swisslog	Swisslog tales over Telelift from Thyssen Elevators. Swisslog created from the former Sprecher & Schuh AG (since 1898 in Aarau, Switzerland)
1999	CREFORM	Founding of CREFORM Technik GmbH Germany, affiliate of Yazaki Industrial Chemical Co. (Shizuoka, Japan) and its US affiliate CREFORM Corporation (Greer, USA), Goal: Marketing simple, flexible material handling systems (modular AGVS building blocks)
2000	Fox	Götting KG founds the independent Fox Company, which automates standard utility vehicles: trucks and wheel loaders
2000	Egemin	Egemin begins building its own vehicles
2001	E&K	E&K takes over INDUMAT from Linde
2001	DS	Voest-Alpine sells off its AGVS business in TMS to VINCI, France
2004	Snox	The Snox Engineering Group enters AGVS business
2005	DS	HK Automotion, Austria, takes over TMS Automotion; 2008 then name change to DS Automotion GmbH
2008	Götting	Fox GmbH activities continued by the parent company as a separate division
2008	MT Robot	Founding of MT Robot AG
2008	Rocla	Rocla becomes part of Mitsubishi Caterpillar Forklift Europe
2012	Swisslog	Swisslog Healthcare Solutions merges with JBT Corporation of Chicago (USA) for hospital activities, drops the name Telelift and focuses its activities in Westerstede, Germany. Separation from the product categories Small Transport Equipment and the corresponding brand name Telelift
2013	Snox	Taken over by Grenzebach Maschinenbau GmbH

- Data transmission predominantly via WLAN
- New areas of functionality, such as serving a bulk-storage warehouse, in commissioning, in the “fractal factory” (lean production) or in hospitals.

Basically, it means that almost any load can be transported with AGVS. Any operations in which pallets, containers, bales, packets or anything similar are transported, can in general make use of AGVS. This means that more and more industries have turned to AGVS since the mid-1990s, but in contrast to the automotive industry in the second era, with a more considered approach and generally with success.

Handling wares has transformed itself from initially unilateral transport to a multidimensional means of delivery, since the vehicles are now equipped to move the goods to practically any spot in the warehouse or factory. In addition, they can position the goods on demand and ergonomically for assembly work. Complex traffic networks arise with a number of vehicles with intersecting pathways and an ever increasing number of load transfer stations.

In Japan, following the principles of Kaizen, the existing storage shelves along the production lines were transformed into automatic logistics units. A modular AGVS building block system was developed to this end, which combined all the necessary elements from a simple magnetic track guidance through to control in a closed unit.

Worldwide, clinical logistics have become a new market for AGVS, one which is growing increasingly more interesting because the AWT equipment is being used to date, such as OM or even previously P&F, can be fully replaced sooner or later through AGVS.[6]

The equipment and the applications used during this era will be the topic of following chapters, which is why we will pause here briefly. It is important to present an overview of the AGVS manufacturers who currently play a major role along with their backgrounds. Table 1.1 thus lists all the companies that are referred to in this book and Table 1.2 gives an overview of the key developments in the European market.

[6] Abbreviations: AWT – automatic wares transport system; OM – overhead monorail; P&F – power and free (chain drive).

Chapter 2
Modern Areas of Application

In the next two sub-chapters we will address modern AGVS, namely equipment and technology typical for the third era of AGVS. First we will subdivide the applications according to processes and then have a look at actual cases from selected industries. All these applications have been realized in the period after 2000. In chapter three we will have a look at the technological standards which serve as the basis for the numerous AGVS projects which have been realized in recent years.

2.1 Task-Based Aspects of AGVS in Use

The main areas of application for AGVS lie in intralogistics, namely in organization, controlling, execution and optimization of internal goods and material flows and logistics, information channels and goods transfer in industry, trade and public institutions (as defined by the VDMA[1]).

These include some limitations: it means we will not be addressing the so-called PeopleMover, automatic vehicles for transporting people. That is rather difficult at the present time. First of all because there are only very few of them in current use and secondly because of a general lack of binding regulations and laws.

Many special applications[2] will also be left out of consideration: applications in space travel, in or under water, military equipment, facade cleaning, walking or climbing machines.

We intend to restrict ourselves to the transportation of materials, especially in the area of intralogistics.

[1] VDMA = Verband Deutscher Maschinen- und Anlagenbau (German Mechanical and Plant Engineering Association).

[2] The first automatic car parking system with AGVS was realized by Serva Transport Systems GmbH in Bernau and at FhG-IML, Dortmund, at the airport. *Source* Hebezeuge Fördermittel, Berlin 53 (2013) 6.

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2.1.1 AGVS in Production and Services

At the beginning of this chapter we want to take a closer look at the tasks of intralogistics since this is the area in which classical AGVS is most commonly used.

The movement of goods (cargo, goods, materials, supplies etc.) takes place in various areas within an operation or its premises, between companies or divisions in different locations as well as between companies and consumers.

The organization, execution and optimization of these goods, wares and material flows within an industrial, commercial or public organization is known as intralogistics. Key aspects of this broad range of topics include

- processes for handling goods and materials, especially incoming and outgoing goods, in warehousing and commissioning, in transportation as well as goods transfer and provision;
- followed by information flows, namely the communication of inventory and movement reports, the outstanding order situation, throughput times and availability forecasts, presenting data to support tracking, monitoring and if needed to make decisions on measures to be taken, as well as the selection and implementation of means of data transfer;
- the use of means of transportation (cranes, lifters, conveyors, industrial trucks, etc.), as well as monitoring and control elements (sensory and actuating equipment);
- and finally the use of techniques (for active/passive security, data management, goods and wares recognition/identification, image processing, goods transfer, namely provision, sorting commissioning, palletizing, packaging).

Within the combination of factors influencing the means of production, the efficiency of the production process, and thus its potential profitability, depends upon the design and selection of the means of transportation.

The **production area** is characterized by the process chain from goods receiving through to shipping. Depending on the incoming order situation, sales, disposition, manufacturing management and administration continuously shape various elements of this process chain, specifically

- increasing or decreasing stocks and the necessary goods, wares and material transfer (goods receiving, shipping, materials warehouse),
- set-up and throughput times while balancing over and under-capacities, as well as the delivery times as required by the recipients,
- establishing or altering order priorities and
- optimizing lot sizes.

These tasks require ongoing regulation, monitoring control, and frequent adjustment to the constantly changing situation. In order to achieve maximum flexibility to efficiently deal with these tasks, a balanced choice of the right means of transportation is every bit as essential as the step-by-step production planning and careful pre-planning (and simulation if needed).

The situation is identical for applications in the **service sector**. If we define the "production area" as the area which makes its services available to the recipient, then we can recognize comparable tasks in the process chain, even when the staff involved have differently designated functions.

In the business economics area of a company, the choice of means of production chiefly influences not only questions of financing means and applications but also the analysis of capacity utilization and planning, applied to both technical means and personnel resources.

Technical and business management has the task of optimizing the available material and personnel resources in light of the demands placed on the company and the means necessary to meet them. This requires definitive and logged operating data such as warehouse transfer times, throughput times with downtimes, production capacity utilization, etc.

At this point, this should suffice to define the role of AGVS in intralogistics in order to cover AGVS more specifically in following sections.

2.1.2 AGVS as a Means of Organization

It is often the case that automated guided vehicles (DTVs) are considered synonymous with AGVS. The discussion moves quickly to the various vehicle types or other concrete topics:

- Which type of AGV is preferable, e.g., forklift or piggyback AGV?
- Which navigation method is preferable (laser or magnetic navigation)?
- Which concepts for personnel protection are available?

Naturally, automatic vehicles (DTVs) are important components of an AGVS, but in the end, they are only components. If we want to be thorough, we have to consider the AGVS as a whole, which according to the VDI 2510[3] guideline consists of the vehicles, the guidance system and the floor-mounted equipment. This guideline lists the key global characteristics of a AGVS (Fig. 2.1).

Here we must emphasize that an AGVS in its capacity as a means of organization has an extensive and ongoing influence on intralogistics. Initially, the high degree of order that is a prerequisite for operating the AGVS seems burdensome. But it soon becomes clear that this degree of order is the consequence of AGVS, offering a chance for the processes to be continuously optimized in the course of ongoing improvements.

When, for example, it is the case of automating a typical "forklift operation" with AGVS that is intralogistics with manually operated vehicles, the operator often mourns the loss of the purported advantages of a forklift: system performance that

[3] VDI 2510 "Fahrerlose Transportsysteme (DTS)", VDI 10/2005, Beuth-Verlag, Berlin.

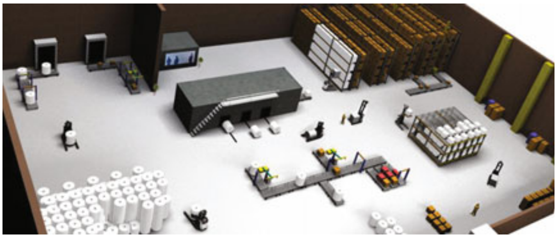

Fig. 2.1 An AGVS connects various processes in paper roll handling (Diagram, *Source* Rocla)

can quickly and flexibly be summoned to fulfill a particular task. But if the operator looks more closely, he will see that AGVS's system performance is also high, in deed, as high as it was "set" during the planning phase; in fact naturally as a long-term level of performance with extremely high reliability.

The high level of flexibility of a forklift is only necessary and called upon when the task is not optimally structured (the responsibility of the planning department) or rather in those rare cases where it cannot be structured. But most processes harbor sufficient optimization potential so that the steps can be organized to take advantage of an AGVS. One of the most underestimated advantages of AGVS lays in its ability to maintain an established order – because it is designed to do so! Examples of this are the clearly defined travel routes and stacking locations.

To this day, automatic guidance vehicles are unable to negotiate around obstructions in their path, such as a group of employees conferring or an incorrectly stacked pallet. That is fully acceptable since a well-organized, automated operation should not allow employees to block the transport routes or misplace pallets!

By observing the current situation and adapting simple rules in AGVS guidance control, it is possible to retain positive developments, while changing or eliminating negative ones. Well planned intralogistics can immediately adapt to ongoing changes in processes/product ranges/stock levels, etc. This means that a AGVS, using simple rules, can optimize logistic processes and grow to meet demand. Which transportation system is as flexible and consistently efficient?

2.1.3 Taxi Operations

Normally a distinction is made regarding the forms employed in flow lines and taxi operations. DTP, with intervals set by the assembly lines as an assembly platform, works in assembly line operations. That will be the topic of this chapter.

In taxi operations the stations (as with passenger stops) are known as sources and sinks. Material transport originates at a source and ends at a sink. Of course, any station can serve as both source and sink (Fig. 2.2).

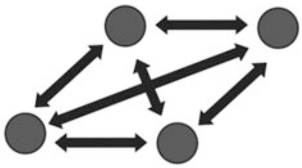

Fig. 2.2 Basic diagram of a taxi operation according to VDI 2710-1 (VDI 2710 Page 1: Overall planning of AGVS Decision-Making Criteria for the Choice of a Conveyor System. VDI 08/2007, Beuth-Verlag, Berlin)

Vehicles that travel within a network of sources and sinks, freely and flexibly combining a number of individual positions, are part of a taxi system. This type of AGVS is comparable to a taxi company in a city.

But a taxi system needs more than high-performance vehicles. Routing is of highest importance (taxi dispatcher), where all important information is gathered and optimally assessed. This is the basis for optimizing potential. To continue with the metaphor of an urban taxi company: A successful taxi operation relies on more than purchasing a taxi as a means to cart people about. It needs a dispatcher's office to receive calls and remain informed at all times (location of individual taxis, current traffic situation in the city…).

The dispatcher is the brain of the operation, ensuring that the right types of vehicles are used and can fulfill all their tasks on time. A number of outside considerations come into play here, such as priorities, temporary layout restrictions (construction sites), daily schedules, etc.

The classical transportation task for an AGVS in a taxi operation is: "Pick up from source X and deliver to sink Y". This task is administered in the AGVS guidance control, just as a passenger orders a taxi, for example, from a hotel to downtown by calling the dispatcher who then sends an appropriate taxi to cover this "transportation order" and reply upon completion.

A taxi system normally serves to deliver or remove items to the production area or to interlink production areas with warehousing and shipping.

2.1.4 Flow Line Organisation and the Focus on Series Production

The first AGVSs could only be used in flow line organisation. There were none of today's possibilities for realizing complex layouts and to control them to meet demands. Today, the flow line principle is usually used in assembly systems (Fig. 2.3).

There are various possibilities to realize assembly systems. Here we describe aggregate serial assembly, such as the classic motor assembly in the automotive industry. There are related assembly lines in the automotive industry such as cylinder heads, gears, differentials, steering, axles, doors and cockpits.

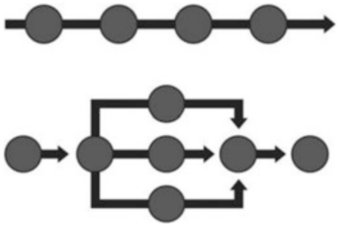

Fig. 2.3 Schematic view of flow line principle, linear and branched (in accordance with VDI 2710-1)

Even smaller industries use such assembly lines, including the electrical industry, household appliances and electronics and plant engineering. The type of transport system employed is determined by various criteria arising from technical and business considerations as well as company policy.

2.1.4.1 Tasks in Series Production

In these assembly areas, there are three main tasks for transportation systems.

We start with the main assembly line, in which the product to be assembled (such as the car motor) has to be transported from the starting to the end of the line. Assembly takes place along the line between the start and end points. (Assembly line application) (Fig. 2.4).

The next task involves commissioning parts for assembly. Because the range of parts is usually too large to allow all need materials to be stored directly along the assembly line, selected parts are collected in a special commissioning area. A transport system is then needed to move articles into the commissioned container, such as a basket of goods. (Commissioning application) (Fig. 2.5).

And last but not least, the commissioned container must be transported from the commissioning area to the assembly line. This does not necessarily need to be transported by the same system used in the commissioning area (transport application). Along with AGVS, the following transport systems are in current use in series production:

Fig. 2.4 Assembly of printing machines at KBA (*Source* Snox 2008)

Fig. 2.5 Automatic fork-lifts used in commissioning (*Source* Rocla 2010)

Fig. 2.6 A simple trailer-pulling AGV moves the transport carts with commissioned parts to the assembly line (*Source* DS 2004)

Fixed conveyor belt This applies to various technical designs, such as work piece carriers that move through the assembly are at a constant rate or at intervals: with chain drives, roller rails or an overhead track based on the inclined roller principle.

Monorail conveyors Individual electrically driven cars move along a track which is either suspended from the ceiling of the hall or mounted on steel supports. The cars have places to affix the goods to be transported (Fig. 2.6).

In principle, all the transport systems mentioned can be used for any task. The following suitability table takes economic considerations into account (Table 2.1).

Fixed assembly lines can only be used for a single line because they are too rigid, inflexible, slow and expensive for commissioning and purely transport-related tasks. In addition, paths and passageways become blocked.

Manually driven industrial trucks make sense for purposes of purely transport-related tasks since slow assembly rate and time-consuming commissioning would increase personnel costs. For commissioning each driver would have to select the parts, which does not make sense, since the driver would have to constantly get in and out of the seat. Hand carts are the cheaper alternative here.

Table 2.1 Suitability table for conveyor systems in mass assembly tasks

	Assembly line	Commissioning	Transport
Fixed assembly lines	+	O	O
AGVS	+	+	+
Monorail conveyor	O	O	O
Industrial trucks	–	O	+

Key None or limited application O, Highly applicable +
Industrial trucks: This term embraces all the manually driven individual vehicles, such as forklifts or tractors. Even hand carts come under this heading (Fig. 2.6)

The overhead monorail occupies a special position. It depends entirely on the size and construction of the hall and its roof. But in most cases there are more flexible and cheaper solutions available. There is generally little comparison between overhead monorail and its competitors.

For reasons stated above, we will now look at three combinations:

For the main assembly line: AGVS versus fixed assembly line

For transport: AGVS versus industrial trucks

For commissioning: AGVS versus Industrial trucks (hand carts)

2.1.4.2 AGVS or Fixed Assembly Line?

This will initially depend on the layout of the line itself. The simpler the layout, the better it is suited for a fixed line. Because branch lines, parallel assembly and production islands can only be realized using AGVS, which turns out to be no more expensive. The layout can become more demanding with synchronized areas in conveyor assembly. Complex layouts for fixed lines also mean extremely limited accessibility. Areas are permanently occupied; pathways are blocked, worsening the ergonomics of assembly.

By limiting itself to a "simple oval", the fixed assembly line has the advantage of being able adjust to constant feed rates. A fixed assembly line does not need AGVS! In addition, fixed assembly equipment is simpler compared to AGVS making it more durable and reliable.

But it is often the case that a "simple oval" remains an unrealistic dream. What about assembly line testing? Is there 100 % testing or only static testing? Do the work piece carriers not have to occasionally be moved to separate testing areas?

The same question is posed for reworking: what should be done if errors are detected? It generally makes no sense to continue to work on defective work pieces, simply sending them down the line despite their defects. A separate island is needed here.

The biggest argument in favor of AGVS its flexible layout. If the layout needs to be altered during operations, a fixed line will be troublesome and expensive. Changes in the line can be made necessary by changes in the assembly itself, such as new products, or if the overall production is to be increased or cut back, or after working with the system has led to implementing improvements. This is where the advantages of AGVS are clear.

Along with the layout of the assembly line there is another equally key criterion: are there automatic stations along that line that demands highly precise positioning or moving large loads with momentum? An example of this is the motor pre-assembly. This poses no problem for the static line. The work piece carrier can be set to move to fixed points with a high degree of accuracy. AGVS can also be used for such stations, but at a considerably higher cost. Here the final decision would be based on the number of automatic stations needed!

One often-named advantage of fixed lines is the smaller space requirement compared to AGVS. This argument is valid to the extent that the space requirements for a fixed assembly line can be minimized – if it has to be (because of limited available area) or it is definitely so desired by the company's philosophy.

But this argument should not be considered separately. The less space available for assembly, the less space there is for components to be stored directly on site. That means that commissioned parts must be delivered to the line just in time. This in itself requires the establishment of an extensive commissioning area. The total area required for assembly and commissioning combined will be nearly identical. And this does not include the area needed to move the commissioned parts to the assembly area or sharing existing routes.

2.1.4.3 AGVS or Forklift for Commissioning and Transport?

We will compare industrial trucks (such as hand carts) to AGVS in commissioning and in purely transporting tasks, in essence, manual versus fully automated transport equipment. Because there are a number of key differences that do not depend from their special tasks, we should first examine these distinctions.

In general, there are two groups of arguments that speak in favor of automation. The first group focuses on the quality of the transportation. AGVS prevents all types of transport damages, both to the transported goods as well as to the stationary facilities such as loading aids, pillars, walls, racks, shelves and gates.

In the end, AGVS is to be seen as a means of organizing, as already mentioned. It offers optimal material and information flows, creating more transparency. In addition, it eliminates delivery errors, automation offers absolutely reliable transport.

In general it can certainly be said that the market for automated material flows systems and thus also for AGVS has grown along with development of computer technology and the related guidance and sensory technology. This especially applies to product and producer liability issues, which drive many industries to document every single production process stage, automation has become a necessity.

The second group of arguments addresses the conceptual advantages of AGVS over manual conveyor equipment: Today's highly modernized logistics demonstrate a leap in technology both outwards and within and has an inestimable motivational and image-enhancing effect.

2.1.4.4 AGVS or Simply Only Handcarts in Commissioning?

But what would that mean for commissioning? The chief advantage of hand carts is clear: Investments for operating costs are negligible in comparison to AGVS. Those who are satisfied with system's performance using the manual version are fine as long as they don't look beyond the boundaries of commissioning! Because the containers or baskets of goods that have been filled by hand cart have to find their way to the assembly line somehow – but certainly not by an employee pulling or pushing a hand cart!

AGVS has other quality advantages in commissioning: Strict procedures can be programmed in, meaning that fixed commissioning areas and destinations can be pre-set. All the processes can be documented ongoing without any extra work. In addition, a combination of fixed and interval-based commissioning areas is only possible with AGVS.

2.1.4.5 AGVS or Forklift for Purely Transport-Related Tasks?

When it is time to transport the commissioning container or basket of goods to the assembly line, then we see how forklift (or tractor) and automated guided vehicles compete. Along with the already-mentioned overall differences between manual and automated conveyor technology, the comparison here is concentrated on the following points:

To compare the systems, not only the initial investment, but in sense of TCO,[4] the initially higher investment costs for AGVS are balanced out by the lower ongoing costs. Automated technology is also easier on equipment: consistent and low-impact driving significantly reduces wear on tires, batteries, gears, etc. In addition it is an open secret that automated guided vehicles are designed and built for permanent use for more than 10 years as opposed to a 3 – 4 year lifespan for forklifts.

To complete the economic comparisons we also have to factor in personnel costs, which make up a significant share for forklifts and tractors. For two-shift operation, three operators are needed for each vehicle, for three-shift operations, four-and-a-half would be needed. At an annual cost of around €40,000 per driver, this seriously counterbalances any purported investment advantages for the manual system.

The comparison of industrial trucks with AGVS also highlights further conceptual advantages of AGVS: for example, regarding availability and continuity. AGVS operates quietly, but calmly and without letup. In addition, it is safer and accident-free. It is orderly and cleanly, reduces stress and creates a pleasant work atmosphere.

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[4] TCO = Total Cost Of Ownership.

2.1.4.6 Summary of Series Production

AGVS is a serious alternative for all three task situations mentioned here. Since series assembly is usually not designed for short periods but for at least 5 years (naturally with regular layout adaptions), there is a lot to be said for the lower operating costs and the ease of making changes in AGVS.

And this runs all the way through all three task situations. AGVS in assembly, in commissioning and transport between the two – an end-to-end version without changing the transport system!

And why should components be placed in a basket of goods, which is then put on a tray or shelf to be picked up later and installed into the workspace, something that makes no sense in light of MTM.[5] It is better to send the work piece directly through commissioning and perform pre-assembly right there: Complex components are not time-consumingly dropped off next to the work piece, but attached directly to it, dissolving the classical distinction between assembly and commissioning.

Although AGVS takes up more space in assembly than fixed assembly, but when we consider the space needed for commissioning, the overall planning with AGVS offers a better solution!

With an additional option that only AGVS offers: Planning with its extensive MTM analyses bucks up against its limits in everyday use. If AGVS assembly lines are already planned in with necessary island solutions or alternating workplaces, it allows the managers, foremen and employees to implement their own improvements on site with minimal effort. This increases the worker's sense of individual responsibility and improves motivation – all of which leads to better productivity.

2.1.5 Warehousing and Commissioning

Warehousing and commissioning are key tasks in intralogistics. The following section will exclusively cover the topic of block storage, since an uncluttered warehouse floor seems to be principally predestined for automated guided vehicle systems.

2.1.5.1 Floor-Level Block Storage Warehouses

Simple floor-level AGVS block storage warehouses have existed for several years now in a number of variations. They started with individual buffer aisles for delivery or pickup of prepared pallets in production or in the warehouse through to buffer aisles that occupy the entire area (Fig. 2.7).

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[5] MTM = Methods-Time Measurement.

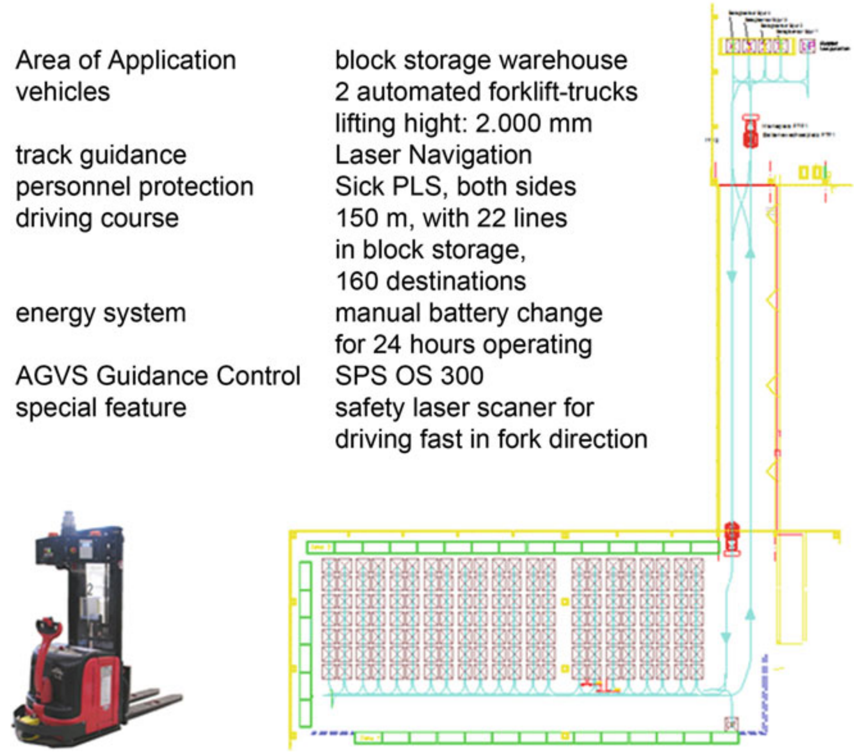

Fig. 2.7 Example of a floor-level block storage warehouse (*Source* E&K 2012)

A typical example already in use is a three-shift production area and a two-shift goods issue area. AGVS buffers the production area overnight with a floor-level block storage area near the goods issue area. This means that AGVS is used for the fully automated transport and the block storage area.

A typical task for AGVS can also be preparing goods for loading onto trucks.

2.1.5.2 Multi-story Block Storage

Block storage areas are often multi-story, i.e., several pallets are stacked on top of each other. Automating such a stacked block warehouse is naturally challenging and requires high-quality and more or less uniformly packed pallets. High-performance vehicles and intelligent equipment control allow realization of highly flexible block storage areas with thousands of stacking sites.

This is of special interest to the beverage and paper industries, which frequently work with large numbers of relatively uniform and easily stacked wares.

An example of this is the Radeberger Brewery in Dortmund. Over 10,000 pallets are automatically stacked on top of each other in a warehouse area of 80 × 80 m, the top level of beer crates is 6.6 m high.

Stacking to this height would be unsafe without the support of sensory equipment. A 3D-pallet recognition followed by analysis of the current pallet position was developed and used for the first time for this purpose (E&K 2011). The AGV approaches the programmed intended position, then generates and analyzes a 3D photo: based on that, the fork is positioned and its lifting height adjusted to fit the pallet position and the pallet is cleanly lifted without even touching the pallet.

3D-pallet recognition allows safe and reproducible addition or removal of goods even at great heights. Individually adapted addition or removal strategies allow optimal use of available space.

Since a block storage warehouse can do without any shelves, the user has the freedom to completely restructure the warehouse without a great deal of effort to relocate or reorient aisles or to temporarily block off areas and use them for other purposes (Fig. 2.8).

As in any automated operation, prerequisite for the reliable and successful use is a tested pallet quality and sufficient level floor space to correspond to the technical specifications for AGVS.

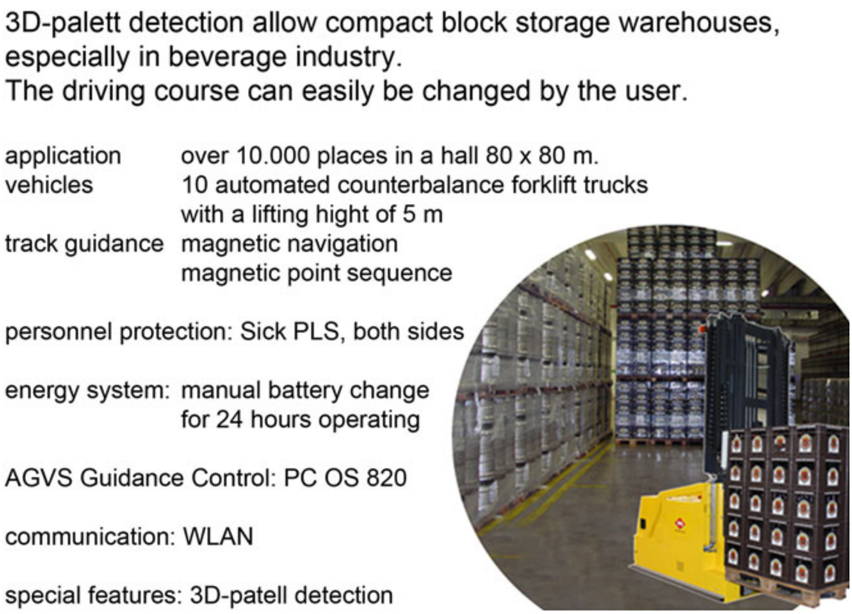

Fig. 2.8 Characteristics of AGVS with pallet recognition in block storage a warehouse (*Source* E&K 2011)

The set-up of the storage blocks is determined by the shape of the hall, the pick-up and drop-off points, the number of articles, the warehousing strategy and the volume of transport. There is an optimal solution for any requirement. Planning an AGVS demands a comparison of the specific demands with the shape of the hall and the possible warehouse structures.

2.1.6 Outdoor Applications

Outdoor use is a particular challenge for automated guided vehicles. First of all, it causes more wear and tear on vehicle components, especially the necessary and sensitive guidance and sensory systems. The weather in Central Europe and most of all the great range of weather conditions make outdoor use very challenging. In particular, the following weather conditions:

- Extremely high summer temperatures (up to 40 °C)
- Extremely low winter temperatures (freezing) (down to −30 °C)
- Extreme variations in temperature for mixed indoor/outdoor operations
- Extremely varied lighting conditions (darkness, cloudy skies, extreme sunlight, high and low-standing sun)
- Fog
- Snowfall
- Heavy rain
- Wind
- Black ice/sleet
- Varying surface conditions (friction coefficients), which influence traction and braking ability (Fig. 2.9).

Weather affects many aspects of planning and construction of an outdoor AGV. Many of the relevant points are not new, but are perfectly common among standard trucks. But the weather presents a major challenge for two typical AGVS functionalities: navigation and security.

Fig. 2.9 Automated trucks in use in winter (*Source* Götting)

Fig. 2.10 Automatic swap body lifting truck (*Source* Götting)

Both functionalities are worth mentioning here in order to present their unique characteristics, even though the principles of AGVS technology will not be discussed until the following chapter (Fig. 2.10).

2.1.6.1 Outdoor Personnel Protection

When designing an outdoor AGVS concept, personnel protection is of the highest priority.

For indoor areas contact-less sensors have already been in use, usually based on laser scanners, which are certified by liability insurance associations. Nowadays, most indoor DTVs have a (yellow) laser scanner for personnel protection.

Mechanical protection devices such as SoDT foam bumpers or plastic roll bars are only rarely used. Often foot switches or emergency cut-off switches are also used in addition to the laser scanners mounted on the front or also on the sides of the vehicle.

Currently there are no such systems for outdoor use. On one hand, the use of laser scanners in all conceivable weather conditions is more complicated; on the other hand, the certification process is very involved. This is why all of the previously employed outdoor DTVs that do not travel only in restricted areas are equipped with relative large emergency cutoff handles. The auxiliary sensors serve only to support these mechanical bumpers. They cannot be solely responsible for personnel protection.

The size or length (along the travel axis) of the mechanical bumper is limited entirely by the design of the vehicle and itself limits the driving speed of the AGV. A bumper of 1.30 m length is usually necessary to achieve a driving speed of 6 km/h! (Fig. 2.11).

Fig. 2.11 Safety features on an outdoor AGV (*Source* Götting)

A new sensor system is urgently needed. This will remove the need for bulky protective bars. Nonetheless, it is recommended to limit the speed to 6 km/h for two reasons:

- This limited speed greatly increases safety over the current manual practice and creates trust.
- For speeds over 6 km/h, the vehicle has to be registered for public roads,[6] which would greatly increase the effort involved

2.1.6.2 Outdoor Navigation

In principle, there a number of ways to navigate an AGV. But when it comes to outdoor use, most methods do not come into consideration. Based on the current state of the art, there are three methods for outdoor use:

- Transponder navigation
- GPS navigation
- Laser navigation.

Laser navigation is inapplicable for outdoor use because of its limited range and sensitivity to intense sunlight or heavy rain/snow.

Transponders are clearly coded data carriers. They are set into the floor along the path, usually just a few centimeters below the surface. The AGV is equipped with a transponder antenna on its underside. This antenna provides the vehicle with an induced current when it drives over the transponder so that the actually passive transponder is able to send its coded signal. The vehicle antenna reads this coded signal and uses it to recognize its position and help it navigate.

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[6] Since March 1, 2007, article 5 of the Regulations for Registering Vehicles covers all vehicles and trailers designed to exceed 6 km/h.

Fig. 2.12 A specially designed AGV moves packages with stones in a cement plant; navigation: Real Time Kinematic Differential GPS (*Source* FhG-IML u. Götting)

There are various large transponders which, in combination with the vehicle antenna used, allow for various signaling ranges and precision. In general, it is the case that the closer the distance between antenna and transponder, the higher the precision. Transponders vary between 2.5 and 8 cm in diameter, their signaling distance from 10 to 40 cm and their precision from 2 to 20 mm. They are easy to install if the driving surface is free of metallic materials. If that is not the case, then a large area must be drilled out and the transponder set in concrete, which correspondingly increases the effort involved.

This type of navigation is very robust, but requires a hard floor, which is resilient to the midday heat in summer as well as to the strain of multiple heavily loaded vehicles driving over it. A precision range of centimeters can be achieved. The truck in Fig. 2.11 uses this type of navigation.

The second means of outdoor AGV navigation is GPS.[7] GPS satellite navigation. dGPS stands for differential GPS and refers to the use of an additional GPS receiver, which is not mounted on the AGV, but is mounted on a fixed installation. This stationary GPS helps to determine the errors in real time that arise within the GPS system. This data allows the GPS receivers on the AGV to immediately determine their exact positions (Fig. 2.12).

This navigation technology works – in contrast to transponder navigation – on any surface, but needs a clear line of sight upwards. Steep walls close to the AGV are anathema, as are bridges or other route crossings such as pipes. Typically, the system needs a free upwards cone of vision of 15 to be able to operate reliably.

[7] GPS = Global Positioning System, officially NAVSTAR GPS, a global navigation system for positioning and timekeeping.

The steps to achieve the necessary degree of precision in driving and positioning are:

1. Examining local conditions, especially satellite reception strength
2. Use of differential GPS
3. Real Time Kinematic Differential GPS.

A "normal" GPS can achieve a precision of ±12 m. By installing a reference station with a precisely measurable position, a correction factor can be transmitted by short-wave to the DT, improving the precision to ca. ± 1 m (differential GPS). When, in addition, the mobile receiver in assesses the transmission time of the satellite signal it is receiving in real time, it can achieve a range of precision measured in centimeters. The promising name of this complex and certainly not inexpensive technology: Real Time Kinematic Differential GPS.

The closer the precision desired, the higher the costs and technical efforts.

The following facts may help us judge the significance and feasibility of outdoor AGVS:

1. There are relatively few outdoor projects.
2. Unfortunately, there have been in the past several AGVS projects which were offered by inexperienced suppliers and led to problems during implementation.
3. There are currently no standards for personnel protection and navigation as they exist for indoor areas.

Finally, every new outdoor use project must be taken seriously and assessed critically – more so than most indoor projects. Potential suppliers must determine whether they are sufficiently competent and experienced for such projects.

Current state-of-the-art AGVS technology (still) does not allow it move predominantly freely in road traffic as manually driven forklifts can. Today's DTVs are "blind" and have to "feel" their way so that they still rely on organizational assistance. The following points are part of this "organized order":

- Wherever possible, define paths to be exclusively used for DTVs. It is best to block off these areas with physical barriers.
- In any case, the traffic areas must be clearly and visibly marked for their use. Lanes, parking areas, loading areas and restricted areas should be clearly delimited.
- Whenever possible, limit the traffic volume in the area of the AGVS routes using, for example, one-way routing or restricted access.
- Where AGV lanes intersect other traffic lanes, install a traffic light, with barrier, if possible.
- High pedestrian traffic flows should not cross the path but be routed around it using raised or lowered walkways.

The main reason for this is that AGV's intentionally oversensitive safety features will cause it to stop repeatedly on routes with a large volume of crossings or oncoming traffic. This reduces its average speed and transport capacity.

In addition, every user should be aware that weather conditions could grow so extreme that AGVS operations would have to be suspended. These certainly include icy conditions or an intense blizzard. Safe operation is no longer possible when there is no more grip between the vehicles' wheels and the ground. And when masses of snowflakes flutter past the personnel safety scanner, disrupting it from all directions, it will shut down on its own.

This should not awaken the impression that AGVS cannot be used safely in outdoor operations. But in any case, outdoor projects require serious co-operation with competent partners.

2.1.7 Arguments for Using AGVS

At this point we would like to summarize the advantages of AGVS. They will certainly appear individually or in a related form on other pages of this book, but here we would like to list them all together. This does not just include considering the economic aspects, but also the technical and organizational arguments:

- Better organized material and information flows; leads to productivity-enhancing transparency of internal logistics processes
- Transport steps can be calculated and planned in precisely at any time
- Minimized reserve stockpiling and waiting times in production
- Reduced personnel assigned to transport, lowered personnel costs (especially in multi-shift operations)
- Minimized transport damages and missed deliveries; reduced follow-up costs
- High availability and reliability
- Improved working environment, safe and pleasant working conditions through ordered work steps, clean and quiet transportation
- Positive effect on internal company image
- Positive external effect within the industry (securing location)
- Positive effect on public image
- High precision of automated loads transfer
- Minimal investment in infrastructure
- Intersections and junctions easily planned
- Multiple use possible in loading and traffic area
- Individual substitute conveyors can be used (forklifts)
- Can be used with high or low overhead areas
- High transparency in goods movement
- Generally no need for extra traffic space
- Uses existing routes
- Can be used indoors and out
- Various additional functions possible:
  Sorting, decision-making, data transfer, data collecting, weighing goods, organizing procedures, warehouse administration, administering storage sites, goods recognition, mastering various layouts, finding pallets, loading trucks, intelligent

security, intelligent situational responses (fire alarm switch, various modes of deployment), faster and more complex work during off times (nightly restocking) intelligent loading strategies, mobile robots, commissioning function etc.

The traceability of the logistics processes is highly up-to-date. Every product movement is reliably performed and logged. This creates an end-to-end process history that is useful and necessary for internal audits and for product liability considerations. In summary, it can be said that AGVS is a powerful and necessary tool for modern intralogistics in all branches of industry, including the pharmaceutical and food industry.

2.2 Industry-Related Aspects and Examples

For us the most significant era of AGVS is the third, which – as described above – began in the mid-1990s and lasted until around 2010. So this chapter will address some project examples realized in this time period. In doing so, we will predominantly concentrate on ongoing products of an exemplary nature.

This third era is marked by an ongoing opening of more and more areas of application and industries for AGVS. That initially sounds very good, because new AGVS suppliers are opening new markets a bit at a time. But we should not forget that this third era started pretty much out of nowhere and had to make up for the sudden collapse of the market in the early 1990s. The new beginning in the mid-1990s was sparked by a new constellation of suppliers, consisting primarily of medium-sized companies with no more than 40–80 employees.

Whereas the second era of AGVS saw a few large suppliers concentrated on a single industry, namely the automotive industry, in recent times a number of small and medium-sized suppliers have been involved in the most diverse areas of application. That is what makes today's DTP business so varied.

AGVS business is terribly exciting since companies can apply their entire range of engineering knowledge to offer demanding products in the most varied markets. That is naturally difficult since most of the distribution process takes place passively. What do we mean by a passive or active distribution process in this project-dominated business?

A passive distribution process means that the great variety of industries and his own limited resources limit the supplier to simply reacting to incoming project offers. An request which arrives by mail, fax or e-mail is processed. This has the advantage of leaving all available resources to be applied towards processing real requests, saving costs related to strategic positioning.

An active distribution process means that the AGVS supplier concentrates on selected target industries and markets actively. That does not mean that they ignore requests from other industries. It simply means that the supplier is very familiar with selected target industries and can expect better chances in landing a project as a competent, co-operative and sympathetic systems partner.

Suppliers decide for themselves whether to run their businesses actively or passively. In any case, the modern AGVS business is not a simple one. There are a number of small and medium-sized companies competing for every individual AGVS project and pricing pressure is extreme. Sales teams create too many offers that do not result in an order. The prices are negotiated down to the bone so that the profit margins for the projects are too low, especially since many projects are laden with unforeseeable risks due to their complexity.

But let us return to the industries that use AGVS and the growing range of possibilities arising worldwide. There is a basic set of technical building blocks that allow for reliable, high-performance AGVS solutions. The demands on quality are constantly increasing in the target industries, as are the personnel costs – to this extent, a positive outlook for the markets. In the following section we will look at exemplary industries and projects, show photos and offer industry-related tips.

2.2.1 Automotive and Auto Components Industry

Initially it seems paradoxical to start with the automotive industry, as it almost completely abandoned AGVS around the turn of the 1980s. But after several years in the wilderness, AGVS projects started finding their way into automotive plants again in the late 1990s. We will present several examples to demonstrate that there are various places where it can be used, from completely simple solutions, based on the Japanese KAIZEN approach, through functional, technically demanding but reasonable applications, all the way to extraordinary uses.

2.2.1.1 AGVS in Transparent Manufacturing in Dresden (Volkswagen)

In its new “transparent factory” in Dresden, Volkswagen AG has been assembling the new top-end model “Phaeton”, which was introduced in 2001. Materials supply for the assembly lines is provided by an automated guided vehicle system (AGVS) with 56 freely navigating vehicles. The AGVS was supplied jointly by Frog (guidance control, vehicle steering and navigation) and AFT[8] (mechanical components) (Fig. 2.13).

The “transparent factory” is a unique automotive plant. The high demands on the new product are directly reflected by the sites at which it is manufactured. The plants and equipment are well-lit and appealing, the manufacturing area is roomy and the floor is covered in high-quality maple parquet. And the work organization is also unique: Emphasis is placed on workmanship-oriented activities in contrast to purely output-based assembly lines, combined with demanding and innovative technology, intended to fit the image of the “Phaeton” and ensure its high standards of quality.

[8] AFT – Automatisierungs- und Fördertechnik GmbH & Co. KG, Schopfheim, Germany.

Fig. 2.13 Vies of the assembly line. A conveyor set in the floor snakes its way through the assembly area (*Source* Volkswagen)

Manufacturing is spread over three levels. Assembly itself takes place on the two upper manufacturing levels. The body in white is mounted on an assembly platform which is part of the conveyor belt that is set flush into the floor of the assembly hall and is moved through the assembly cycles at a constant speed. Then it is transferred to a heavy electronic overhead conveyor for overhead assembly. During the overhead assembly, the "marriage" takes place: i.e., the body is fitted with chassis and drive train, in which the drive train is delivered by an automated guided vehicle (AGV). Then the body is mounted again on a moveable platform, the conveyor, for final finishing and quality control.

On the underground floor, the logistics level, all of the material to be assembled is held ready and commissioned. The AGVS assumes the supply of the assembly lines with this material, a key logistical function. The automated vehicles use elevators to move between floors.

One unique feature of the navigation: The assembly lines of the "transparent factory" are not covered in the usual screed, but with high-quality maple parquet of equal sized tiles. These were fitted with permanent magnets before installation. The magnets, 8 mm in diameter and 5 mm high, are set into blind holes on the bottom of the tiles and enclosed with a filler. This results in an even magnetic grid covering both assembly levels, making it possibly to determine drive paths completely and flexibly.

The AGVS has the basic task of supplying the assembly lines. In doing so, the following type of goods must be delivered:

1. Goods basket to the conveyor and overhead assembly line
2. Control panels (Cockpits)
3. Wiring
4. Motors and powertrains, performing the "wedding"
5. Doors and additional goods baskets.

The broad range of goods call for various types of vehicles. The small vehicles (for positions 1 to 3) have a load capacity of 800 kg and a differential drive, i.e., two

Fig. 2.14 The “wedding” station. The body approaches from above suspended from the overhead line, below in the foreground a AGV waits with the powertrain, in the back ground a goods-basket AGV drives past (*Source* Volkswagen)

separately driven non-steering wheel in the middle of the vehicles and a freely flexible support wheel in the middle at the front and rear. This allows it to move just as precisely forwards as in reverse to negotiate tight curves and to turn on the spot (Fig. 2.14).

The large vehicle transports the motor with chassis and doors (positions 4 and 5). It can carry up to 2,500 kg, and it is 1 m longer than the small one. The diagonal vehicle has four-wheel suspension kinematics – on the right front and left rear there is a driven and steered wheel and a freely turning support wheel on the front right and rear left. This vehicle allows almost all movements to be carried out on the floor, especially diagonally. This is required at the wedding station, where the powertrain and chassis (on the AGV) are put together with the body (on the overhead monorail) (Fig. 2.15).

Transporting the goods baskets from the conveyor line is completely new and places the highest demands on the AGVS and AGV guidance. The AGVs pick up a

Fig. 2.15 Once again the wedding station: in the foreground and empty AGV leaves, behind it the “wedding”, powertrain from below, body from above (*Source* Volkswagen)

Fig. 2.16 Underride AGVs with small trolleys for pallet cages (*Source* DS 2006)

commissioned goods basket on the logistics level by underriding and slightly lifting it. Then an elevator takes them to the assembly level. There they drop off the goods basket filled with assembly materials for a particular auto on a particular hopper on the conveyor. In addition, the AGVS has to approach the slowly moving conveyor belt from the fixed hall floor. The AGVS guidance control tasks the selected AGV to transport a goods basket from the waiting area to the conveyor belt and to wait there. The position of the passing hopper is constantly monitored by the hopper guidance and reported to the guidance control. The correct goods basket can be verified with the aid of a goods basket identification.

As soon as the hopper as stopped opposite the waiting position, the AGV is tasked with approaching the hopper, taking into account the hopper's relative speed. It can approach with a precision of around 10 mm, which is immediately corrected by the magnetic grid on the hopper. The hopper is moved away in an analogous manner.

2.2.1.2 Production of the BMW 300 Series in the New Leipzig Plant

In 2005 The BMW plant in Leipzig started up production of the 300 series (E90). For the first time in the history of the automotive industry, an automated guided vehicle system (AGVS) took over extensive logistics function in the area of parts supply (Fig. 2.16).

The following standard processes were defined for the parts supply to the assembly area at the Leipzig plant:

1. Direct delivery by truck: large, simple parts (e.g. floor mats or trunk liners) are delivered just in time by truck to the direct vicinity of their assembly areas.
2. Module delivery by OM[9]: large and complex aggregates (e.g. cockpit) are assembled directly at the plant site by external suppliers or BMW employees.
3. Warehouse goods via AGVS: Most of the parts are stored in a staging area, commissioned and brought to their respective assembly sites in the assembly area with automated guided vehicles (AGV).

[9] OM = overhead monorail.

Fig. 2.17 The AGV with oversized roller carts for picking up large containers (*Source* DS)

The entire route layout is 14.5 km long with around 400 load pick-up and drop-off stations. 74 DTVs are in operation, around 2,000 roller carts in two different designs are used to aid loading. Either two small roller carts are used per AGV to pick up containers up to DIN size, or a so-called oversized roller cart is used to pick up large containers. In addition there are also the sequencing racks with special superstructures.

To transport a roller cart the AGV underrides it and lifts it slightly. In the main direction of movement, the vehicles do not exceed a speed of 1.2 m/s. Personnel protection and obstacle recognition is performed by a laser scanner that monitors the area ahead of the vehicle. The vehicles reverse only for positioning, no faster than 0.3 m/s, giving off an acoustic warning signal. A foot-operated switch plate mounted on the rear of the vehicle prevents workers from being injured by reversing vehicles (Fig. 2.17).

Starting with the initial phase of planning, economic efficiency calculations were made and simulations were conducted. Manually operated vehicles, such as tractors, were the main competitors for the AGVS. The long delivery routes from warehouse to assembly area favored automated vehicles, in addition, the assembly area was to be kept free of stacked materials to ensure quality and operating safety. AGVS prevailed because of its comprehensive scope and sustainability, as well as the lack of damage to peripheral installations. In addition, the economic efficiency calculations showed that the AGVS solution brought the highest returns.

The automated guided vehicles find their way with the help of so-called free navigation. It works without physical guide tracks and works based on a combined principle of taking bearings and dead reckoning. Dead reckoning means analyzing sensors mounted within the vehicle (measuring wheel and a fiber-optic gyroscope)

Fig. 2.18 An AGV takes a roll container with audio components (*Source* DS)

which determine the path traveled, including curves. Bearings are taken every five meters. Over 3,000 small permanent magnets are set into the floor at this interval for the entire layout. These cylindrical magnets have a diameter of 20 mm and are 10 mm high. When they are driven over, they are recognized and analyzed by a magnetic sensor strip that is attached to the bottom of the vehicle.

Every time bearings are taken, the deviations from course that might be caused by tire slippage or changes in the diameter of the wheels are corrected. The advantages of this process, also known as magnet navigation, lie in its reliability and flexibility for future changes to the layout (Fig. 2.18).

The use of free navigation is necessary in this application because the course layout is marked by a number of overlapping curve radii. A guide wire or physical guide tracks cannot be used to realize such a course layout. In addition, the demand for precision at the goods transfer points is very high. With the gyroscope- supported magnetic navigation the AGVs can position themselves to ±5 mm (Fig. 2.19).

Fig. 2.19 *Left* Detailed view of a vehicle with two sequencer frames. *Right* Battery loading station for the NiCd batteries (*Source* DS)

2.2.1.3 Logistics Tasks at Deutz AG in Cologne-Porz

The renowned motor manufacturer Deutz in Cologne-Porz does not just produce diesel motors for trucks, but also for powered machinery, shipbuilding and agriculture. In 2009/2010 the main components of an outdated automated guided vehicle system were replaced (retrofitted) in the assembly area (Fig. 2.20).

The retrofit included the delivery of 43 free-driving forklift trucks with laser navigation. They replaced the previously used, inductively guided vehicles and have been in operation in three shifts for up to six days a week – along a total course of around 6,800 m and with speeds of up to 1.6 m/s (forwards and in reverse).

The enormous challenge in modernizing the nearly 20-year-old equipment was a matter of the time available to do it: within only twelve working days between the end of 2009 and the beginning of 2010, the new vehicles had to be fitted with components from the previous devices, while further key equipment was installed and put into service. At the same time, the equipment's output was improved and the guidance computer functions optimized.

The reconverted vehicles are able to manage various loads: to do so, the vehicles were fitted with four different lifting forks – some of them with load centering, as they are used to transport extremely varied loading units of up to 1,000 kg (transport boxes, cage boxes, pallets in both lateral and perpendicular orientation, small and large motors and also special mountings). In addition, the lifting forks can be raised to a height of up to 3,500 mm to access the shelving system (Fig. 2.21).

Another not entirely common task involves energy management. The new automated forklift transporters retained their old batteries, but these had to be augmented with two additional cells in order to increase battery capacity. Deutz has broken new ground in the area of design: the vehicles were pure white in order to meet the tougher requirements of automotive manufacturers for cleanliness.

Fig. 2.20 Three forklift AGVs from the Deutz vehicle fleet (*Source* MLR)

Fig. 2.21 Flexibility in load handling and navigation: the forklift vehicles (*Source* MLR)

The AGVS guidance control is also new, which was integrated into the complex Deutz computer landscape. A few key indicators: highest availability via hot standby operation, administers over 1,600 load transfer points and interfaces with numerous peripheral installations such as conveyor equipment, transfer tables, visualization systems and terminals. Overall, the equipment completes over 7,000 transports per day.

2.2.1.4 Front-End Assembly at BMW AG in Dingolfing

Dingolfing is the site of front-end assembly for vehicles including the BMW 500 and 700 series. For this purpose there are two AGVS courses with to AGVs each. Maximal bearing load totals 400 kg (Fig. 2.22).

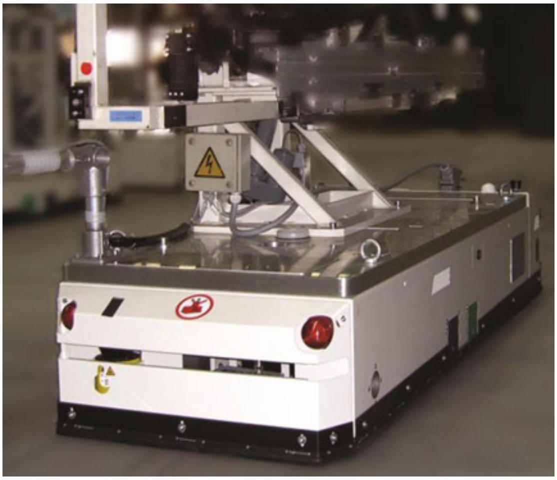

Fig. 2.22 Assembly vehicles at BMW in Dingolfing (*Source* dpm 2011)

Fig. 2.23 Twenty AGVs in a simple assembly layout (*Source* dpm 2011)

Since the plant layout is rather simple and is to remain unchanged for several years, inductive energy transfer was chosen. This means that the vehicles derive their electricity from a power cable set into the floor; at the same time, these twin cables are used for track guidance (Fig. 2.23).

The trip through the assembly area takes place at a slow pace of 30 m/min. The vehicles stop at the individual work stations. At the end of each work step the workman starts the AGV with a foot switch, sending it to the next station. At the end of the assembly line, the finished front end is measured by robot and transferred to an overhead monorail which then transports it to installation on the main assembly line.

2.2.1.5 Assembly Line for Cockpits at VW in Wolfsburg

In Hall 12 of the main VW plant in Wolfsburg, there is a cockpit assembly line for VW Tiguans. This line is based on a AGVS with thirty AGVs equipped with "contact-free energy transfer" technology and has been producing around 450 Cockpits per day since March 2008.

The contact-free energy transfer to provide the AGVs with energy was a fixed precondition set by Volkswagen, as they had already gathered positive experiences with other products with this innovative and robust technology. The systems are wear and maintenance-free, allowing a significant reduction in equipment down times. The contact-free energy transfer technology will be discussed in greater depth in Chap. 3 "Technological Standards" (Fig. 2.24).

The task of the AGVS is relatively simple: along a circuit with a length of 190 m, the two assembly vehicles pass through various stations at which the Tiguan cockpits are assembled piece for piece. At the end of the cockpit assembly, the course runs parallel to the skid, on which the compact SUV bodies are conveyed. A robot fits the cockpits with an adhesive strip, then the assembly vehicle moves on

Fig. 2.24 Thirty AGVs in a simple assembly layout for cockpits (*Source* SEW 2010)

to the final assembly station. Here the cockpits are removed by a handling unit and installed in the bodies. The empty assembly vehicle is "loaded" after a few meters again with the basic cockpit module and the process is repeated.

The AGVs consist of a tractor and a part-carrying trailer. All of the parts and components including the cockpit receptors are optimally adapted to the workers, and the production process is designed so flexibly that cockpits for several vehicle types can be run along the same line. This means that in principle, they can dispense with retooling or system changeover of the work piece carriers in the conveyor equipment circuit. In addition, in case of disruptions or malfunctions, the individual components – AGV tractor vehicles and parts-carrying trailers – can be easily switched out along the line. This increases the overall availability of the system.

The vehicles do not drive at a constant speed; the route is divided into four speed zones. In assembly line manufacturing the vehicles have to maintain the corresponding interval speed. In addition, the foreman has the possibility of flexibly adjusting the interval speed. Between the final assembly station and the waiting station in front of the gluing robot the AGVs accelerate to a speed of 0.5 m/s.

At the gluing and assembly station, the vehicle slows down again to 0.05 m/s. At both stations, an exact positioning of ±2 mm is necessary, even if the final positioning was done with a positioning frame. Once the vehicle has been relieved of its load, it continues on at maximum speed to the start of the assembly line (Fig. 2.25).

The AGVS was not produced by a traditional AGVS manufacturer, but rather in a joint project by VW specialist departments and a systems supplier for drive and energy equipment. Volkswagen's goal is to generate a standard for similarly functioning assembly lines in the future based on experience from this project.

Fig. 2.25 A combination of tractor and assembly AGVs (*Source* SEW 2010)

2.2.1.6 Use of AGVS in Automotive Seat Manufacturing

Since 2009, Toyota Boshuko has been using AGVS equipment to automatically deliver individual components for seat manufacture in their Somain plant in France. The equipment consists of eleven vehicles, which are used in the two production lines in their manufacturing plant.

One of the operator's requirements was that all of the individual components such as the foam and sheet metal parts could be delivered without additional containers according to the so-called Minomi principle. Minomi is the name of a process in which the processed parts are conveyed directly, e.g., with a gravity-roller track without interim storage and multiple handling by the automated guided vehicle.

A highly flexible material handling system was needed to implement the project. The individual components are delivered directly to the corresponding production line, the load transfer is fully automated and fully mechanically based on gravity feed.

Fig. 2.26 Underride AGV tows the materials wagon with lateral gravity transfer system based on the Minomi principle (*Source* CREFORM 2009)

Since materials such as shaped foam are as a rule hard to move, high-quality roller tracks are used to ensure that the gravity-feed transfers can function without impeding production.

In a further section of the production equipment, underride AGVs with a towing cylinder assembly are used. A materials wagon already commissioned by an employee is underdriven by a AGV, "towed" and finally dropped off at the production line (Fig. 2.26).

2.2.1.7 Use of AGVS as a Mobile Final Assembly Platform

In Bremen, the automotive manufacturer Daimler has been using a AGVS since the end of 2011 consisting of two vehicles, which support the final front-end assembly stages. Along with forward and reverse driving, key characteristics of the vehicles is lateral movement. This was necessary due to space restrictions along the production line.

Since the AGVS crosses its path with forklifts and milkrun[10] trains, a traffic light was installed which communicates with the AGV using optical data transmitters and also controls the traffic of both AGVs.

Since the AGVs remain for a time at their end stations, it was a good idea to equip each of them with an automatic battery charging system (Fig. 2.27).

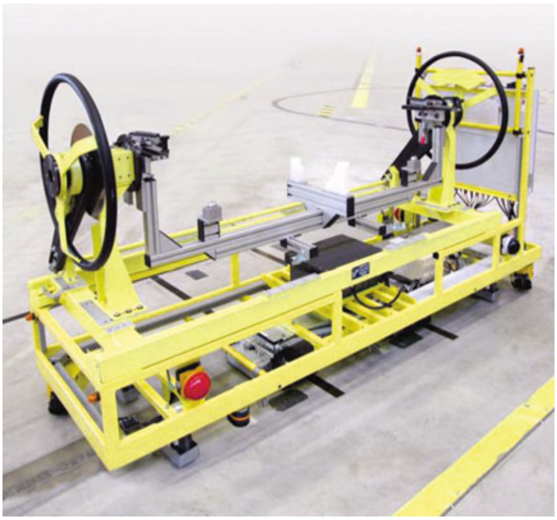

Fig. 2.27 AGVS for assembly and delivery at Daimler in Bremen (*Source* CREFORM 2011)

[10] Need-based in-plant provision of wares from one source at various sinks (e.g. production lines) or between plants from various sources (suppliers) to a sink (producer's receiving area).

2.2.1.8 Improving Production Efficiency at Denso in the Czech Republic

Denso Manufacturing in Liberec in the Czech Republic is an international company producing air conditioning units for the automotive industry. By introducing an automated guided vehicle system, it increased the efficiency of its production.

Two years before the system was started up, Denso resolved to further increase the effectiveness and flexibility of its production lines. The manufacture of automotive air conditioning units and their components was already predominantly automated. But the matter of automating and thus optimizing transport traffic within the production halls remained unresolved up to that point (Fig. 2.28).

After intensive planning analyses, a decision was made for a modern AGVS concept involving two Linde P30C towing tractors with a trailer capacity of max. 3,000 kg. In doing so, it was important to integrate the unmanned tractor into the complex production system with as cleanly as possible. At the same time, adjusting the work in random sections was to be made easier. An important requirement was that the tractors could be manually operated when necessary.

In addition, one of the two existing towing tractor lines was to be done away with entirely and down times eliminated.

Eight production lines are served by two vehicles: Three manufacturing lines with six stations, the warehouse and the so-called empty boxes with one station each. A towing tractor can go through up to twenty cycles per shift. The vehicles have a small remote control with which they can be exactly (manually) positioned at the loading and unloading sites. In order to guarantee maximum flexibility, the vehicles can serve all the assembly lines. There is no AGVS guidance control: despite the various intersections and junctions, it was not needed. Vehicles are currently called up manually at the user terminal by pressing a button.

The equipment is inductively guided. The tractors are guided along an induction path milled into the floor. This allows various sections to be driven along without

Fig. 2.28 AGV as towing tractor: rebuilt Linde tractor (*Source* E&K)

service personnel, that is, automatically, as needed. The simplicity of the inductive track guidance means that the two lines to be served could be reduced to one.

The tractors can also be used outside the closed system, by pressing a button at the terminal they can be switched from automatic to manual. This makes the tractors flexible in use for other activities. There is all-around personnel safety protection.

Automated vehicles have a longer service live since the replacement parts and most of all the batteries do not wear out as quickly. The loss of time that occurs by hand steering between starting and ending sites can be compensated by the parallel preparation of container filling in the warehouse.

The system depreciation pays for itself by savings in service personnel, usually in less than 2 years. Two employees per shift can be assigned elsewhere, for a three-shift operation, this comes to six equivalent full-time positions.

In the end, the AC manufacturer, in co-operation with his AGVS supplier has installed a customized, all-round successful and flexible system that fits his requirements – and that all with more efficiency and reduced production costs.

2.2.2 Paper Manufacturing and Processing

Paper roll handling was one of the first jobs performed by AGVS in Europe. As early as the beginning of the 1970s, attempts were made to automate the handling and transport of the valuable rolls of paper from the warehouse to the printing machines. A key reason for these efforts was to avoid damage to the rolls, as conventional manual handling often made the outer layers of the paper useless, not uncommonly up to 10 cm of the external diameter of the roll!

2.2.2.1 Transport and Handling of Paper Rolls at Einsa Print International

Einsa Print International is one of the leading companies in the Spanish print industry. It produces catalogs, magazines and telephone books. Since 2007, it has been successfully optimizing its production and warehousing with AGVS.

The system configuration at Einsa – a combination of vertical paper roll warehousing and horizontal delivery of paper rolls to the printing machines – is typical for the paper industry. Thanks to the integration of a downender system into the AGV it is no longer necessary to install a swiveling unit on the conveyor equipment, which leads to considerable savings of space and costs. In addition, turning the rolls during transport also shortens production time (Fig. 2.29).

The downender system is a technology which Egemins itself developed to allow the AGV with hydraulic clamps to vertically lift heavy paper rolls, turn them during transport and then deposit them in horizontal position in the printing machine. In the plant, there are currently three AGVs with downender function in operation and

Fig. 2.29 Paper roll transport with multi-functional AGV (*Source* Egemin)

Fig. 2.30 The AGV with laser navigation (*Source* Egemin)

four forklift AGVs, which transport printed and cut sheaves of paper on pallets to the production machines (Fig. 2.30).

Depending on the size of the rolls, a downender AGV stacks up to four rolls vertically on top of each other (up to a height of 6 m). When the software sends a transport order, one of the vehicles takes a roll and brings it to a precisely defined position in the production plant. Here the roll is turned and deposited in a horizontal position. From this spot, they are picked once more up by the forklift vehicles and taken to the printing machines.

2.2.2.2 Newspaper Printing in the Druckzentrum in Braunschweig

The Druckzentrum in Braunschweig belongs to the WAZ Media Group and produces numerous daily newspapers. Three high-performance MAN Colorman S 40 offset rotation machines print in four colors in highest quality, quickly and cost-effectively.

Along with standard newsprint there are various higher-quality grades of paper to choose from.

In 2007 an existing AGVS was replaced by a new one. It was started up without interrupting operations. The three AGVs have a lifting frame equipped with two fork tines, which can be adjusted to up to 700 mm in height. This means that they can transport various types of paper rolls. The largest possible roll is 1,500 mm in diameter, 1,280 mm long and weighs 2,000 kg. The rolls can be stacked in shelf niches up to a height of 3.5 m and removed again (Fig. 2.31).

The equipment can be used for the following: paper rolls are prepared during the day for evening printing. The side portions are knocked off at an unpacking station in order to store them in the day paper storage area. By scanning a paper roll, a pickup order is sent to the AGVS control computer. During this time, other orders are also carried out to the roll changers at the printing machine (Fig. 2.32).

Main production commences just before midnight, whereby the AGVS has already filled the roll changer with rolls from the day storage area. During production, the other roll changers must also be kept supplied with new rolls. At the end of a production run, the rolls which have been started but not used up are returned to the day storage area (Fig. 2.33).

The equipment is in use around the clock, during which eight hours are available for the automatic battery charging. The vehicles have 48 V lead batteries with a

Fig. 2.31 A shelf warehouse as day storage area for paper (*Source* DS)

Fig. 2.32 A AGV brings paper to the staging areas (*Source* DS)

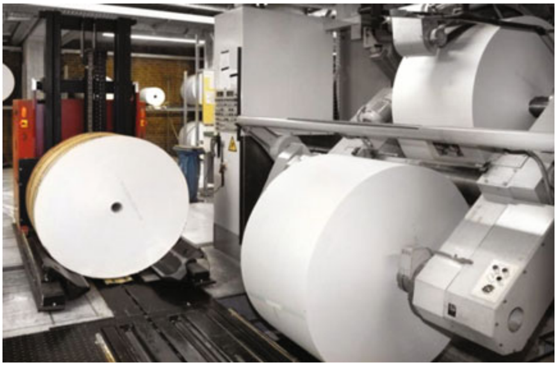

Fig. 2.33 An AGV supplies the roll changer at the printing machine (*Source* DS)

capacity of 420 Ah. A battery weighs 750 kg, so that a ready-to-use AGV totals 3,600 kg empty weight. The driving speed is 1.2 m/s forwards, reversing is done at minimal speed (0.3 m/s).

The AGVs navigate with the aid of magnetic navigation (magnetic point sequence). The entire layout has a length of 500 m.

2.2.3 Electronics Industry

The electronics industry is representative for manufacturers of high-quality small serial components. Their quality demands often include extreme cleanliness and orderliness. The weights to be transported are often not great, standard boxes of sizes such as 600 × 400 mm are commonly used.

In these production sites, flexibility is key: both the layout and the processes often change over the course of ongoing optimization. It is an accepted standard that information technology permeates the processes, WLAN is usually present and there is less aversion to automated technology than in other industries. Small vehicles with free navigation are in demand (Fig. 2.34).

Fig. 2.34 Two Lifestyle AGVs in the electronics industry (*Source* FROG)

Fig. 2.35 Material delivery in the assembly area (*Source* FROG)

2.2.3.1 Just-in-Time Container Transport at Wöhner

Highest quality and product design are the focus of the production plants at Wöhner GmbH & Co. KG in Rödental. These include a fully modern, extremely clean and appealing assembly as well as flexible intralogistics based on an automated guided vehicle system (AGVS). Wöhner is a supplier of innovative busbar systems, load switches, and safety switches for electrical equipment (Fig. 2.35).

Within 4 years, AGVS functionality and the size of the AGVS vehicle fleet was successively expanded, so that two vehicle types have taken over supplying the entire production area since the beginning of 2010. Five vehicles transport the small containers (600 × 400 mm) and two carry the large containers (800 × 600 mm). The current seven automated guided vehicles have taken over supplying assembly with individual parts, components and finished productions from the container warehouse and the ASPW.[11]

The main reason for automating transport was to ease the burden on employees, who earlier distributed the palletized containers to the workplaces manually. Delivering the containers from the existing and the new container warehouse to the eighty work places with over 1,000 drop-off points is now done by the automated guided vehicles. The AGVS transports 700 containers per shift.

The passive load transfer and the low costs that it incurs for the transfer stations help keeping the system price low; the depreciation period for the initial investment shrank to less than 2 years. The freed-up personnel were relieved of a heavy physical burden and could be employed productively. Wöhner also uses the possibility of integrating the AGVS as a visual highlight in the appealingly designed production setting. The unique aspect of the vehicles is in how they handle loads. A height-adjustable telescopic belt conveyor was specially developed, which makes it possible to pick up containers at various levels from smooth surfaces (shelves, tables, etc.) or to place them on passive roller tracks and pick them up again (Fig. 2.36).

[11] ASPW = Automated small parts warehouse.

Fig. 2.36 The AGV at the roller track load transfer (*Source* FROG)

There is no administration of storage sites. But this is no problem for the mated guided vehicle system, since the vehicle can seek a free spot while delivering within the assigned shelf area and deposit the container there. If all the shelf sites are occupied, the vehicle sends a message that is displayed both locally and at the AGVS guidance control.

The AGVS, with its pleasing design, its reliability and flexibility, fits well into the demanding Wöhner assembly equipment. The employees accept the system as an ergonomic and high-performance support for their work.

2.2.4 *Food and Beverage Industry*

At this point we would like to address the food and beverage industry. Pricing pressure in these sectors is merciless. This is why interest in intralogistics and subsequently for AGVS has increased considerably over recent years because of their cost-savings potential. The motivation and potential that they contain will be the topic of the following section. For that reason we will take a closer look at the beverage industry from the point of view of AGVS before presenting actual equipment used in the foods sector.

2.2.4.1 Intralogistics Initiatives in the Beverage Industry

The beverage industry is subject to enormous price pressure worldwide. After heavy investments in production equipment over the last 20 years, a remaining savings potential has been discovered in intralogistics. High-output production facilities must be adequately supplied with empty bottles and ancillary materials and the finished products must be picked up and delivered to interim storage facilities and distribution promptly, reliably and quickly.

Historically, intralogistics in breweries, bottling plants and beverage wholesalers has been based on conventional forklifts. High transport and warehousing capabilities with maximum favored the use of forklifts, especially as there were no tried and tested alternatives offered by AGVS.

Conditions in beverage logistics: High transport capacities are required because bottling plants turn out ever-increasing volumes. Nowadays, a typical beer bottling line can produce up to 15 hl/h, that comes to almost forty pallets per hour that must be carried off, often around the clock. Since most breweries have more than one filling line in operation, the volume to be transported increases accordingly. Special adapter extensions allow the forklifts to transport up to eight pallets at once.

The loaded pallets have to be transported from the filling line to the finished goods warehouse with high frequency. Normally, the forklifts bring the pallets to the bulk storage area where they are stacked on top of each other at floor level. It is not uncommon for them to be stacked to heights of up to 10 m. The advantages of bulk storage lie in the low system costs and in the fact that the means of transport (forklifts) can store the goods in the warehouse directly and on their own, without reloading or interruption. In the final account, these advantages are reflected in the way they have been implemented in traditional operation (see Sect. 2.1.5).

Forklifts and bulk storage areas were always guarantees for maximum flexibility. Previously supported by human dispatchers, nowadays by materials flow computers. This combination is able to adapt to maximally adapt to changes and situational demands. It does not only include the bulk storage area for the finished goods, but also the warehouse for empty containers or storage areas for outside products or ancillary materials. Such storage areas are often located outdoors and demand a great deal of flexibility in the transport system.

This would seem to speak fully for the use of forklifts and the "bulk storage area" warehousing concept – if not for the limited turnover capacity and bottle resources of the bulk storage area and the all-too-familiar drawbacks of forklifts:

- High personnel costs: wage rates are especially high in the beverage industry. Annual costs for a forklift operator can run up to €50,000. If a forklift has to be operated around the clock, then at least four drivers are needed. Adding the invest costs of €10,000 for a forklift truck to the personnel costs, the annual costs for one forklift come to over €200,000.
- Human error leads to unreliable transports, damages to the forklifts, products and the surrounding facilities. And then there are accidents, even injuries, which always cost time and sometimes money.
- Traceability and thoroughness of information: all these time-based requirements – especially in the food industry – speak in favor of more automation.
- And this also calls the ostensibly high transport capacity of forklifts into question: there is often a great gap between the top capacity and average performance. Automated equipment is considerably more consistent and reliable, making much more calculable.

Alternative solutions The logistics questions then are:

1. A new HBS[12] warehouse instead of a bulk storage area?
2. Replacing conventional forklifts with AGVS, overhead monorail or stationary conveyor equipment?
3. Mixed operations with several systems, or consistent, standardized warehousing and transport systems?

The advantages of an HBS warehouse lie in the high, reliable system performance. In a relatively small space, this closed system functions autonomously, safely and with high availability. But a systems transition is required, no matter what technology is used to solve questions of supply and disposal. Transfer points must be created, probably also with a buffering function. In this context, we want to see HBS as a fully automated warehouse, in which storage heights of 10 m are exceeded several times over, considerably reducing demand for space. Shelf-serving devices (SSD's) are a permanent component of an HBS warehouse.

Manual or even automatic warehousing with forklifts, in contrast, is only possible with heights up to 10 m, highly dependent on the loading weight.

Location plays a key role in the decision for an HBS warehouse or bulk storage area. Conditions at the location itself might preclude building an HBS warehouse, on the other hand, an HBS warehouse might be unavoidable because of a lack of space for expanding the existing bulk storage area. In addition, an HBS is much taller than a bulk storage area, namely from 12 to max. 50 m.

The advantages of a bulk storage area lie predominantly in the low system costs and in the fact that both forklifts and alternatively automated guided vehicles can take care of loading and unloading directly. A change of transport system: as with an HBS warehouse initially to stationary conveyor equipment and then to the shelf-serving devices – is not necessary. This saves time and money at the start. Detaching the transport and warehousing systems also has great advantages. It can be realized with special buffering zones on the floor or special conveyor courses.

On one hand, the transport is not burdened with time-consuming warehousing activities, on the other hand the buffering areas provide security for any sort of system disruption. In the end, transport systems demonstrate their strength in their ability to quickly cover distances, and warehousing systems in their ability to reach up to great heights, i.e. two-dimensional drive paths. This means that an HBS warehouse can achieve a greater volume of warehousing activities than any sort of transport system.

An HBS warehouse is not economical if the warehousing volume is small or the aisles are too short. Slow warehouse turnover is not economical with an HBS system using RSD's. The high speed of the RSD's is not fully exploited and the number of them needed makes the HBS warehouse too expensive. In such cases the uniform solution (bulk storage area) has its advantages.

In the case of transport in interlinking production areas with the warehouse, and shipping and receiving, then not only forklifts and AGVSs come into consideration, but

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[12] HBS = high-bay storage.

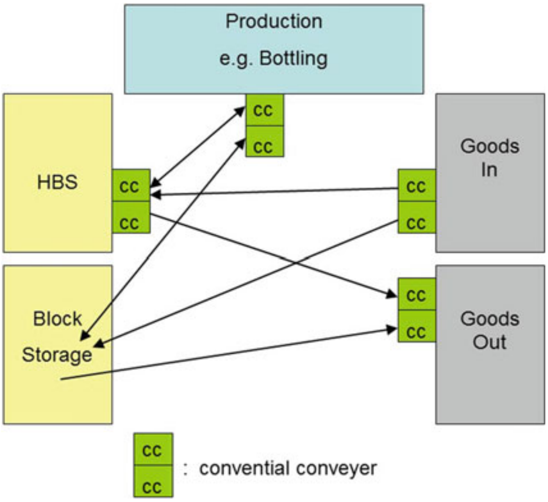


Fig. 2.37 Material flows in a typical brewery (*Source* Ott/Ullrich 2008)

also an overhead monorail or stationary conveyor equipment, such as roller tracks or chain-driver conveyors. Figure 2.37 shows the sources and sinks in the materials flow.

The illustration also shows the load transfer stations that will be necessary. These are where goods are made available or buffered. Such a system is unavoidable both after production and before the HBS warehouse. Only the block storage area can be served directly by forklift or AGVS.

On the right-hand side of the illustration there is a diagram of the shipping and receiving areas, each load transfer stations. These are to be recommended in any case when internal transport is automated. This means that these load transfer stations strictly separate automated transport from truck loading and unloading using forklifts. Although there are already some examples of AGVS applications in automated truck loading and unloading, they are far from standard.

But in the future, these types of AGVs will not be the same as those used for mass transport. The specifications are too varied, so that in each case there must be a transfer from one type of equipment to another. If one also considers that shipping and receiving, in contrast to production, does not operate around the clock and that loads for trucks have to be made available in shipping areas, the transport paths have to be kept separate. It cannot be assumed that in the near future it will be possible to load online direct from the warehouse or onto a truck. For this reason shipping areas, gravity-feed tracks or other stationary conveyor equipment will have to interrupt transport.

It is thus recommended from today's point of view to divide things as follows: the automated realm within the brewery and the manual forklift area outside with the trucks and the outdoor warehouse areas (e.g. for empty bottles). Automation is not as clearly pressing a matter for outside as it is for inside areas.

In internal areas the following equipment comes under basic consideration: forklift versus AGVS versus OHM versus conveyor equipment. There are technical and economic aspects to the choice of systems. The VDI Guideline VDI 2710 sheet 1 "Decision Criteria for the Choice of a Conveyor System". Table 2.2 was based on this guideline.

Table 2.2 Technical suitability of conveyor equipment solutions according to VDI 2710, sheet 1

Criterion	Forklift	AGVS	CE	OHM
Task flexibility	++	+	–	O
Layout flexibility	++	++	–	–
Continuity of performance	+	+	+ +	+
Peak performance	++	O	+	O
Space requirements	++	++	–	–
Strain on ceiling	++	++	+	–
Personnel safety	–	++	+	+
Orderliness and reliability	–	++	++	++
Round-the-clock operations	–	++	++	++
Grade	2.1	1.4	2.4	2.8

++ excellent
+ good
O satisfactory
– unsatisfactory

The table gives the initial impression of how the relevant criteria come into play. But the table must be adapted to fit local conditions. In general, there is nothing to speak against using several systems in combination, which can certainly be applied to expanding existing equipment. This means, for example, that an existing bulk goods storage area can continue to be served with forklifts while removal of goods to the filling lines and the warehouse can be performed with AGVS. This can be used to achieve a continuous, low-disruption clearing of the filling lines while the more trouble-prone service of the bulk storage area can be uncoupled from the filling line, using for example stationary conveyor equipment as a buffer zone.

It should be mentioned at this point that a mixed operation with conventional forklifts and AGVS in the same layout is possible. Special rules are needed (e.g., "The AGVs always have priority") and the forklift drivers have to be intensively prepared to work with their new automated colleagues. Nonetheless, the forklift-free factory is still the safest and most consistent logistics solution.

Possible AGV Concepts In principle, two different vehicle types can be used: the piggyback vehicle (Fig. 2.38, left) and the forklift vehicle (Fig. 2.38, right). Piggyback vehicles are equipped with conveyor equipment elements (roller tracks or chain conveyors) and manage pallet pick-up and drop-off laterally onto stationary conveyor equipment. The typical characteristics of both vehicle types are listed in the table.

For purposes of standardization only one vehicle type is used for area of use at each site. The choice is based heavily on the importance of the bulk storage area. If a bulk storage area is used or must be used, then it should be served directly by the AGV, which answers the question of the vehicle type.

Fig. 2.38 AGV models for the beverage industry: *left*, a piggyback AGV, *right* a forklift vehicle (*Source left* FROG; *right* E&K)

If conveyor equipment seems feasible, for example, to uncouple various systems or to separate transport (e.g. AGVS) and warehousing equipment (e.g. SSD[13]), then the choice of piggyback vehicles offers more consistent automation. In addition, larger-dimensioned load transfer stations (longer conveyor equipment sections) offer a buffering function which brings more security to the overall process (Table 2.3).

Table 2.3 Comparison of traits for both vehicle types

Technical characteristic	Piggyback AGV	Forklift AGV
Lifting pallets directly from floor	Not possible	Possible
Stacking pallets	Not possible	Possible
Space and time required for load handling	Low: can be positioned along drive path with lateral load transfer	High: load transfer must be done along axis of drive path
Driving speed	Top speed on long straight-aways up to around 2 m/s	As on left
Suspension kinematics	All variants can be used	Classic three-wheel construction, up to three steered wheels
Navigation equipment	Current systems can be used	Restrictions in bulk storage area which can be patched over with special solutions. New, innovative processes are in demand
Space required for layout	Only slightly larger than load itself	Considerably larger than the load, especially in the counterweight version
Manual operation	Barely possible	Possible under circumstances, depends on the model and make
Flexibility of use	High	Very high, as no stationary conveyor equipment is needed

[13] SSD = shelf-servicing device.

Summary There is no fully optimal logistics solution in the beverage industry. Conditions at the various locations are simply too different. One often encounters fixed structures in historical buildings surrounded by built-up areas. There is only rarely the opportunity to plan from scratch on an unoccupied area. The key elements of modern intralogistics are listed above. An optimal solution can be found for each individual case. These rules can include:

- Greenfield project: HBS warehouse, short transport paths with conveyor equipment which also serves as buffer. Additional AGVS in internal areas, clearly separated from truck loading/unloading, additional AGVS for flexible transport.
- Integration into an existing site: expansion and reworking (of data) of bulk storage area capacities, AGVS for internal areas: flexible, depending on transfer possibilities and buffering, with forklift AGV and/or piggyback vehicles.
- Definition of pilot projects for a step-by-step approach to new technologies. For example, automating individual sections or individual bulk storage areas – the main thing is to clearly delineate the tasks of this pilot project. This helps both in the economic feasibility calculations as well as in the definition of the project, including judging its success.

2.2.4.2 Innovative Commissioning at Marktkauf Logistik GmbH

Marktkauf Logistik GmbH, with headquarters in Bielefeld, combines all of its warehouses to optimally transfer goods for the EDEKA Group. Marktkauf Logistik GmbH, part of the EDEKA Group, has installed a concept with the name "Logistics by Voice" for commissioning in its Laichingen warehouse in combination with an automated guided vehicle system. Without the usual lists and manual collection vehicles, the individual pickers can double their commissioning volume with noticeably reduced error rates. No market is as hotly contested as the food industry. Margins are calculated to a minimum, low logistics costs play a key role. This led Marktkauf to decide to effectively modernize its logistics: step by step, all of the warehouses belonging to the company are receiving the solutions created by new technologies for improved goods transfer (Fig. 2.39).

The first model solution was introduced in the Marktkauf warehouse in Laichingen. Primary focus was on analyzing individual functions, primarily for planning an efficient systems solution for commissioning. Various samplings and calculations made over an extended period of time came to the conclusion that the existing commissioning in its usual form involved many ineffective motions: The individual picking orders were to be crossed off a list position for position. Even the screen-readable orders had to be confirmed by hand. In addition, the manually steered collection routes, the need to cover long stretches to the distribution area was a great disadvantage.

Fig. 2.39 A commissioning AGV, with optional manual operation (*Source* E&K 2004)

This traditional way of commissioning was marked by time-consuming peripheral activities. This conclusion could be reached not just by observing the processes, but more and more clearly by the calculated values. They showed that a commissioner on a 7.5-h shift spent only three hours doing their actual job of compiling packing units from the shelves to ready-to-send shipment units.

The new concept involves the commissioner receiving verbal orders by radio over a headset. The picker has both hand free to work, especially since an assigned automated guided vehicle moves on ahead to the next order point as soon as a verbal OK is given after the goods are removed. This means that the commissioner does not have to get in or out of the vehicle, which has to be parked in the correct position. Even the distances from vehicle to shelf have been reduced, since the pallets to be loaded are always placed directly adjacent to the shelf. The automated picking vehicles make the automated trip to the transfer point. Then they continue, after picking up empty pallets from the reserve storage, back to one of the predetermined shelf aisles. This technology has nearly doubled the productivity of the commissioners.

As soon as the next shift is reporting for duty, an AGV sets itself in motion. Every job starts with a short announcement by the commissioner. The voice manager then names the number of the first shelf and the pick spot for removal. In addition, the system names the number of the packing units that are to be picked. When the process is completed, the commissioner verbally confirms it to the system over a headset microphone and receives the next order.

When a collecting pallet is full, it is temporarily secured with foil wrap. The commissioner sends the collection (pick) vehicle to the transfer point with a verbal command. During this time, another AGVS collection vehicle moves into position to commission the next order. The picking vehicles then take the full pallets to the end of the lane and drop them off there to be picked up by automated transport vehicles. The picking vehicle then lifts an empty pallet and moves on to the predetermined shelf aisle (Fig. 2.40).

The loaded pallet then continues on its way from the transfer point to the stretcher to be wrapped in foil for shipping. An integrated printer attaches the data sent from

Fig. 2.40 A series of picking AGVs on charging area (*Source* E&K 2006)

the system with the destination in the form of a pallet label. This includes all the important information for shipping, provision and truck loading by the forwarder.

In summary, it can be said that productivity was doubled and the error rate reduced by 60 %. In addition, it considerably improves the ergonomics of handling, since the collection pallets in a lifting area can always be adjusted to the optimal loading height. The increased picking rate is achieved in combination with a, in the end by automating the collection trips.

2.2.4.3 AGVS Monitors Cheese Aging Process at Campina

The cheese maker Campina is a brand belonging to Royal Friesland Campina and operates an automated guided vehicle system with laser-guided AGVs in Bleskengraaf, The Netherlands. The automated vehicles transport the cheese wheels within the cheese making plant. In doing so, they move the racks of cheeses completely independently between the warehouse in which the cheeses age and the two processing machines (Fig. 2.41).

Die AGVS guidance control assumes, in addition to its usual functions, the task of integrated recipe and warehouse management. This administers the cheese recipes within the process. Each recipe contains a number of preset treatments which have to be regularly performed on the cheeses. Depending on the set recipes, the AGVs automatically bring the cheeses to the processing machines.

With an advanced warehouse management module, the entire warehouse and every ware stored in it can be visualized. Depending on the current status of the warehousing location (row occupied, number of free sites) and the recipe details of the wares, the software calculates which load is to be picked up first by the AGVS (Fig. 2.42).

The automated guided vehicles transport cheese pallets with a total length and height of more than 2 m and a width of only 85 cm. This means that they are small and highly unstable loads, which called for the development of a special customized AGV.

Fig. 2.41 The Cheese AGV entering the narrow warehouse lane (*Source* Egemin 2008)

Fig. 2.42 Two vehicles handling cheese in the aging warehouse (*Source* Egemin 2008)

The cheese pallets are stored one after the other in underground warehouse racks. Ventilation lines run to the left and right of the shelves. The free space between each cheese pallet and the ventilation lines is only 5 cm on each side. That means that the AGV must guarantee high stability to avoid vibrations when driving in and out.

2.2.4.4 Stainless Steel AGVs at the Schönegger Cheese Makers, Steingaden

Vehicles made entirely of stainless steel are best suited to meet the strict hygiene requirements in the food industry. The polished metallic surface deflects bacteria and can be quickly and easily cleaned. When, in addition, all the cladding and the steering and drive modules are sealed off, the vehicles can be disinfected from all sides – also from below – with hot steam.

In addition to its regular transport tasks, the automated guided vehicle system installed for the Bavarian cheese maker works its way through a detailed handling program for every one of the 120,000 wheels of cheese (Fig. 2.43).

The stainless-steel, free-driving forklift trucks serve the refrigeration and the aging warehouses, bring wares to and from the cheese-handling machines and bring the racks to shipping to be packaged. When the automated guided vehicles pick up a stack of cheese wheels, they automatically identify them with the bar code scanner

Fig. 2.43 The stainless-steel forklift carries 4.6 tons and reaches a lifting height of 3.8 m (*Source* MLR 2009)

and send the data to the warehouse administration software, which organizes the cheeses in the ripening warehouse by batch and ensures that the cheese-handling process is carried out exactly. This means that every batch can be traced along the entire logistics chain. It can be determined at any time when and where the goods were received, produced, processed, stored and transported.

2.2.5 Construction Materials

Neither the construction business nor construction materials production are typical AGVS target industries. Nonetheless, we find possibilities for uses here, too, of which we would like to present a (theoretical) example. Let us consider the manufacture of styrofoam insulation panels. This rigid foam material is ubiquitous as a building isolation material, used in roofs, walls and floors. As an intermediate product, it has to be transported in 5-m tall monoliths. The logistical demands for maneuvering and handling are high (Fig. 2.44).

The monoliths are created in the so-called block molds by means of thermal expansion. There the enormous cubes (5,100 mm × 1,050 mm × 1,300 mm) are lifted upright and brought to a warehouse. The automated guided vehicles are fitted with impressive-looking grippers that allow them to pick up one or two of the blocks, weighing up to 230 kg each, at a time. Load pickup and transfer can be adjusted to be done on rolling racks of up to a height of 500 mm or at ground level.

They transport the monoliths to the bulk storage area where they are dropped off at ground level to age. Depending on the final product, such an aging process can take from one day up to several weeks. The bulk storage area is served only by the AGV. Manual handling, e.g., by forklifts, are undesirable as they cannot drive as precisely and economically as automated vehicles. The bulk storage area is very densely packed, the distances between the blocks are very small.

After aging, the giant blocks have to be taken to the cutting machines. This transport is also performed by the AGVS. Here the blocks are cut into panels with the desired final dimensions. These panels are stacked for packaging and brought to the finished goods warehouse using manual forklifts.

Fig. 2.44 The AGV with its enormous grippers for the delicate giants (*Source* DS 2007)

Fig. 2.45 Narrow stacking conditions in the bulk goods area, a task for the AGV (*Source* DS 2007)

The AGVs navigate freely in the layout, i.e., with the aid of a magnetic point series. This system allows a great deal of flexibility in the layout and lets them work well within the narrow but very high bulk storage area. The AGV is a clamping lifter, whereby in this case, it is a custom-designed clamp construction combined with a standardized lifting frame. The clamps must apply their gripping power in very gentle increments to avoid damaging the sensitive styrofoam monoliths. The lifting frame is able to place the load at various heights (Fig. 2.45).

The vehicles draw their power from lead-acid batteries that last for two shifts. Then the vehicles automatically drive to the loading station where the empty batteries are manually exchanged for charged ones. Workers have special roller carts available which carry the batteries to be charged (Fig. 2.46).

Fig. 2.46 Load transfer onto a roller rack (*Source* DS 2007)

2.2.6 Steel-Making Industry

Automated guided vehicle systems are not only used in the traditional areas of intralogistics, they are increasingly moving into areas where the work is tougher and more physically challenging.

This also includes the steel industry, from production to processing to packaging. Outokumpu GmbH is one of the world's leading manufacturers of stainless steel. The group is headquartered in Espoo, Finland. In Terneuzen, The Netherlands, Outokumpu operates a European delivery center. There they process and deliver around a half a million tons of stainless steel every year.

In doing so, they base their operations on a modern, thorough and reliable logistics system. This consists of an automated warehouse for steel coils, two automated guided vehicle systems, four production lines, an automated interim warehouse for sheet metal packages and a modern production planning system.

The delivery center in Terneuzen receives most of its steel in the form of coils delivered by ship. There they are unwound and cut into lengths according to customer orders, and then delivered as scheduled in the form of coils or sheet metal packages. There are four production lines for this. Two in which the material is cut to length and two in which it is cut to the proper width.

Automated guided vehicles play a key role in these processes. They deliver the raw materials from the warehouse to the production area and return the finished products to the interim warehouse or directly to shipping (Fig. 2.47).

Two thirty-ton heavy lifting AGVs, designed as coil lifters, are responsible for supplying the production area from the automated coil warehouse. The coils are picked up and dropped off at the transfer station at the warehouse exit on the so-called thorn in the center of the coils. The coil is brought to its respective production line suspended from this thorn and mounted on a turnstile. One side of the turnstile is served by the AGVS, the other by the production area. This means that the turnstile serves as the interface between the coil lifter AGV and the production area. Coils that have not been used up entirely are returned to the coil warehouse by the two coil lifter AGVs to the warehouse and stored automatically (Fig. 2.48).

Fig. 2.47 Coil transporter carries 30-ton rolls directly with pallet (*Source* FROG 2005)

Fig. 2.48 Coil transfer from the coil lifter to the turnstile (*Source* FROG 2005)

Removing goods from the production area is the task of two coil lifter AGVs along with a further six-ton heavy load AGV which has a chain conveyor as a load receiver. Trimmed metal sheets that are to be rewound into coils for customers are made available at the exit of each production line and taken to shipping by the heavy AGV, Coils that are to be sent to the customer stacked as packages are made available on disposable pallets at the automated transfer stations on the production lines, where they are picked up by the chain conveyor AGV and brought either to the interim warehouse or directly to packaging and shipping (Fig. 2.49).

All or the production processes are controlled by the Outokumpu production planning system (PPS), which transmits the transport needed in the form of transport orders to the AGVS guidance control system. This then combines and optimizes the transport orders and directs them to the best-suited vehicles. All completed transports are reported back to the PPS. This guarantees end-to-end traceability of goods.

The vehicles' wheels are configured to fit their payloads. In addition, the coil loader AGVs can move about the area; that means that they can drive freely in all directions and turn on any virtual spot.

Fig. 2.49 AGV for disposable pallets with trimmed sheet metal up to six tons in weight (*Source* FROG 2005)

The vehicles navigate freely programmed over a magnetic grid set into the floor. They measure the magnets they have driven over with a magnet sensor strip. The vehicle guidance compares the position of the detected magnets with the positions established in the layout and corrects any deviations that might have arisen.

The vehicles plan their own route based on a map of the work area stored in their own guidance computer. This map contains both the routes and the positions, dimensions and functions of all the elements that are of relevance to the topography of the workplace. These include walls, doors, gates, elevators, loading devices, active and passive transfer station and all important facilities. The maps containing these elements can be changed by the user at any time.

2.2.7 Clinic Logistics

In the past, clinic logistics was generally paid little attention. But financial pressures on clinics is growing, so that more and more emphasis is being placed on the overall results. In doing so, logistics connects the various areas, not just technically, but also organizationally and, in the ultimate sense, economically. If these interactions are properly planned, they can unlock untapped economic potential. A logistics manager for a (large) clinic thus has the task of separating out sections of the various departments and using them to meet common goals. This fact must be made aware to decision-makers at all levels.

AWT, or automatic wares transfer equipment, has long been in use in large clinics. Initially, P&F equipment was used, followed by OM[14] systems. P&F[15] systems are mechanical chain-drives that transport roller containers[16] along the ceilings of the supply passageways. The OM systems are individual, electronically controlled and electrically powered monorails that transport one container each along a rail mounted below the ceiling.

P&F has definitely grown obsolete and has been completely replaced by OM equipment. Right around the start of the new millennium, many hospitals worldwide started replacing their AWT equipment with AGVS. The use of AGVS focuses on the main goods flows in clinic logistics, which are all transported in roller containers, this being food, laundry, sterilized goods, supply stores and waste. Various models of these roller containers can be seen in the following illustrations; the technical demands are described in Chap. 3. There is also a pneumatic transfer system available for dispatching files, samples and other small packets in-house.

The advantages of AGVS over OM are:

- Ease of installation (during supply operations)
- No ceiling mounts

[14] OM = Overhead Monorail.

[15] P&F = Power & Free.

[16] The roller containers are also called transport carts or transport containers.

- Existing pathways and facilities can be incorporated
- Flexible use, ease of reprogramming
- Permanent accessibility for each individual AGV.

In principle, AGVS is best used in clinics for:

- Optimizing logistics procedures
- Organized materials flow
- Reliable and prompt deliveries as part of a HACCP[17] concept
- Automatic tracking of materials
- Reducing logistics costs
- Increasing safety
- No damages to containers, doors, walls or facilities
- Integration into existing structures without interruption of supply.

At first, only large university clinics started using AGVS since the economic advantages were obvious. Nowadays, it comes into consideration for clinics with around 600 beds or more.

The vehicles commonly used are distinguished through their load pickup. Basically, there are three versions: the roller container can be picked up by the AGV from above and lifted, for which a forklift-like AGV is needed.

The other two versions underride the container, towing it or piggybacking it. In the towing version, pickup thorns on the upper side of the AGV hook into the roller container, which remains on its wheels while being transported. The piggyback vehicle lifts the roller container by a few centimeters after position and carries it along (Fig. 2.50).

Fig. 2.50 A forklift AGV for frontal pickup of a roller container (*Source* MLR)

[17] HACCP = Hazard Analysis and Critical Control Points concept, a preventive system to guarantee food and consumer safety (1998).

Fig. 2.51 Underride AGV with thorn pickup for towing roller containers (*Source* DS)

Fig. 2.52 Underride AGVs from three different AGVS manufacturers (*Source*, from *left* DS, MLR and Swisslog, all 2009)

Actually, forklift AGVs are only used where a AGVS is to link up with an OM or a P&F and no other solutions are available (Figs. 2.51 and 2.52).

The vehicle type most commonly used in modern plants is, however, the underride AGV with lifter. The advantages of this over forklift AGVs are:

- Less space requirement: the container itself determines the space required almost entirely.
- High maneuverability when loading and unloading.
- Speedy transfer from automated transport to manual pushing of the roller container.

2.2.7.1 AGVS in the State Hospital in Klagenfurt, Austria

In the Klagenfurt State Hospital (1,400 beds) some of the most modern AGVS-based AWT equipment has been in use since 2009. The impressive installation with a large vehicle fleet shows the potential of AGVS as an intralogistics tool.

Fig. 2.53 A AGV carries a roller container. The vehicles have a maximum payload of 500 kg (*Source* DS 2009)

The reorganization of clinic logistics was undertaken as part of new construction measures The overall project with the name “LKH Neu” (New State Hospital) has a duration of 10 years in total and comprises new wards, a central kitchen, a laundry, various other functional areas as well as a supply and disposal center. All of the areas are connected underground, creating a 14-km network of passageways. The overall concept shows that logistics is being given a fittingly large share of attention (Fig. 2.53).

Sixty automated guided vehicles fulfill the tasks of transporting food, laundry, medicines and stored supplies. They do their job effortlessly and exude a quiet, calm atmosphere. The reasons for this lie on one hand in the drive and steering equipment, but not least of all in the advanced navigation process. The use the so-called free navigation, in which the AGVs do not follow physical guidance tracks such as drive wires or colored lane markers, but make do with small permanent magnets. These magnets are set in the floor at intervals of several meters apart and are sufficient for the vehicles to use for referencing.

Intelligent laser scanners provide protection for personnel and equipment: each vehicle has a scanner mounted at the front and rear which recognizes obstacles in the vehicle’s path. This allows vehicles to adjust their speed to meet conditions and to integrate themselves homogeneously into ongoing operations. These personnel protection features, recognized by insurance organizations, reliably prevent any sort of collision with personnel or facilities.

Fig. 2.54 Waiting for the elevator. The lifting and depositing positions directly on the elevator make it possible to dispatch roller containers (*Source* DS 2009)

The transported materials – regardless whether they are food, laundry, waste or medicines – are transported in roller containers which can be pushed by the clinic staff and positioned for automated transport at predetermined pickup points. These points are marked with guide plates on the floor, and sensors indicate when they are occupied. The employee then enters a destination for the transport manually on a terminal and the rest takes place automatically.

The AGVS guidance control orders a nearby AGV to take carry out the transport. The vehicle underrides the container, lifts it a few centimeters from the floor and takes it to its destination. While underriding, it additionally reads a transponder on the bottom of the container and checks whether the transport is plausible. This prevents, for example, a waste container from being taken into the kitchen (Fig. 2.54).

Preconditions for planning: In order for the overall system to function, comprehensive planning is necessary. Two key preconditions were the ring concept and creating redundancies.

Each functional area was laid out as a logistical ring. All material flows move consistently in one direction: materials are brought to one place, pass through a function area and leave it in another place. This avoids conflicting material flows, making the "supply chain" a reality. This means that the kitchen and laundry, for example, appear extremely tidy – a necessary condition to ensure high productivity.

Practice-based planning also involves foreseeing redundancies. When designing the processes, thought is given to a possible breakdown of any and all components involved: How can clinic operations be maintained when, for example, an elevator or conveyor equipment is out of service? For each emergency scenario, a plan B has to be thought out so that a breakdown in one technical unit does not lead to a disaster in daily operations (Fig. 2.55).

One special emergency scenario is the fire alarm. If this is sounded, the AGVS switches over to a special mode that ensures that the AGVs act in accordance with the situation, keeping pathways free and not using elevators. Automatic doors are not driven through so that they can close without problem.

Fig. 2.55 The subterranean world of the AGVs. Here we find the long transport paths, buffering areas and battery charging stations (*Source* DS 2009)

Example kitchen: Additional wards and the newly built kitchen required basic changes in the preparation and delivery of meals for the patients. The previously used "cook & serve"[18] was replaced by the modern "cook & chill"[19] approach. "Cook & serve" meant that meals had to be served directly after being made, which was not possible with longer transport paths, because the legally prescribed serving temperatures could not be maintained. By the time the food reaches the patients, the warm foods were too cold and the cold foods too warm.

This is why hospitals have switched over "cook & chill": The food is chilled immediately after cooking according to HACCP guidelines. Both the serving trays with the food and the roller containers themselves are pre-chilled to four degrees C before they are sent to the station by AGVS. There is a special refrigerated room for the containers there. Forty trays fit in one cart.

A AGV delivers the transport carts weighing up to 350 kg to the station and drops it off at a regeneration station. There the cart is opened and docked with the regeneration station, where the warm food is reheated while the cold food remains chilled. At the end of the regeneration process, the staff serve the food trays to the patients.

After the means have been eaten, the transport carts are loaded with the dirty plates and utensils and sent back to the kitchen where they are emptied by kitchen staff. Then each transport cart is required to be sent to an automatic container wash, delivery and removal is naturally managed by the AGVS. In order to avoid having to use more transport carts than necessary, food delivery is performed almost exclusively at lunch time, other freight such as for waste or medicines are not transported during this "rush hour".

[18] Cook & serve = meals are served directly after preparation.

[19] Cook & chill = the meals are chilled after cooking and then later – when needed – reheated and served.

2.2.7.2 Advanced Clinic Logistics with AGVS in Vorarlberg

Similar equipment – albeit on a smaller scale – is used in Vorarlberg in Austria. It replaces a pickup and delivery service. The Austrian State Hospital in Feldkirch has optimized clinic logistics, based on the changeover from cook-and-serve to cook-and-chill and pickup and delivery service to AGVS (Fig. 2.56).

The State Hospital in Feldkirch, as a university instructional clinic, is the central medical services provider for the Austrian state of Vorarlberg. It has around 600 beds located in two wards, and a central wing. Previously, the internal hospital logistics were handled by the pickup and delivery service, which manually pushed the roller containers (transport carts). With the new construction project as well as the changeover from cook & serve to cook & chill, logistics were converted to an automated guided vehicle system as AWT equipment.

Brief description of the project: The State Hospital in Feldkirch began new construction of a central kitchen, a distribution center and a supply link to the east and west wards in mid-2008. An AGVS was to assume the transport of roller containers for food service, waste disposal, laundry supplies as well as medicines, stores and re-sterilized instruments (Fig. 2.57).

All of the transports are take place along the supply corridor. A newly built double elevator is used to connect the various areas in the distribution center. The supply corridor connects the distribution with the East and West wards; in both of the wards there is a newly built elevator tower with a double elevator and a AGVS station on each of the six uppers on which the transport destinations for most of the care stations are located.

Only a few destinations are located in the central wing of the hospital that is directly in the main building. These areas can be accessed by way of west elevator tower. Driving through the main building is rather challenging, because the height and width of the equipment passages are restricted in some places.

There is a special roller container for each of the goods to be transported: 41 food containers, 40 for laundry, 15 for waste, 35 for sterilized instruments, and 25 standard transport containers. Although they vary in design, they all have the same undercarriage with a uniform light frontal pickup surface of 660 × 365 mm (w x h). This means that they can all be underdriven from the front by the automated guided vehicles (AGVs), lifted and transported.

Fig. 2.56 The State Hospital in Feldkirch (*Source* State Hospital, Feldkirch)

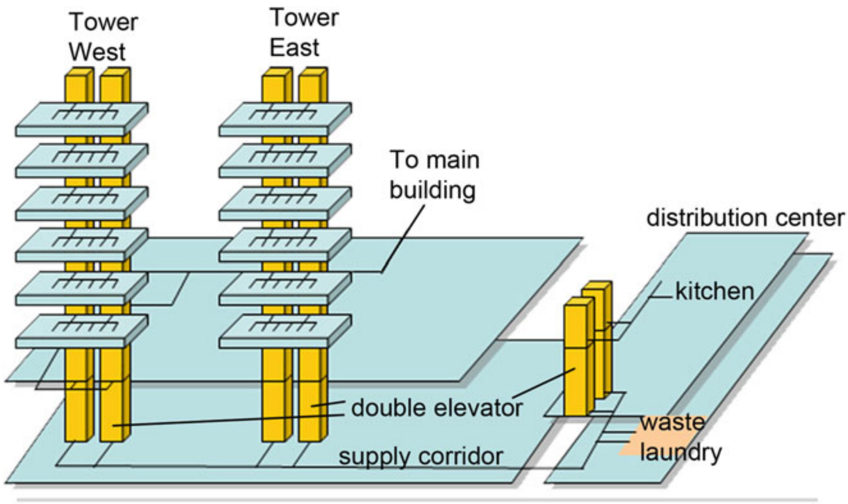


Fig. 2.57 Overview of the AGVS layout (*Source* DS 2010)

A data transponder is mounted on the bottom of each container to clearly identify it. This allows the AGVS to recognize what sort of container it is. Additional reflectors are needed to properly calculate the correct pickup positions on the parking positions by way of the location sensors to insure that the container is picked up safely according to the process. The location sensors monitor the spaces, recognizing whether or not there is a container at the parking position.

The technical solution: The new construction made it necessary to rethink clinic logistics. The existing concept (manual transports with the aid of pickup and drop-off services) was compared with alternative concepts. The key alternatives were manual route trains with trailers, and AGVS.

The location of the new distribution center made the pathways too long, while the kitchen's new cook & chill process made the food containers too heavy to be pushed from the kitchen to all the stations. The length of the supply trains was a reason against the use of the manual route train with trailers (especially in the narrow main building) as well as the strict quality requirements (traceability of transports). In the end, a comprehensive cost-benefit analysis and a projected ROI (return on investment) of 3.5 years led to a decision to use the automated guided vehicle system.

The contract was awarded to the Austrian AGVS manufacturer DS-Automotion, with whom the project was launched in May, 2010. Eleven automated guided vehicles were delivered, which were connected via WLAN to the AGVS guidance control system. The AGVS guidance control system is the heart of the equipment and is networked with all sources and sinks in the transport logistics chain via LAN (Fig. 2.58).

The vehicles are so-called underride AGVs, which are already in use in this form in many hospitals. The following table lists key technical specifications for the vehicles (Table 2.4).

Fig. 2.58 A AGV with shouldered food container on its way through the supply corridor (*Source* DS 2010)

Table 2.4 General description of the underride AGV with lifter

Dimensions and weights	L × W × H: ca. 1,800 × 600 × 330 mm Max. payload: 500 kg
Driving speed	1.6 m/s bidirectional, i.e. the vehicles can drive equally fast without restrictions and are equally mobile in both directions
Positioning precision	±10 mm
Grade climbing	Short stretches up to 7 % can be driven, with “gentle” transitions (25 m radius). There is such an incline at the transition from the new construction to the main building
Navigation	Magnet series navigation: small permanent magnets are set into the floor and allow the AGV to reliably orient itself. The so-called “free” navigation works along the principles of “dead reckoning and bearings taking”
Safety	Blinkers, emergency stop switches (front and rear), acoustic warning signals, programmable languages
Personnel protection	Current laser scanner recognized by insurance associations for personnel protection, with numerous warning and protection areas front and rear
Data transfer	Each vehicle is equipped with a WLAN client
Suspension kinematics	3-wheel: one steering and drive unit plus two fixed coasters In addition 2 measuring wheels Motors: maintenance-free three-phase AC drive, brushless AC hub drives, 24 V Wheels: non-marking Vulkollan wheels
Outer hull	All cover plates in stainless steel, from above, protection class
	IP54
Lifting equipment	Electro-mechanically activated lifting platform with load recognition sensor
	Lifting height: 80 mm
	With transponder reader device and light sensors to identify and localize containers
Energy concept	The vehicles are equipped with a traction battery (lead-gel, 200 Ah), which remain in the AGV. Batteries are charged automatically at special battery charging stations with the aid of charging contacts on the bottom of the vehicles. Each AGV has its own battery charging station

Unique aspects of the process: With the goal of limiting the number of AGVs needed, a precise delivery plan was worked out taking all necessary transports into consideration. This highly refined plan ensures that vehicle use is evenly distributed throughout the day. This is determined primarily by the food transports, which are given priority. These are the basis for determining the remaining free capacities for other transports. Overall, the equipment is in use from 6:00 am until 10:00 pm. At night the vehicles are at their parking places where they are recharged by a floor-mounted contact (Fig. 2.59).

The distances from the distribution center to the stations range from 130 up to 400 m. The AGVs move independently through automatic doors and use the elevators. They use WLAN to open the doors or the elevators in advance so that they do not lose time waiting. The fire alarms and fire doors are also networked with the AGVS so that certain pre-programmed reactions in the vehicles can be activated in the event of a fire alarm (Fig. 2.60).

The care stations are the main destinations for the transport trips. Each station has a food container with 26 trays delivered to it at every mealtime. The AGV brings the container by elevator to the required floor and drops it of directly before the elevator exit at a predetermined site. The sites are marked with guide strips which are fitted with sensors that recognize when a container has been dropped off there (Fig. 2.61).

When a container has been delivered and dropped off with the AGVS, it is reported over the in-house phone system to the staff. They can then pick up the container. After the food has been served and the dirty dishes have been collected, the container is returned manually to a free spot in the elevator tower, where an automatic pickup order for the AGVS is generated.

Fig. 2.59 A AGV recharges itself at the battery charging station (*Source* DS 2010)

Fig. 2.60 The AGV's pass through automatic doors and use elevators (*Source* DS 2010)

Fig. 2.61 Container operations in the elevator tower (*Source* DS 2010)

A AGV comes and picks up the container – while reading the transponder to determine the type of container and determining the destination itself. But an explicit destination can be entered manually at a locally available terminal.

Equipment performance: It is the kitchen that determines the overall performance level of the system. It has a so-called kitchen rhythm according to which it has to load the individual containers to keep the stations properly supplied. The AGVS has to be able to pick up the containers from the kitchen according to this rhythm. In the Hospital in Feldkirch this rhythm is every 2 min.

A buffer zone was installed to uncouple the containers between the kitchen and the AGVS. This is an accumulating conveyor with five container sites, which is served by kitchen staff from one side (release container and enter destination): from the other side, the AGVs take one container each – as long as containers are present (Fig. 2.62).

The equipment was taken into service in January and February 2011. Performance tests were conducted and the availability was determined. The required 99.5 % availability rate was achieved. Since then, the equipment has been running properly and to the operator's satisfaction.

Fig. 2.62 A AGV picks up a loaded food container from the accumulating conveyor by the kitchen (*Source* DS 2010)

In retrospect, the project can be assessed positively:

- The scope of the project was not too complex for a 600-bed clinic, but the logistics solution was comprehensive. The technical solution is comprised of standard elements that fulfill their task perfectly.
- The in-house team with outside support from a planner worked in an exemplary manner, the individual steps were well thought out and well prepared.
- The equipment supplier DS-Automotion was praiseworthy in its performance, based both on its experiences with similar and even significantly more complicated applications (such as the State Hospital in and the University Clinic in Cologne); this applies not just to the equipment but especially the project management.

2.2.7.3 AGVS in the "Nye Akershus Universitetssykehus", University of Oslo, Norway

State-of-the-art AWT equipment has been installed in the Nye Ahus State Hospital at the University of Oslo. The hospital has over 615 beds and a pediatric clinic. The AGVS, with 22 vehicles, is a central component of the extensive AWT equipment.

The AGVS brings goods in roller containers from the main pickup stations (kitchen, laundry, apothecary, sterilizing center) to the examination, treatment and care areas and returns empty containers or containers filled with used goods (e.g. laundry) or waste to the appropriate processing stations (waste handling center, laundry, kitchen). The vehicles have a payload of 500 kg and visit around 300 load transfer stations, which they reach by way of 14 banks of elevators. They make 500 trips per day.

The central computer passes on the work orders to the AGV via Ethernet and WLAN, and directs traffic along the 850-m route. The guidance computer communicates with the programmable logic controllers (PLC) in the conveyor

Fig. 2.63 An AGV with laundry cart leaving an elevator (*Source* MLR 2009)

equipment and elevators. It processes and administers the identity information (including the bar code tags on the containers) for all components and elements involved. In addition, all of the fire doors, fire alarms for elevators, automatic doors and charging devices are monitored. An OPC[20] server is used to connect the guidance system with the building automation (Fig. 2.63).

The entire system serves to bring containers with food, laundry, medicines, medical equipment, sterilized equipment, stores as well as dirty laundry, dirty dishes and waste to their intended destinations on time and with a minimum number of vehicles. To do this, it functions as a taxi system. This means that the vehicles do not visit the stations at fixed intervals, but that the transports are initiated when the corresponding dispatching stations are occupied. The guidance computer calls up a AGV to a dispatching station when a container is detected there. The container is identified by the AGV when it is being picked up by means of a bar code on the container.

The following strategies have been implemented to optimize the transport procedures in the guidance control software:

- Combined transports: The guidance system automatically combines individual transports (double plays) to minimize empty trips (time/distance).
- Empty vehicles can be redirected to parking stations en route. This allows the containers to "hitchhike" instead of being picked up by a separate vehicle, which leads to a reduction of empty trips.
- A new destination is automatically selected in the event of automatic interim buffering of currently undeliverable containers or when obstacles in load transfer are recognized.
- Schedule for prioritized transports, such as the transport of food containers in the morning. Flexible schedules define how many vehicles are reserved for a certain time frame. The remaining vehicles are free for other transport tasks (Fig. 2.64).

[20] OLE for Process Control (OPC) = standardized software interfaces for automation applications from various manufacturers.

Fig. 2.64 AGV traffic in a section connecting two wards (*Source* MLR 2009)

The underride AGVs employed here are made entirely of stainless steel. All the cladding and the lifting equipment is sealed off on all sides. This means that the vehicle can be easily cleaned and disinfected from all sides – even from below – to meet the ever-stricter hygiene requirements. The vehicle's surfaces can reach a temperature of up to 85 °C. The noise-dampening sealed drive uses AC technology. It can move the vehicle forwards or in reverse up to 1.7 m/s. Laser scanners on the front and rear sides of the vehicle provide the necessary personnel protection and obstacle recognition.

The expanded safety concept includes additional "bed sensors" that recognize beds left standing along the route or in the elevator. Additional functions such as "backing out of the lift" ensure that persons or obstacles that the AGV recognizes in the elevator can easily leave the elevator car or be moved aside. In such a case, the AGV resets and frees up the elevator car.

2.2.7.4 AGVS in St. Olav's Hospital, Trondheim, Norway

The new St Olav's University Clinic in Trondheim, Norway has 950 beds. Integrated functions here include ambulatory treatment, research and specialist training. In order to fulfill the complex transport demands of the hospital, the AGVS has to be able to automatically transport food, waste, medicines, publications and sterilized equipment. It uses underride AGVs for this task, which underride the roller containers, lift (shoulder) and transport them along 4,500 m of pathways.

Supplying patients with food, stores and laundry is a key element of hospital procedures. In St. Olav's Hospital, most of the goods are delivered in roller containers from an external warehouse to the truck ramp at the hospital and are ready for transport with the AGVS. Storing the containers at their place of use improves control of the material flow and reduces inventories (Fig. 2.65).

Loading and unloading is automatically performed by the system and the transport orders are transmitted by transponder. These chips allow ease of handling being located in a special pocket on the container (Fig. 2.66).

Fig. 2.65 An AGV exiting an elevator; *left*, with roller container (*Source* Swisslog 2009)

Fig. 2.66 A loaded and an unloaded vehicle meet (*Source* Swisslog 2009)

The free navigation system allows any sort of changes in the vehicles' movements and routes by simply resetting the software. The building did not need to be altered in any way. The so-called building navigation is used here, a very advanced procedure, requiring no separate navigation sensors, but rather using the already available data from the personnel protection scanners for navigation purposes. This makes fixed artificial markers such as magnets or reflectors unnecessary.

The automated guided vehicles call up elevators, open and close doors via a wireless IP network. Shade screens in the building are automatically controlled by sensors and provide for proper settings, which are especially needed for the navigation technology described here. The lighting switches off automatically when motion is detected. Technicians can track all the procedures in the hospital's supply center. This makes AGVS part of a "digital" clinic.

2.2.8 Pharmaceutical Industry

An international pharmaceutical company with headquarters in Southern Germany has been operating a automatic guidance vehicle system (AGVS) since 2005. The AGVS consists of ten freely navigating forklift vehicles with magnetic strip navigation and a AGVS guidance control center (Fig. 2.67).

The equipment manages the delivery of raw and ancillary materials from the existing high-bay storage warehouse to the three production areas. At the same time, it removes finished products from the production areas back to the warehouse. Europallets are transported with a weight of up to 600 kg and height of up to 2 m (Fig. 2.68).

The equipment was expanded in two stages in 2010 and 2012 to include a current total of 20 vehicles, a new production area and a new high bay storage warehouse in a neighboring building. Since operations involve transfers between the old and new high-bay storage warehouses, the hierarchies of the individual systems had to be rethought (Fig. 2.69).

Fig. 2.67 Vehicle 1 and 10 at the warehouse (*Source* FROG 2005, 2010 u. 2012)

Fig. 2.68 Vehicle 1 at the parking space and vehicle 10 at the warehouse transfer point (*Source* FROG 2005, 2010 and 2012)

Fig. 2.69 Vehicle empty, loaded and with payload at transfer station (*Source* FROG 2005, 2010 u. 2012)

The company places a lot of emphasis on the ability of the two warehouses and warehouse administrations, hosed in separate buildings, to operate independently of each other. The AGVS supplier developed a special solution for this, allowing the two warehouse administration systems to be combined with the company's guidance control.

This solution made it possible for them to implement all their customers' requirements their fullest satisfaction. The entire AGVS was expanded while operations were still running. First, the new areas were equipped with the necessary infrastructure and the new warehouse and the new PPS system were integrated. Then, step for step, the new vehicles of identical design were taken into service.

The 20 vehicles now cover an area of around 15,000 m^2 and serve more than 60 loading stations with over 120 storage locations. The nickel-cadmium battery concept is can be adjusted to fit other shift models, such as three-shift operations at any time and without further changes to the system.

The AGVS guidance control system receives the transport orders indirectly from an in-house developed production planning system (PPS), which is connected between the two WAS (warehouse administration systems) and the AGVS guidance control. Thanks to a targeted optimization of the transport orders in connection with intelligent prioritizing, the individual transports can be assigned to the most appropriate vehicle as they arise. The vehicles plan their own routes, they seek the best and quickest way to their destinations. All these measures serve the sole purpose of carrying out the incoming transport orders safely, reliably and most of all, promptly. The key point here is that all transports are fully traceable at all times, which is indispensable for the pharmaceutical industry.

The solution realized in this way allows the customer to create, adapt or remove routes, stopping points, transfer station, traffic rules and much more.

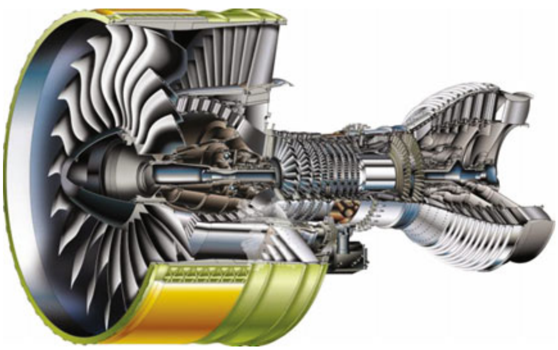
2.2.9 The Aviation Industry and Its Subcontractors

MTU Aero Engines in Munich produces turbofan engines for Airbus and Boeing jumbo jets. The intralogistics solution with automated guided vehicle system is entirely appropriate for this fascinating environment.

Upon viewing these special assembly lines at MTU Aero Engines GmbH in Munich, one is torn between the intralogistics solution using AGVS and the object under assembly, especially the final product. Because the GP7000 and GEnx turbofan engines are part of the Airbus A380 (Megaliner) and the Boeing 787 (Dreamliner), currently the world's most fascinating airliners.

The engines are not completely fitted out on this assembly line, they are too large and complex for that. The finished engines have a fan diameter of around 3 m and an overall length of nearly 5 m, providing a some 300 kN of thrust (Fig. 2.70).

Fig. 2.70 Parts for the GP7000 turbofan engine are assemble in Munich on automatic vehicles (*Source* www.baisi.net)



The turbine housing frames that connect the ND and HD pressure stages are assembled on this line. This module is called the turbine center frame (TCF). Currently they produce around 100 modules for the GP7000 and around 240 for the GEnx. This means that they complete seven modules per week, requiring 40 h of working time, 35 of which take place on the AGVS line.

New concept for small-scale serial assembly with AGVS Starting in 2010 the project team commenced planning for the new assembly line. Based on the relatively high number to be produced, they decided to adopt a new assembly concept. This involves an automated bar line with seven assembly stations and a pre-assembly area. To avoid friction in the assembly process, comprehensive conditions were created and implemented (Fig. 2.71).

A key goal was to minimize disruptions in assembly through defective components. To achieve this, commissioning was done by workers with the same level of training as assembly workers. This means that these parts can be pre-tested directly during commissioning. The entire range of parts are commissioned to meet the needs of the assembly area (Fig. 2.72).

At the same time, they wanted to achieve forced intervals for the overall line. This called for automated conveyor equipment. After extensive market research and internal comparisons, they decided against conventional conveyor equipment (such as chain, roller, band, steel plate or skid conveyors) and for an automated guided vehicle system. The key reasons for choosing AGVS over the other systems are:

Fig. 2.71 A view of the assembly line (*Source* Daum + Partner Maschinenbau GmbH, Aichstetten)

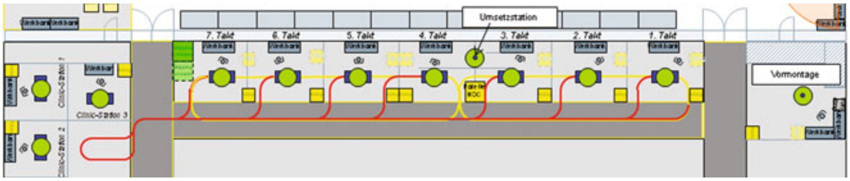


Fig. 2.72 The layout of the assembly line in overview (*Source* MTU Munich)

- space-saving design
- best accessibility to the assembly object
- high flexibility of the AGVS for ease of refitting the assembly line
- no fixed structures on the floor, leaving pathways and open areas free
- no cost disadvantages compared to conventional conveyor equipment.

Figure 2.72 above shows the schematic layout of the assembly line as it was realized. After pre-assembly, the object is moved onto the line itself with its seven assembly sites. The first three and the last four have been combined into closed cycles. In each of these cycles, three or four automated guided vehicles (AGVs) are in use, which have various pickup capabilities depending on the stage of assembly. Overall, there are seven AGVs in the system, one for each assembly site.

After pre-assembly, the pre-assembled components are delivered to their station in the first AGVS circuit in which a predefined range of components is mounted and installed in the housing. Then the component group is loaded onto the first vehicle in the second cycle (starting with assembly station 4), set onto a universal tool, whereupon the assembly is continued along the four stations of the second cycle. At the end, the TCF module is completed.

The AGVS needs no complex guidance control system: No extensive guidance control in the traditional sense is required for the automated guided vehicle system. The key element here is the forced intervals, extractability at each assembly station as well as the visualization of the equipment.

The interval time of five hours is rather long for interval assembly. A large monitor is mounted at each assembly station on which the workers can read at any time how much time remains in the interval and what progress is being made at all seven stations. When disruptions arise, they are made visible on all the monitors. The basic red, yellow and green traffic light symbols are used so that it can be seen at a glance if, and if so, where there are problems. These measures have led to a high degree of reliability and assembly quality.

If quality issues should arise at an assembly station that cannot be solved on the spot within 30 min, then the AGV, along with the module at its current state of assembly, is extracted from the line and taken to a separate “clinic station” where a special team corrects the problem.

Automated guided vehicles (AGVs) with standardized equipment: The seven AGVs are notable for their uncompromisingly standardized equipment and well as

Fig. 2.73 The automated guided vehicle with rotating assembly mounting. (*front* and *rear* view, *Source* Daum + Partner Maschinenbau GmbH, Aichstetten)

quality design and comprise the undercarriage for the various superstructures used in both assembly circuits (Fig. 2.73).

In the first cycle, the superstructure is used for the gas channel of the TCF (flow path hardware). In the second cycle, the AGVs shoulder a housing receptor which allows the internal parts to be installed as well as being attached from outside. Both superstructures can be rotated for ergonomic purposes and remain on the AGV unless there some reason to change the orientation of the vehicles to the assembly cycles. The superstructures were not originally available from the AGVS manufacturer, but were assembled by the MTU fixtures assembly department. Only the mechanical and electrical interfaces were co-ordinated with the AGVS supplier.

The vehicles are battery-powered. The vehicle has a built-in charger for the lead-acid traction batteries. When necessary, the vehicles are plugged into a cable connected to an electric outlet over the weekends.

The safety concept is simple yet effective. All the vehicles are equipped with a forward-mounted SICK laser scanner for personnel protection. Along with the obligatory emergency stop switch. Aside from blinking lights and acoustical signals, no other safety measures are required, since the speed of 0.5 m/s is moderate.

There is also a simple and effective solution for vehicle navigation. Because the assembly line equipment is simple in its layout, optical track guidance is completely sufficient. A black guide track on the floor serves to orient the AGV. Stopping and junction points are realized using transponders set into the floor.

Project and operational experiences: The equipment was taken into service in February 2011. Track guidance using a colored strip affixed to the floor is best suited for the current use and relatively simple assembly layout. The strip is easily adjusted and provides reliable operation. This makes it entirely possible to consider adding more assembly stations to the seven already existing – a relatively simple matter for the concept and the equipment used.

Thus, seven AGVs play a key role in manufacturing these fascinating turbofan engines for the world's largest airliners – with innovative solutions in the assembly concept for a small-scale serial production. And this will continue for quite some time, as the GP7000 and GEnx programs are projected to run for at least 20 years!

2.2.10 Plant Engineering

At the site of a mechanical engineering plant, an automated guided heavy load transporter carries heavy machinery parts weighing up to 63 tons between the various production halls. The platform vehicle, 6 m in length and 2.50 m wide, crosses a 140-m outdoor section.

A traffic light with a half-barrier has been installed to regulate traffic in each direction along those sections of the route where manned vehicles cross the AGVs path. As soon as the AGV enters the intersection area, the guidance system switches the light for intersecting traffic to red and lowers the barriers. After the AGV has left the area, the light switches back to green and the barriers are raised.

Since laser scanners are not allowed for personnel protection in outside areas, the vehicle uses radar sensors. They are mounted on the front and rear. Wrap-around protective strips and bumpers complete the protective measures (Fig. 2.74).

The chassis consists of a stable welded construction and four steered swivel axles. The hydraulic steering has a separate setting range so that the platform truck can be maneuvered in tight areas despite its size.

The automated vehicle is loaded manually with a crane at the changeover stations. There are safety features here as well: A 360-degree light tells the crane operator when an AGV is in the intersection area with the crane. Only after the crane has left the route, i.e., it is out of the reach of the vehicle and its load, the operator pushes a button to clear the AGV to continue. Then the free-driving vehicle seeks its destination.

The equipment is controlled by a guidance computer. It transmits the location of the vehicle to the eight industrial-grade terminals. This is also where workers enter the orders for the AGVs. The guidance computer ensures a low rate of empty trips.

Fig. 2.74 Automated guided heavy load transport crosses the outside area, carrying loads of up to 63 tons (*Source* MLR 2012)

2.2.11 *Retail and Transportation Logistics*

2.2.11.1 Automated Guided Narrow Fork Lifters in an HBS Warehouse

The logistics services provider DSV Solutions operates a high bay storage warehouse with over 30,000 inventory sites, in which an automated guided vehicle system independently stacks and removes the pallets loaded with cocoa on an ongoing basis.

In its high-performance warehouse, DSV uses six automated high-bay forklifts, which can move up to 160 pallets per hour. The vehicles with their telescopic mounts can move their fork tines out right and left in order to stack or remove the loading units.

Fine positioning via laser scanner allows the exact transfer height to be maintained. When stacking, the laser scanners measure not only the height of the traverse, but also the free space available. If variations have arisen as the result of an improperly positioned mast or base unit, the measuring units can make adjustments as quickly as possible. The laser equipment keeps the reaction times extremely short and measuring the free space takes only a few milliseconds (Fig. 2.75).

The narrow fork lifters, which are only 1.50 m wide, move loads of up to 1.3 and can extend their lifting mast up to a height of 10.5 m. Driving through the narrow lanes, the unmanned vehicles reach speeds of up to 2.7 m/s. Thanks to the magnetic navigation, the forklifts can navigate freely in the loading area and can, for example, independently change aisles.

An especially low-energy use concept was developed for the equipment: a batteries hold their charge for over 18 h. Only then do the vehicles have to be recharged to be ready for the next use.

Fig. 2.75 Automated narrow fork lifters for use in HSB warehouse (*Source* MLR)

Efficient Fulfillment with Automated Guided Vehicles: Hermes Fulfillment GmbH operates a large mail-order shipping center in Ohrdruf in the central German state of Thuringia. An automated guided vehicle system (AGVS) offers quick and problem-free procedures in commissioning and shipping of the range of products from its parent company OTTO and other customers.

The logistics site in Ohrdruf is specialized for a broad range of articles, including electronic devices, small furniture, household accessories and rugs, as well as home improvement articles. The articles can weigh up to 31.5 kg, with dimensions of up to 3 m on a side. An automated guided vehicle system is used in the commissioning area.

Commissioning The overall length of the AGVS layout comprises 13 km of pathways over an area of 366 by 140 m and includes a high bay storage warehouse of 50,000 m^2. The goods to be commissioned are located in this warehouse, generally in the lower level, level 1. However, this level is not entirely sufficient, so that goods have to be picked from levels 2 and 3. Level 3 is located at a height of 4.70 m (Fig. 2.76).

Since highly diverse and sometimes rather large packages have to be processed in Ohrdruf, a single pallet often is not enough for a commissioning order, so that a second or third pallet is often needed. If conventional manually operated forklifts were used for this purpose, the commissioner would have to drive into the warehouse repeatedly, bringing out a loaded pallet each time. This would require a great deal of driving, creating a larger workload.

The new system relies on automated vehicles that allow the commissioner to order additional vehicles (with empty pallets) in advance if needed. This means that he can commission on one vehicle, loading the pallets there, but can call up additional vehicles with empty pallets. When the first pallet is loaded, he dispatches the AGV and then moves over to the next waiting AGV. This allows him to continue working and saves the time needed to drive away the full pallet and bring back an empty one (Fig. 2.77).

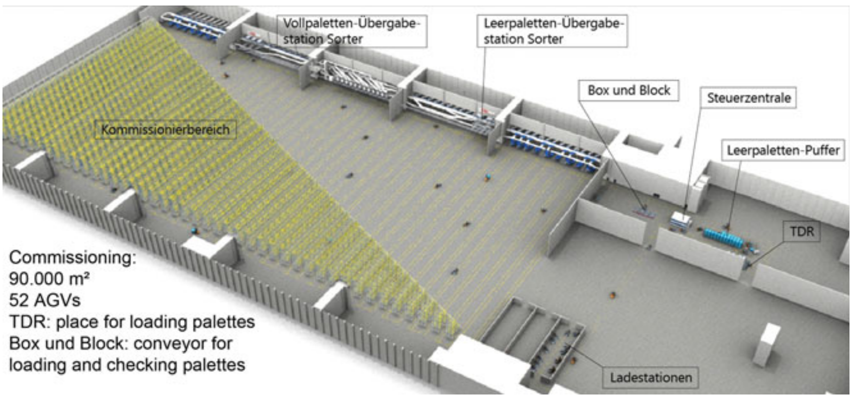


Fig. 2.76 Schematic overview of the AGVS layout (*Source* DS 2012)

Fig. 2.77 The two vehicle types in the main corridor of the shelf rows (*Source* DS 2012)

The AGVS, like the other automation components at the site, is operated and monitored in the control center. The 52 AGVs are displayed on extra-large, flat-screen monitors. The commissioning orders are transmitted via interface from the HERMES warehouse administration system to the AGVS guidance control and assigned there to the individual employees and vehicles (Fig. 2.78).

AGVS guidance control is connected to the AGV by WLAN. The wireless network along with the access points is provided by Hermes. Thus, the AGVs receive their orders and report their own status.

Fig. 2.78 The control center – not just for the AGVS: full overview on flat-screen monitors (*Source* DS 2012)

Fig. 2.79 The pallet robot loads an AGV with a collapsed special pallet (*Source* DS 2012)

Special pallets and palletizing robots The commissioning pallet is a special pallet with dimension of 1,400 × 1,200 mm (L × W). It is made of plastic and has collapsible side panels so that it can be stacked when empty. The side panels are reinforced with special construction elements. Since the pallets must be open during the commissioning procedure in the upper levels on the side facing the warehouse, there is a strap around them that provides the necessary stability.

Market research could not find an appropriate product available from suppliers. For this reason, development was started in-house for the goods-specific demands on the AGVS process, which included the choice of materials, the construction elements and the design. Today there are 250 of these pallets in use – they remain on site and are virtually indestructible.

At the empty pallet buffer, a palletizing robot picks up a folded empty pallet and sets it on a AGV. The AGV takes it into the shelf row in which the commissioner who ordered an empty vehicle is working. The commissioner takes over control of the AGV, unfolds the pallet and can continue with commissioning (Fig. 2.79).

The ride-along AGV The actual commissioning level is the floor level (level 1). This requires no lifter on the AGV; the pallet is kept near floor level by the forklift vehicle. For this purposes there is the CX-M model AGV. This is an automated version of a standard Still forklift (horizontal commissioner). There are 40 of these models on site (Fig. 2.80).

For commissioning in the upper levels 2 and 3, a EK-X model AGV is used. This is an automated version of a standard Still forklift (vertical commissioner). There are 12 of these models (Fig. 2.81).

Overall, there are 52 vehicles in the AGVS. The table shows their key technical specifications. (Table 2.5).

There are not many automated guided vehicle system that allow personnel to ride along. There are a few PeopleMovers that are designed for that purpose – primarily in public transport. And there are automated guided vehicles that can be operated either manually or automatically – most of these are forklifts.

Fig. 2.80 Manual riding: two contacts in the floor place as well as the two SAFE balls must be engaged while driving (*Source* DS 2012)

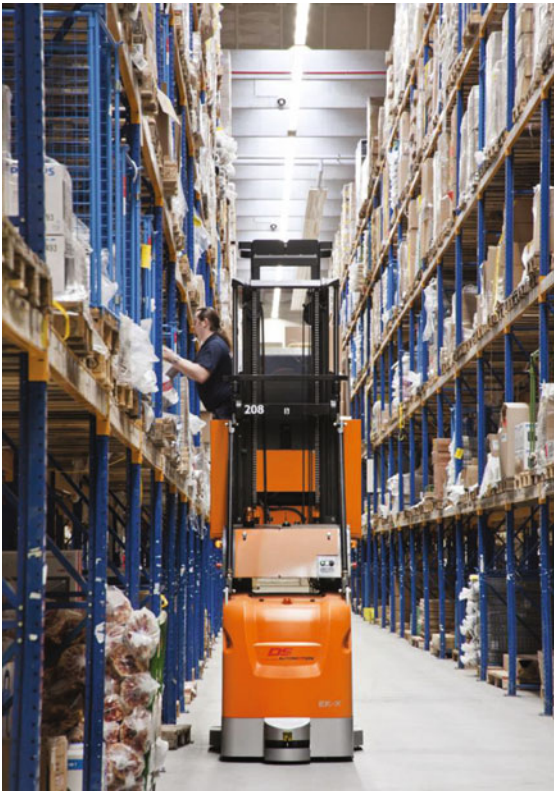


Fig. 2.81 Manual commissioning on the 2nd and 3rd storage level (*Source* DS 2012)

Table 2.5 Key figures for the two vehicle makes

Parameter	AGV type CX-M	AGV type EK-X
Dimensions and weights	L × W 2,942 × 940 mm Height min. 1,489 – max. 2,075 mm Weight: empty 1,350 kg Payload: 1,000 mm/LSP 600 mm	L × W 3,332 × 1,200 mm Height min. 2,903 – max. 7,000 mm Weight: empty 2,900 kg Payload: 800 mm/LSP 400 mm
Driving speed	Forwards 1.6 m/s Reverse 0.3 m/s	Forwards 1.4 m/s Reverse 0.3 m/s
Navigation	Magnetic point series	Magnetic point series
Safety	Ride-along technology, in addition, blinkers, emergency stop switches, load panel for pallet, bright wrap-around lighting for better visibility in the shelf aisles	Ride-along technology, in addition, blinkers, emergency stop switches, load panel for pallet, bright wrap-around lighting for better visibility in the shelf aisles
Personnel protection	SICK laser scanner (yellow)	SICK laser scanner (yellow)
Suspension kinematics	3-wheel with roller 3 KW/24 VDC	3-wheel 3 KW/24 VDC
Lifting equipment	Hydraulic, from 86 to 786 mm	Hydraulic, from 65 to 5,415 mm
Energy concept	Lead-gel battery 24 V/450 Ah	Lead-gel battery 24 V/930 Ah

Vehicles for this application are ones which persons can constantly mount, dismount and ride along on during automated operations while performing commissioning activities. There are two European standards to be met in doing so, namely EN 1525 and EN 1526. In general, only developers are concerned with these standards. This means that the AGVS manufacturer DS Automotion had to do ground-breaking work and developed the solution described below together with external consultants and insurance associations.

The safety concept installed for the ride-along AGV comprises a foot pedal, switching pads and the so-called safe balls. The foot pedal is located in the middle of the vehicle, just where the worker stands when riding along. Switch pads are located on the perimeter which automatically stop the vehicle when they are activated. These force the worker to remain in the middle of the vehicle when driving, since as soon as he steps off the foot pedal, the AGV stops. And if another person tries to climb onto the vehicle while it is driving automatically, this will activate one of the outside switch pads and stop the vehicle.

The commissioner who is riding along has to activate a safe ball with each hand. These are located facing forward at hand level. Only when the foot pedal and both safe balls are activated by the worker the AGV drives. When it gets to the stopping position, the worker can release the safe balls and continue commissioning.

Summary The project was realized in 2011, followed by a ramping-up of the system's performance lasting until January 2012. The system has been operating

Fig. 2.82 The AGVs at the automatic battery charging stations: current passes through a contact plate in the floor (*Source* DS 2012)

without major disruptions since March 2012. The AGVs at the Ohrdruf site are in operation 12–14 h daily. The vehicle's energy concept is based on lead-gel traction batteries that do not have to be charged during the day when in use. In the evening, they automatically park over the battery chargers, where they are charged overnight so that the entire vehicle fleet is available again the following morning (Fig. 2.82).

Although the project is rather new, the operators in Ohrdruf are convinced of the performance and the rationality of the concept and are already considering expanding the use of AGVS in Ohrdruf. This use is a successful example of how automated guided vehicles can save time and make processes safer, even when carrying out high-performance tasks.

Chapter 3
Technological Standards

If we return to the topic of the history of AGVS and its eras, we find that AGVS technology is at the start of its fourth era of development. The third era was marked by advances in AGVS equipment: a stable technological standard has arisen, which can be used to realize custom systems. *Here we should note that this standard still applies to the fourth era of AGVS and that it is not about to be replaced but rather expanded!* This chapter will be dedicated to describing this technological standard.

But let us start with the definition of an AGVS, according to the VDI 2510 guideline, which we will adhere to in the following text: "Automated guided vehicles (AGVs) are fixed-area means of conveyance with their own drive, which are automatically steered and driven without direct contact. They serve to transport goods, namely to pull or carry freight with active or passive means of load transfer. This guideline will consider only wheeled vehicles, excluding track-guided vehicles, air-cushion vehicles or walking machines."

Implementing customer demands has brought forth a wealth of new system designs. And customer expectations have grown accordingly. The systems have become more complex as the range of uses expands and technical developments progress.

But system costs cannot grow in line with increasing complexity. Customers expect, just as with the domestic IT market, constantly improved performance to be offered and realized without an increase in price. Successful optimization using automated systems is based on a balanced mix of various means of transport and degrees of automation. Manufacturers can rely on their years of experience and tested technologies.

At first glance, this chapter may seem illogically structured. We are not looking at AGVS systems strictly from the viewpoint of system hierarchies, but emphasize wherever we see how automation determines technology, namely the automated guided aspects. These arise from the functional differences between manually driven vehicles, such as traditional forklifts:

- Automated vehicles orient themselves in their surroundings without being directly controlled by an operator.
- Automated vehicles guarantee safe performance, i.e., they take care to protect personnel as well as their loads and the surrounding fixtures and facilities.

G. Ullrich, *Automated Guided Vehicle Systems*,
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- Automated guided transport systems organize themselves to optimally carry out their transport tasks.
- Automated guided transport systems have to integrate themselves into existing surroundings and be able to communicate on demand with other neighboring systems.

This is why we will start by looking at navigation and safety, the most basic functions of an AGVS. Then we will have a look at AGVS guidance control, since it plays a bigger role in organizing the AGVS than the individual vehicles. The latter will be addressed along with their chief components in the third section of this chapter. The fourth section will – last but not least – discuss the stationary surroundings of the AGVS, including the infrastructure and the peripheral units.

3.1 Navigation and Safety as Central System Functions

In our day-to-day activities, we do not view the concepts of "navigation" and "safety" as entirely separate, but rather as interconnected functions. Whenever we walk, jog or run, we try to remain on course and to reach our destination (navigation). At the same time, we continuously pay attention not to collide with anyone or anything (safety). We thus practice safe navigation with all our senses – whenever the situation allows it.

AGVS in its third era cannot yet do all that. There are still very different functions that have to be performed using various equipment and components. The automated guided transport vehicle follows a physical or virtual path until a separate safety system orders it to stop. Certain navigational components and steering elements function until something else, such as a personnel protection scanner and its emergency stop circuit, are activated.

Integrating these two systems in the future is a topic for the nascent fourth era of AGVS. Here we will use the current situation to provide a simplified sequential description of the functionalities that correspond to the "standard".

3.1.1 Navigation

According to DIN,[1] navigation refers to measures to guide the vehicle using it as an aid,

a. where the vehicle is located,
b. where the vehicle would proceed if nothing were undertaken to change its course
c. what needs to be done in order to safely arrive a desired destination, and if needed, along a prescribed route.

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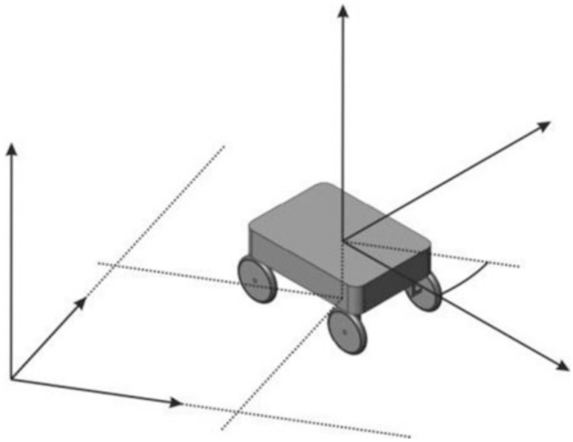
[1] DIN 13312:2005-02 "Navigation – Terms, Abbreviations, Formulaic Symbols and Graphic Symbols".

Fig. 3.1 The fixed-location AGVS with its own coordinate system



In doing so, the AGV moves within a fixed coordinate system whose area corresponds to the operating range of the AGVS (e.g. a factory hall). A vehicle coordinate system can be installed in the vehicle itself, usually originating in the middle of the vehicle, its center of gravity or at the center of one of its axles. Within this “mobile” coordinate system, it does not describe the vehicle’s movements, but rather its movement relative to the vehicle, such as how the payload moves.

The fixed coordinate system – information technologists call this the “global coordinate system” – usually originates from a hall ceiling or one of the outer corners of the operating area. The AGV then operates exclusively on the area defined by this coordinate system. Vertical movements along the fixed axis do not take place except for trips in an elevator from one level to the next, when a simple designation of the level number serves to describe the “height” (Fig. 3.1).

The key to these processes is how to determine the position[2] of the vehicle in the fixed coordinate system. This is usually described in terms of the two translation coordinates of the surface area and a radial coordinate, or its orientation in the surface area. Here we see two basic principles in action whose emphasis is determined by the system: dead reckoning and bearing taking.

Dead reckoning is also known as odometry and refers to determining position by means of internal sensors. Just as a sailboat determines its position with aid of a compass, watch and log, an AGV uses an angle sensor on the wheels and sometimes a magnetic compass for dead reckoning.

Dead reckoning, however, is imprecise by nature, affected by influences such as wheel slippage or a change in their radius cause by varying payload weights. AGVS manufacturers often put enormous effort into improving precision and reliability. Sometimes this involves installing a special measuring wheel in the undercarriage that only serves to register the movement of the vehicle as exactly as possible

[2] Position, or reference point.

independent of influences from the drive or steering, and additionally, a magnetic compass. These systems are there only for redundancy and safety. But just as with a sailboat, despite all efforts to the contrary, the cumulative errors produce unacceptable results. This is why bearings have to be taken regularly and promptly.

These bearings, or locations, use either fixed passive points or active technologies. Fixed points can be artificial in nature: a sailboat might take a fix on lighthouse with its compass, the AGV might measure a reflection point affixed to pillars or walls. Fixed points can also be natural: the skipper on a sailboat might recognize a spit of land or a church tower, which he can use to "take a bearing" and enter it into the chart. Under certain conditions, the AGV can recognize certain building contours and use them to determine its position. The terms artificial and natural are both common, but not particularly well chosen. What is natural about a wall or a building contour? A better way to characterize the points used for navigation would perhaps be to say reference points (for artificial points) and surrounding points (for natural points).

The most common representative of active technologies for taking bearings is the GPS system. This uses satellites to measure the GPS receiver. The AGV uses these measurements to determine its position – just like a navigation device in an automobile. But especially during the second era of AGVS, active inductive track guidance was use, which was common and also worked actively.

Before we turn to the navigation system that is in use today, we should clarify the term "locating". A location is a different approach to describing a position. Whereas a position means an exact set of coordinates, the location can also contain other information, such as when certain activities are necessary. These can include junctions, load transfers, docking stations, other stations or points in the layout that call for blinking or warning signals, or for a change of speed. This means that certain individual positions in the layout can be defined as locations and be serially numbered.

Let us now turn to navigation procedures. We will not delve too deeply into the theory behind the procedures but rather concentrate on their benefits for the user. Then we will summarize the relevant procedures in a table in the last Sect. 3.1.1.5.

3.1.1.1 The Physical Guideline

Automated guided vehicle systems that navigate or drive along physical guidelines (Fig. 3.2a) use fixtures on or in the floor. The most common versions are:

- The actively inductive guidance track, in which a current-bearing conductor is set into the floor. Here – similar to the block section control of a railway – the layout is subdivided into separate sections that can be switched on and off individually. Two coils are mounted under the vehicle at right angles to the conductor in which the alternating current of the guide wire induces a flowing current. The differential current in both coils is a measure of the deviation from the guidance track and controls the motor using negative feedback.

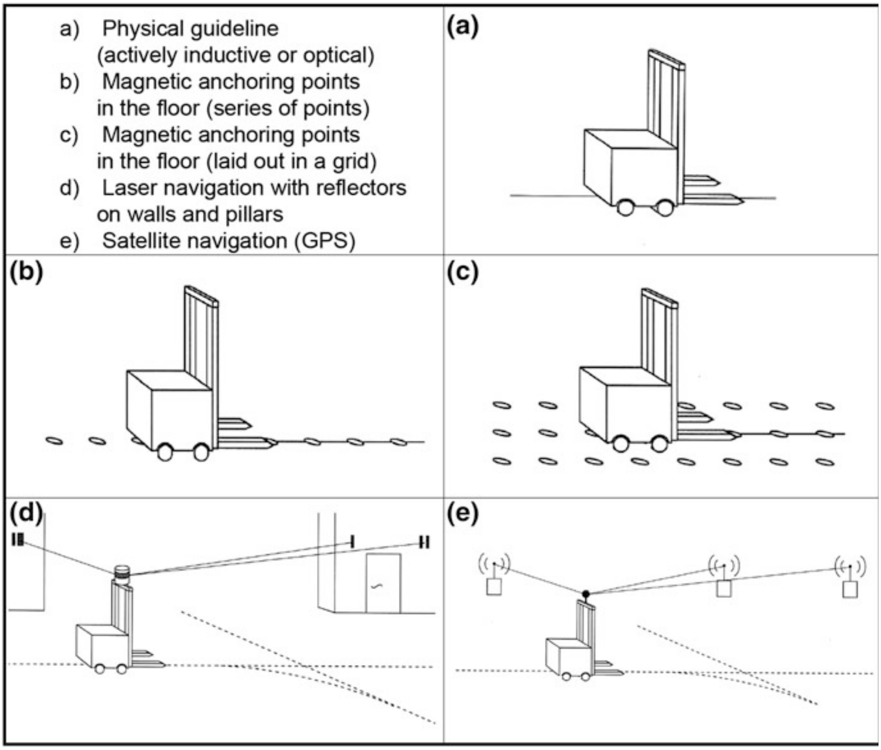


Fig. 3.2 The common navigation procedures: **a** the fixed and **b**–**e** the free procedure with a virtual guideline

- The passively inductive guidance track, in which a 5–10 cm wide metal strip is affixed to the floor. A sensor, consisting of two to three magnetic field sensors beneath the vehicle, detects the metal strip or the change in field with the aid of an edge detector and uses this to guide the steering motor. There is also a procedure by which magnetic strips are laid down instead of a simple metal strip. The reading distance typically comprises 10–30 mm.
- The optical guidance track, in which a colored strip with a color that clearly contrasts to the floor is either painted on or taped down with a strip of material. An appropriate camera sensor under the vehicle also uses edge detection algorithms to calculate guidance signals for the steering motor. The digital signal processing commonly in use today allows recognition of highly damaged tracks as well as coded marks next to the track to determine locations (Fig. 3.3).

The first version became one of the key technologies in the second era of AGVS in the form of inductive track guidance. Using a generator (4–20 kHz, typically 100 mA) an alternating current is fed through the guidance strip. An inductive alternating field is not influenced by dirt, rain, snow or the track (concrete, asphalt). It is only necessary to maintain a certain clearance to metallic coverings and

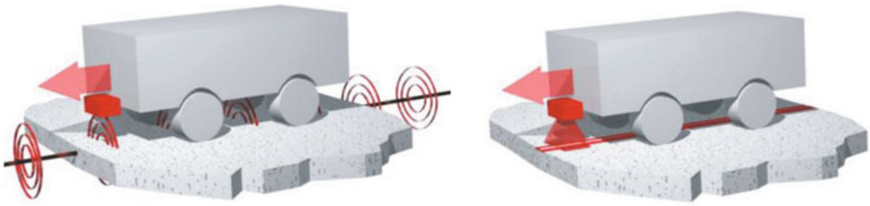


Fig. 3.3 Basic sketch of inductive and optical track guidance (*Source* Götting)

Fig. 3.4 Inductive and optical track guidance devices (*Source* Götting)

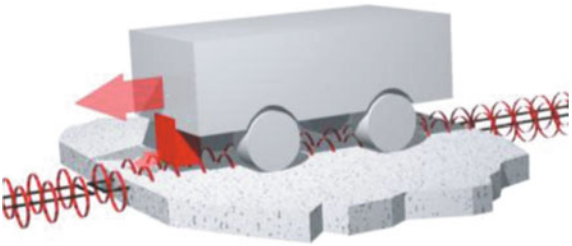


Fig. 3.5 Basic sketch of track guidance with a double conducting track for non-contacting energy transfer (*Source* Götting)

induction strips (steel mats). Using at least two field sensors, e.g. with two perpendicularly mounted coils, the inductive field or the horizontal deviation from the sensor alignment over the guide wire can be detected. Modern equipment rarely uses this original form as described here. In complex layouts, the free approach, i.e. with a virtual guidance track, is used today (Fig. 3.4).

When the layout is simple, that is, without many junctions, the passive-inductive or optical track is the most cost-effective option. Unless the operator relies on non-contacting energy transfer which works with a dual conductor set in the floor and along with the energy also helps navigate as a side effect. This technology is covered in greater detail in Sect. 3.3.2.3 “Energy Supply” (Fig. 3.5) the metal or colored strip is usually used in simple layouts or in vehicles at the lower end of the price range. It is typically employed to support serial production.

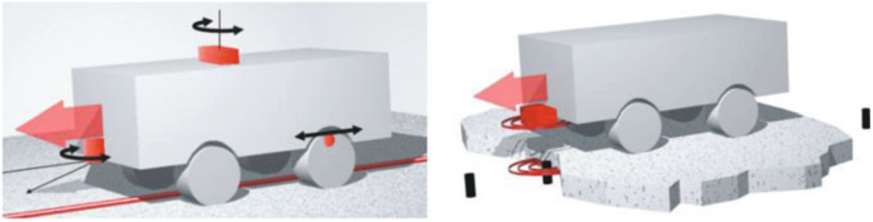


Fig. 3.6 Basic sketch for dead-reckoning navigation (*left*) and for magnetic or transponder navigation (*right*) (*Source* Götting)

3.1.1.2 Anchoring Points in the Floor

Artificial orientation sites in the floor are often used as representatives of the so-called free navigation; "free" in the sense that the route is not physically fixed but realized virtually in a computer. To calculate the guide line, it relies on one hand on dead reckoning, but takes advantage of the anchor points set in the floor to regularly take bearings. These anchor points can be purely passive permanent magnets or quasi-active transponders (Fig. 3.6).

The inexpensive permanent magnets are usually made of neodymium-iron-boron (NdFeB) and are cylindrical in shape with a length of 5–30 mm and a diameter of 8 to 20 mm, depending on the manufacturer. They have a simple north-south poling and are extremely powerful. They are set in special holes drilled for them, in which the magnet is affixed with epoxy adhesive. The floor can be covered with an epoxy or vinyl layer, or painted.

They can be laid out in a grid or as a series of points. A grid covering the entire surface area offers greater layout flexibility, while a series of points in principle requires fewer floor markers. The distance between points or grid intersections is determined by the demands on the precision of the vehicle's movements, the vehicle's kinematics and dimensions. A key factor is the quality of the dead reckoning navigation, which can be improved by using a gyroscopic compass.

The number and placement of the drill holes are to be determined by the AGVS manufacturer. Magnets in a series of points are usually set between 1 and 10 m apart. Ones laid out in a grid are usually set at a distance less than the width of the vehicle, whereby on each grid line, only every second point contains a magnet and the lines are staggered relative to each other (Fig. 3.7).

Figure 3.8 shows a typical magnet sensor bar, which was developed especially for use with automatic guided vehicles. Hall sensors are used to measure the magnetic fields of the floor magnets. These convert the magnetic field flowing through them into a voltage that is proportional to the strength of the field.

The length of the MSB can be configured. Its maximum length is limited to the width of the vehicle because it is set vertically to the track under the vehicle. The sensor consists of up to nine groups of eight hall sensors each. Each of these groups is administered by a processor. All of the processors deliver their data jointly to the

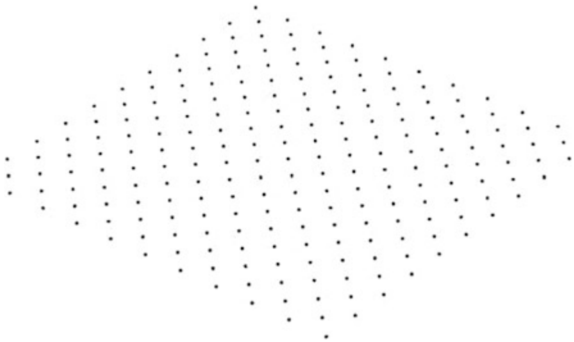


Fig. 3.7 A staggered magnetic grid

Fig. 3.8 A magnetic measurement sensor for indoor use; standard length: 387 mm, height: 43 mm, width: 50 mm (*Source* MLR)

device's main processor, which ultimately determines the position of the magnets underneath the sensor. The MSB has both a CANopen and an RS 232 interface.

Permanent magnets of the dimensions (diameter × length) 10 × 10 mm, 15 × 5 mm or 20 × 10 mm are used for the MSBs. Their remanence, that is, the strength of their magnetic field, ranges from 1,100 to 1,250 mT. Measurement intervals, the distance between the MSB and the magnet of 10–60 mm, provide an accuracy of measurement better than 2 mm.

Another product on the market is the MMS (magnet measurement sensor), designed for both indoor and outdoor use. It does not achieve the precision of the MSB, only around 5 mm. But it does so over large measurement intervals (up to 200 mm) and by drive-over speeds of up to 80 km/h. This means it is not designed for traditional AGVS use, but rather for fast, partially automated vehicles operating outdoors, such as public buses which support the driver when approaching a bus stop (Fig. 3.9).

For external areas, quasi-active transponders are often set into the floor in place of passive magnets. These are provided with energy by induction from the reading unit beneath the vehicle, which they use to send their own identification (coding) to the reading unit. At the same time, antennas in the reading unit ensure that the position of the transponder is measured precisely (Fig. 3.10).

Fig. 3.9 An MMS (magnet measurement sensor) for indoor and outdoor use; lengths from 530 to 2,210 mm, height: 30 mm, width: 60 mm (*Source* Frog)

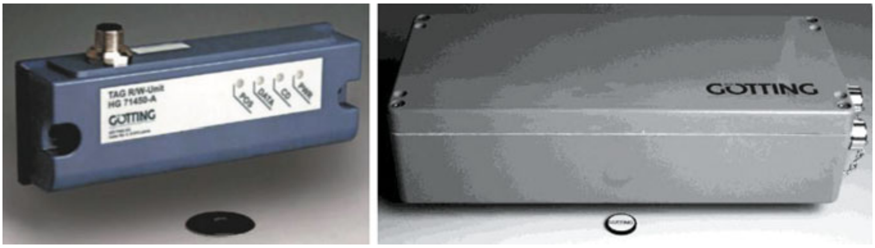


Fig. 3.10 Reading units for transponders (*Source* Götting)

Along with the absolute coding and the possibility of entering additional layout information for positioning, an advantage over magnetic navigation lies in their larger measuring intervals, which provide more freedom of movement for the vehicles. But these devices are considerably more expensive and larger than magnetic sensor bars.

3.1.1.3 Laser Navigation

Laser navigation is the most prominent representative of free navigation, making it the main competitor with magnetic navigation. Retro-reflecting foil is mounted on the walls and pillars above the workers' head level and can be read precisely and at great distances by a rotating laser scanner (Fig. 3.11).

Fig. 3.11 Basic sketch (*left*) and laser scanner with reflector (*right*) for laser navigation with artificial reflectors on the walls and pillars (*Source* Götting)

Fig. 3.12 Laser scanner used to determine the position based on reflectors (artificial landmarks) as well as surrounding contours (natural landmarks); *left* functional principle, *right* NAV300 or NAV350 (*Source* SICK)

Depending on the procedure used (with or without direct distance measurement) at least two or three markers must be visible to allow positioning. The procedure is highly flexible, which means that new drive routes can be directly programmed in or created by a "training drive" (teach-in). In order to avoid confusion, it is sometimes necessary to code the markers. Both processes, laser and magnetic navigation, are similarly flexible. Ultimately, the choice is to be based on certain criteria: floor magnets require (minimal) work on the floor; the line of sight to the laser reflectors must be free from every position in the layout (Fig. 3.12).

When mounted on the AGV, the laser scanner scans its surroundings without contact while driving and continuously measures the positions of the fixed reflectors. Comparing these to the coordinates of the reflectors as they were entered during start-up and configuration, the sensor recognizes the landmarks that lie along the route. These are then used to determine its own current position and orientation along the route, which at the same time determines those of the AGV. The current positioning data can be called up on the AGV computer in the form of coordinates. The vehicle computer continuously corrects the vehicle's deviation from the route caused by tolerances in the vehicle's geometry, differing loads, wear on the wheels, etc.

The key difference between the two devices lies in the way the data are presented. The NAV300 gives the position of artificial landmarks relative to its own position with a timestamp. These data allow the vehicle's position to be calculated externally (Fig. 3.13).

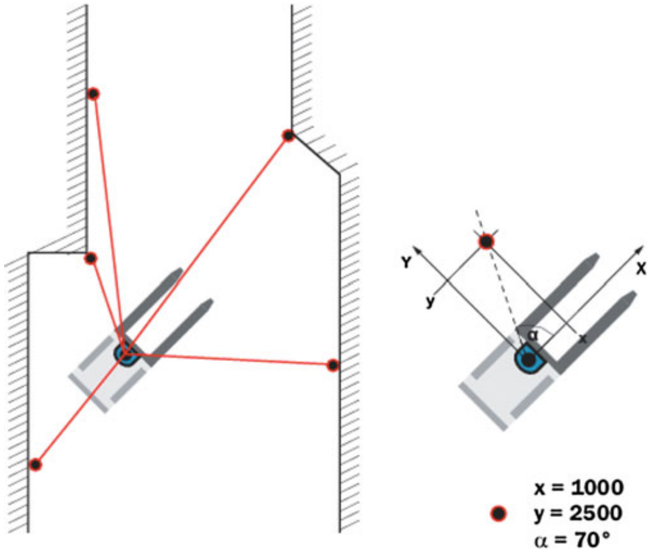


Fig. 3.13 Landmark recognition (*Source* SICK)

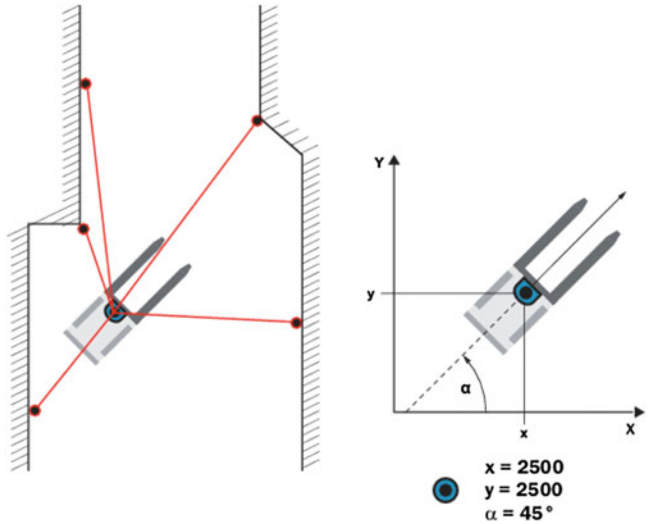


Fig. 3.14 Positioning based on reflector locations (*Source* SICK)

The NAV350 additionally calculates the resulting absolute position (x, y, angle a) of the AGV in the coordinate system. The NAV350 is also designed as a successor to the NAV200 and will replace it in the future (Fig. 3.14).

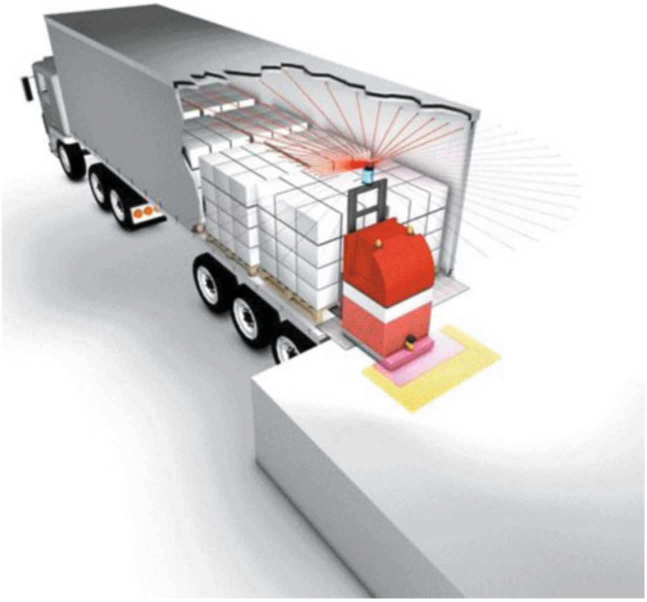


Fig. 3.15 Positioning by measuring coordinates, example of a truck loading (*Source* SICK)

In addition, both scanners (NAV300 and NAV350) can call up the measured contours to recognize the natural landmarks in an external computer with the proper algorithms (Fig. 3.15).

In addition to, or in place of artificial locating markers, natural locating markers (landmarks such as pillars or walls) can be used for vehicle guidance. It is important that these markers are clearly recognizable and that their positions do not change.

Since it is already widely accepted to use optical sensors to recognize obstacles, it is natural to use these sensors to guide the vehicle along natural orientation markers. One typical application involves the use of a distance-measuring laser scanner to drive along a wall. In this case, the wall only helps to aid orientation. Complete positioning/navigation is only possible with additional methods, such as edge detection or artificial location markers (Fig. 3.16).

When the laser scanner is additionally moved around another axis, it is possible to create a 3-D image of the surroundings. This process takes more time than two-dimensional measurement and is generally not compatible with high-speed vehicles. The advantage is that it is possible to orient the vehicle along the ceiling of a building (ceiling navigation). The line of sight to the ceiling is generally free of obstacles and thus can be reliably used.

Lessons learned from current developments and projects show that exclusive use of ceiling navigation can achieve a positioning precision in the area of ±20 mm. At the same time, a side benefit of navigation is offered in the overall concept with the

Fig. 3.16 The principle of the moveable laser scanner, mounted on the roof of a forklift, making it into a freely navigating vehicle. *Above*, looking for natural markers on the ceiling: the *red*, moving scanner, *below*, at shin level, the *yellow* fixed personnel protection scanner. (ceiling navigation: autonomous navigation system (ANS), *Source* Siemens)

moveable scanner which also recognizes obstacles for vehicles, including payload. This is not “safe” obstacle recognition in the sense of personnel protection, but it does recognize static obstacles, such as the hand-service unit of a portal crane, and can initiate braking. Ceiling-mounted cranes are not anathema to this technology: although they might temporarily or locally obstruct the line of sight to the ceiling, the software is capable of simply blacking out the height in which the crane moves.

3.1.1.4 The Global Positioning System (GPS)

We have now come to the active technologies with artificial floor-free markers. Passive markers are generally not sufficient for orientation in large or open areas. Actively transmitting markers, such as lighthouses, have the advantage that they can be sighted across great distances in their orientation to the vehicle. Using several of these markers makes it possible to determine the location and course of the vehicle.

Fig. 3.17 Basic diagram for GPS navigation (*Source* Götting)

Radio-based methods are the most prominent, in which vehicles take their own bearings using running time to a satellite (GPS) or stationary, coded radar reflectors. One condition for taking precise and reliable bearings is a clear line of sight between the bearing-taking antenna on the vehicle and the satellite or radar reflectors. This makes satellite navigation principally feasible outdoors on an un-built area.

GPS is not suitable for built-up surroundings, such as between buildings or in parts of large, open halls. In these locations, a so-called LPR (local positioning radar), an "indoor GPS" can be installed and used. Instead of highly precise, moveable and expensive satellites, relatively inexpensive fixed radio beacons are used in the operating area. These devices also measure the running time to the beacons, fixing their position. Well thought-out positioning of the beacons can give full coverage to a built-up area as well. This system is, however, considerably less precise than the costlier GPS, rarely achieving precision of ±10 cm, usually more in the range of ±30 cm (Fig. 3.17).

General information on GPS can be easily found on the Internet, so that we need not to go into detail here. Concerning GPS navigation for AGVS, Sect. 2.1.5.2, "Navigation in Outside Areas" already discussed the various steps required with regard to the technical efforts and expenditures needed to achieve the necessary degree of positioning accuracy. To achieve a precision of only a few centimeters, the so-called "real time kinematic dGPS" is needed, which requires a clear upwards cone of sight of 15°. Narrow gaps between buildings, metal cranes and bridges greatly restrict its possibilities for use.

3.1.1.5 The Procedures in Comparison

The following table lists the various navigation methods as well as their advantages and disadvantages (Table 3.1).

Table 3.1 Navigation Methods in Comparison

Procedure	Advantages	Disadvantages
Guidance cable (actively inductive)	Proven technology	Outdated technology
	Simple Vehicle guidance	Inflexible
		Costly and time-consuming floor installations
		Layout changes extremely expensive
		Subject to disruption if guidance cable breaks
Optical or (passively) inductive guidance track	Low cost, "simple solution"	No guidance control
	Simple layout, easy to put into operation	Hard to expand
		Inflexible
	Simplest system guidance: stops when the guide track is interrupted or with additional floor markings	Easily disrupted by damage to the paint coating or metallic strip
Inductive energy transfer (double power cable in the floor for energy transfer, serves also for navigation)	No (or only small) battery needed	Installation costly and time-consuming
	Well suited for simple route system (AGV as assembly line vehicle)	Complex layouts not possible
Magnetic navigation in series of points: Guidance cable emulated by permanent magnets in a series of points	Floor installation easier than guidance cable	Routes can be changed only by changing the floor installation
		Limitations due to floor space availability and state of floor (depending on the magnetic sensor strip used)
		Limited flexibility: lateral deviation from course only up to ca. ±30 cm
Grid (optical or magnetic)	Free navigation	Floor must be prepared, e.g. magnets installed
	Flexible within grid area	Limitations based on floor space available and floor condition
	Layout can be adapted easily by changing software	

(continued)

Table 3.1 (continued)

Procedure	Advantages	Disadvantages
		Laying out grid is costly and time-consuming
Transponders in place of magnets	Can be used outside without limitations regarding available floor space	More expensive than magnets
		Installation costly and time-consuming
	Suitable for large, heavy vehicles	
	Absolute safety thanks to absolute coding	
Classical laser navigation (with artificial markers)	No floor installations	Reflectors on walls, pillars, machines needed
		Laser head must be located above the payload level and have free 360 degree field of vision above the heads of employees
	Free navigation	
	Simple layouts are easily “learned”	
		High laser head mast requires a level floor
	Flexible within the area fitted with reflectors	
		Reflectors must be fixed and cannot become dirty or obstructed
	Well thought-out positioning of reflectors allows high degree of precision	
		Extraneous light can disrupt the system. Outdoor use only very limited
	Minor changes to layout can be performed by operator	

(continued)

Table 3.1 (continued)

Procedure	Advantages	Disadvantages
Laser navigation without artificial markers as… … building navigation or … ceiling navigation	No reflectors or other artificial markers needed	Higher demands on software
		Building navigation susceptible to changes in route, only suitable for simple scenarios without high traffic volume
	Systems for building navigation simultaneously use the available personnel protection laser scanners for navigation	
		Ceiling navigation requires additional, costly (moveable) sensory equipment
	Systems for building navigation are oriented on a ceiling which cannot be changed	
Free-flight or dead-reckoning navigation without taking bearings, or with gyroscope if needed	No fixed installations needed	Not reliable, since free flight = flying blind
		Poor driving precision
		Only useable for short distances
Satellite navigation (GPS) better: dGPS (differential GPS) even better: real-time kinematic dGPS	Does not depend on fixed installations	Can only be used in external areas
	Flexible	A free overhead cone of sight of 15° must be present
		High driving and positioning accuracy can only be realized with a great deal of technical effort

3.1.2 Safety

European legislation – meaning legislation in the European Union – is the strictest in the world. Lawmakers, institutes in charge of norms and standards, the VDI and insurance associations all maintain a package of technical regulations to minimize potential harm to workers arising from automatic guided vehicle systems.

This has been so successful that there have been almost no accidents requiring reporting caused by AGVS.

One could be of the opinion that Europe has even gone too far, making EU products too expensive for the world market. But these high demands are met by European manufacturers not just for safety systems, but are carried over to the overall quality of their products. In addition, this situation is certainly responsible for the fact that suppliers from Asia and America have found it difficult to gain a foothold in the EU market. In the final account, our high safety standards have both their advantages and disadvantages.

The topic will be divided into four subsections. First we want to awaken some understanding for the state of legislation, then we will stress the duties of the manufacturers and operators, in order to finally highlight the safety equipment that is being used in greater detail.

3.1.2.1 Legislation

A legal notice is important here right at the start of this chapter: no claims can be made against the validity of the information provided here – first of all because the legal situation is subject to constant change and secondly, because each and every AGVS demands a specific solution. At this point we would like to refer to the Leitfaden AGVS-Sicherheit (AGVS Safety Guideline),[3] published by the expert committee on AGVS of the VDI "Production and Logistics" organization, and kept up-to-date, as well as the VDI Guideline VDI 2510 Page 2 "AGVS Safety".

Table 3.2 lists all (AGVS-relevant) laws and ordinances. They are followed by the guidelines in Table 3.3 the norms and standards in Table 3.4.

[3] This guideline can be found free of charge on the VDI Internet site (www.vdi.de/fts) and of the Forum-AGVS (www.forum-fts.com).

Table 3.2 AGVS-relevant laws and regulations

GPSG	Device and product safety for technical work equipment and consumer products Act
9. GPSGV	Ninth ordinance for device and product safety (Machine ordinance)
BGV D 27	Accident prevention guideline for "work vehicles"
ArbSchG	Work protection Act Act concerning conducting measures for work protection to improve security and health protection at work
BetrSichV	Plant safety ordinance Ordinance for safety and health protection in the provision of working equipment and its use while working, safety in operating equipment requiring monitoring and on organizing plant safety

Table 3.3 AGVS-relevant norms

DIN EN 1525[a]	Safety for working vehicles, automatic guidance working vehicles and their systems
DIN EN ISO 3691-4	Working vehicles – requirements for safety equipment and verification Part 4: Automatic guided working vehicles and their systems
DIN EN 954-1	Machine safety, safety-related guidance components
DIN EN ISO 14121	Machine safety, guidelines for risk assessment (prev. 1050)
DIN EN 1175-1	Work vehicles safety, electrical requirements
DIN EN 1175-2	Work vehicles safety, electrical requirements, Part 2: General requirements for work vehicles with internal combustion motors
DIN EN 1175-3	Work vehicles safety, electrical requirements, Part 3: Special requirements for electrical power drive systems for work vehicles with internal combustion motors
DIN EN ISO 12100-1	Machine safety, basic concepts for general implementation guidelines, Part 1: Basic terminology, methodology
DIN EN ISO 12100-2	Machine safety, basic concepts, general design guidelines Part 2: Technical principles
DIN EN ISO 13849-1	Machine safety, safety-related guidance components, Part 1: General design guidelines
DIN EN ISO 13849-2	Machine safety, safety-related guidance components, Part 2: Validation
DIN EN 1755	Work vehicles safety, use in external areas
DIN EN 982	Machine safety – safety equipment requirements for fluid technical equipment and their components – hydraulics
DIN EN 983	Fluid technical equipment and components – pneumatics

[a] The European norm for AGVS (EN 1525) was not harmonized with the new machine guidelines. In future, the EN ISO 3691-4 is to be introduced, but has apparently been delayed. Until this norm appears and its location is published in the Official EU Gazette, we recommend continuing to apply EN 1525

Table 3.4 AGVS-relevant guidelines

2006/42/EG	New machine guideline As of December 29, 2009 the new machine guideline has come into legal force, it replaces the previous machine guideline 98/37/EG
2004/108/EG	EMV guideline/ EMV Act Elektromagnetische Verträglichkeit (electromagnetic compatibility) of electric and electronic products
VDI 2510	Automated Guided Vehicle Systems (AGVS) >Technical implementation guidelines >with all sheets
VDI 2510 Page 2	Automated Guided Vehicle Systems (AGVS) – AGVS Safety
VDI 2710	Overall planning of Automated Guided Vehicle Systems (AGVS); Principles >Planning guidelines >with all sheets
VDI 4452	Acceptance Rules for Automated Guided Vehicle Systems (AGVS)

3.1.2.2 Manufacturers'/Suppliers' Obligations

Manufacturers are required to construct their vehicles so that they meet the basic safety and health requirements of the Machine Guidelines. They are to integrate safety issues starting with the design process. The AGVS manufacturer must compile a so-called "original operating manual" for each product. All installed systems must be accompanied by an operating manual, if necessary, in the official language of the land in which it is being used. The AGVS manufacturer must compile technical documentation.

- This should include all plans, calculations, test protocols documents necessary to observe the basic safety and health requirements relevant to the Machine Guideline,
- It must be kept on file for at least ten years after the last date of manufacture of the AGVS and
- Must be presented to the authorities upon any justified demand.

The Machine Guideline does not constitute a requirement on the part of the manufacturers to provide the purchaser (user) with the technical documentation. If the machine builder has properly constructed his vehicles, then he must have his compliance to these guidelines confirmed by issuing a legally binding declaration of conformity and marking the AGV with the CE symbol. Only then can the AGV be offered for sale in the European economic area.

The manufacturer is required to conduct a risk assessment. This involves a hazard analysis to determine all the dangers associated with the system. To establish the required measures, he is to conduct a risk assessment according to ISO 14121.[4]

[4] EN ISO 14121 – Machine Safety – Risk Assessment, March 2008.

The risk assessment includes the following stages: system delineation, hazard analysis and risk estimate. This is followed by the central question of whether the system is sufficiently safe. If the answer is "YES", then the risk assessment ends (positively), if "NO" then a "risk reduction" must be commenced, following the three-step method:

1. Safe design: removing or minimizing the risks to the greatest extent possible (integrating safety into the design and construction of the machine).
2. Technical protective measures: Adopting the necessary protective measures against risks which cannot be removed by redesign.
3. User information about remaining risks.

Technical protection measures are realized by protective equipment (coverings, doors, lighting installations) or monitoring units (for position, speed etc.), which fulfill a safety function. Wherever the effect of a protective measure depends on the correct functioning of a guidance system, then the term used is functional safety.

The C-Norm DIN EN 1525 exists to realize functional safety in the AGV. This norm has been developed in harmony with the publication 98/37/EC. It provides for the basic safety requirements of the Machine Guideline and the EFTA[5] rules and serves as a basic, unified standard. The design and technical measures will be described in Sect. 3.1.2.4.

User information includes the operating manual and if needed all information for proper and safe operation of the equipment (operator information).

3.1.2.3 Operator's Obligations

The instructions for the operator in the operating manual and operator information are to be followed. These apply to the working environment of the AGVS and the vehicles.

The minimum requirements for the surroundings of the working vehicles are to be taken from DIN EN 1525. The following points are to be observed in particular:

Dangerous locations are to be secured by floor markings. The manufacturer is to instruct how to affix the floor markings and they are to be installed by the user! The manufacturer is to describe proper conduct in the operating manual. These are binding for the operator! Access to marked areas is to be restricted!

The operator is to fulfill all the manufacturers' requirements for keeping the pathways clear, clean and maintained. The manufacturer must describe all the details in the operating manual. These instructions are binding for the operator!

When using an AGV, the operator is to pay special attention to the personnel recognition systems on the vehicle as well as the loading equipment. The operator is to ensure that equipment using AGVs are to be inspected after assembly and before their first use. The inspection serves to ensure that they are convinced that the work

[5] EFTA = European Free Trade Association.

equipment has been properly assembled and functions safely. An external auditor can be called in for this purpose or the TÜV (Technical Inspection Association) can be consulted.

The operator is to ensure that the AGV and its attached devices are inspected at intervals not to exceed 1 year. These recurring inspections must cover inspecting the state of the components and equipment, of the completeness and effectiveness of the safety equipment as well as the completeness of the inspection documentation.

3.1.2.4 Components and Equipment

The safety equipment-based requirements for automatic guided transport vehicles are listed in DIN EN 1525, as well as in the necessary guidance categories according to DIN EN 954-1 (Table 3.5).

We now come to the key technical safety features in the AGV. These include:

- As with every machine, the AGV has an emergency stop switch, which has to be easily recognizable to everyone and accessible. When activated, the vehicle stops immediately and remains stopped until the switch is reset.
- In order to allow people to be aware of the AGV in operation, the vehicles generally have a combination of optical (rotating warning lights) and acoustic warning signals. This includes blinkers to indicate a change of direction as with automobiles, but with acoustic support.

Table 3.5 Guidance categories according to DIN EN 954-1

Guidance system		Category
Speed control	General	1
	To the extent that stability is affected	2
	To the extent that the effectiveness of the personnel recognition system is affected	3
Load handling	General	1
	To the extent that stability is affected	2
Steering	General	1
	To the extent that stability is affected	2
Battery charging system		1
Warning lamps		1
EMERGENCY STOP		3
Personnel protections system		3
Side protection		2
Bypassing the obstacle recognition system		2
Stopping the work vehicle before end of loading		2

Fig. 3.18 Personnel safety features: *left* Plastic bale plus laser scanner (*Source* Egemin); *right* soft foam bumper plus ultrasound wand (*Source* MLR)

- Mechanical, independently operating brakes ensure proper stopping. These are designed to be intrinsically safe, i.e., while driving, they need an energy supply in order not to activate. In order to stop, or in an emergency, the interruption of energy supply causes immediate braking (reverse principle to the standard automotive brakes). The brakes must be designed so that they can stop the AGV even with a maximum payload and also at maximum incline of the drive path (slope).
- Kick plates and special safety equipment for load handling provide for safe operations.
- The personnel protection system is essential. It has to ensure that people or objects located on the drive path or on the envelope curve of the AGV together with its payload are reliably recognized. Should this occur, the vehicle has to safely come to a stop before persons or objects are injured or damaged. Mechanical systems react to contact and are designed, e.g., as plastic bales or soft foam bumpers. Contact-free sensors scan the endangered areas ahead of the vehicle using laser, radar, infrared or ultrasound, or a combination of several technologies.

During the first two eras of AGVS, personnel safety was realized mechanically. Metal bales or wire mesh was used as shown in Figs. 1.2 and 1.3, and then later in the 70s and 80s, plastic bales (see Fig. 3.18). Soft foam bumpers were somewhat of an advancement (also Fig. 3.18), because they are activated when force is applied from above, which means that the safety equipment cannot be climbed on.

According to EN 1525 the mechanical bales or bumpers must be designed so that upon contact with maximum speed and payload, the force exerted on a test body does not exceed 750 N. The cylindrical test body has a diameter of 200 mm and a height/length of 600 mm, based on the shape of the shin of a grown man (employee). The friction values between the wheels and the floor, the braking capacity and the length of the safety equipment then determine the maximal rated speed for the AGV.

The plastic bales are activated either through winches and mechanical pull switches in the interior of the vehicle or though a light barrier, which is interrupted when a reflector mounted inside the bale loses contact through deformation of the bale. Soft foam bumpers are shock absorbers made of a foam-like substance in which optical conductors are mounted. The optical conductors lose their conductivity when deformed, breaking the emergency stop circuit.

Fig. 3.19 Safety laser scanner for personnel protection from SICK; *left* S 3000, S 300 and S 300 Mini (*Source* SICK)

Nowadays, automatic guided vehicles generally use non-contacting laser scanners, most of these coming from the SICK company. There are other manufacturers on the market, but their market share is insignificant. It is important that these devices are approved for use in an AGV by the insurance associations.

The main representatives of this range are the products shown in Fig. 3.19.

The areas of use for the devices differ in the possible driving speeds and the resulting stopping distances. Whereas the S 300 and the S 300 Mini have a protective radius of up to 3 m, their big brother S 3000 allows this up to 7 m. The protective areas adapt to the situation to account for changes of speed, direction, curves or docking maneuvers. They adapt automatically, allowing considerably more dynamic driving. All three devices have a safe data communication interface (EFI), allowing them to exchange guidance signals with other vehicles. In connection with Flexisoft safe fine guidance, which also has an EFI interface, complex monitoring functions can be covered (Fig. 3.20).

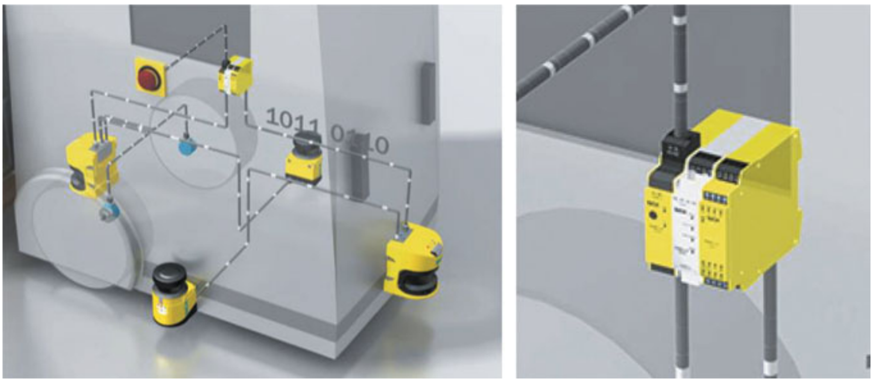


Fig. 3.20 Internally mounted safe data communication with Flexisoft safety fine steering (*Source* SICK)

In addition, both versions S 3000 and S 300 have a serial data interface which sends measurement information in real time in order to allow supporting functions during navigation or automatic load pickup.

3.1.2.5 Mixed Operations with Outside Personnel

In the previous chapter we highlighted the technical safety equipment for personnel protection for internal operations traffic. During mixed operations with outside persons, such as craftsmen, suppliers and other persons present, the existing safety measures reach their limits, especially in critical situations. These can be brought about, for example, by suspended load, a raised fork, scaffolding or a ladder (Fig. 3.21).

This is why it is important to pay attention that outside personnel are instructed in safety-relevant situation where they are working and on how to interact with AGVS technology.

In addition, it is a good idea to add sensors on the front of the AGV to augment the usual yellow laser scanners (for personnel safety), allowing 3-D obstacle recognition. In this case, it is important to distinguish between personnel safety sensors (approved by the insurance companies) and obstacle recognition sensors.

Finding appropriate sensors for 3-D obstacle recognition has (recently) become a major priority. The reasons for this are:

- Safety consciousness is of growing importance.
- More demands are being placed on equipment (in this case: more intelligent vehicles).
- There are more uses involving outside personnel (example: clinic logistics).

ToF cameras, radar and ultrasound sensors are currently being tested. But more progress is needed, there are currently no standard solutions.

Fig. 3.21 Critical situations for safety equipment in operational setting

3.2 AGVS Guidance Control

AGVS guidance control has the key task of integrating the AGVS into its surroundings. In addition, it guides the automated vehicles that belong to the system. This allows the AGVS to perform all the tasks demanded of it.

The VDI defines an AGVS guidance control system as follows[6]: *An AGVS guidance control system consists of both hardware and software. It is centered around a computer program which runs on one or more computers. It serves to coordinate multiple automated guided vehicles and/or assumes the task of integrating the AGVS into internal operations*.

The guidance control system

- integrates the AGVS into its surroundings (Sect. 3.2.1)
- offers users various service possibilities and receives transport orders (Sect. 3.2.2)
- provides corresponding function blocks to fulfill tasks (Sect. 3.2.3).

AGVS of the third era is a hierarchical system. That means that the individual AGVs are entirely intelligent, but not autonomous. The AGVs do not communicate with each other at all or only at a rudimentary level and rarely make independent decisions. Decision-making authority is reserved for the superordinated AGVS guidance control system. This gives it the overall responsibility and the rules necessary to manage the overall AGVS.

There is equipment that has no guidance control – how does that work? One hand, this equipment is certainly rather simple and does not require complex decision-making. One example might be a single towing vehicle that simply moves back and forth along a predetermined route. When it reaches its destination, it stops and waits for an employee to change the trailers. He then presses the start button on the AGV, sending it out on its return path. Having reached its destination, the vehicle stops and waits again. This sort of "equipment" certainly has its uses, but its functionality is quite limited. There is no fleet of vehicles to coordinate, transport orders to administer or peripheral interfaces to serve.

On the other hand, a guidance control system need not be purely physically recognizable as such. This is because it is not a matter of the computer or server, but depends on the functionalities which are fully "hidden" or spread out and run, for example, on the vehicle computers. This would also comprise a guidance control according to our definition – although such a setup is not at all common up to today. How it will look in the future is hard to foretell and will also comprise the topic of our fifth chapter.

[6] VDI 4451-7 Compatibility of Automatic Guidance Vehicle Systems (AGVS) – Guidance Control for AGVS, last update: 2005–2010, VDI/Beuth-Verlag.

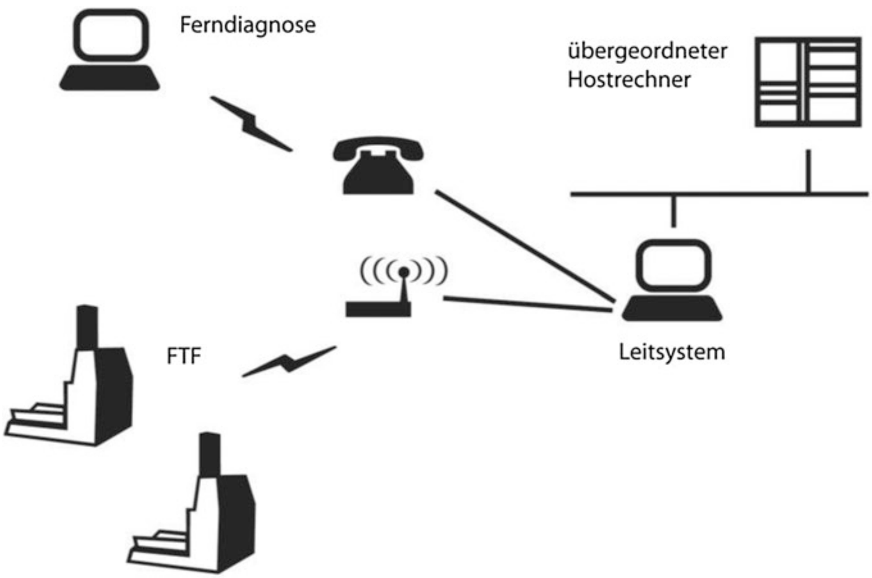


Fig. 3.22 System architecture of a simple AGVS (according to: VDI 4451-7)

3.2.1 AGVS System Architecture

Figures 3.22 and 3.23 give examples of systems of differing complexity. Figure 3.22 shows a typical small-scale setup: There are only a few AGVs in contact with the guidance control system via WLAN. In addition there is a LAN,[7] which provides direct contact with a superordinated computer which issues the transport orders. It gives a telephone link to a VPN[8] connection which is set up for long-distance diagnoses.

Figure 3.23 shows the high-end stage of an AGVS. Here you find a multiserver system and separate operating and visualization computers (clients). Secure data storage with a corresponding RAID[9] level is also present along with an Internet link for long-distance communication.

Independent, wireless communication systems do not just provide connections to the numerous vehicles, but also integrate commissioning devices and other peripheral equipment. Examples here are automatic doors, gates (or fireproof barriers) and elevators.

[7] LAN = Local Area Network, an in-house computer network.

[8] VPN = Virtual Private Network, a connection between physically separate, independent networks.

[9] RAID = Redundant Array of Independent Disks, a "logical" drive consisting of several physical drives to increase data availability.

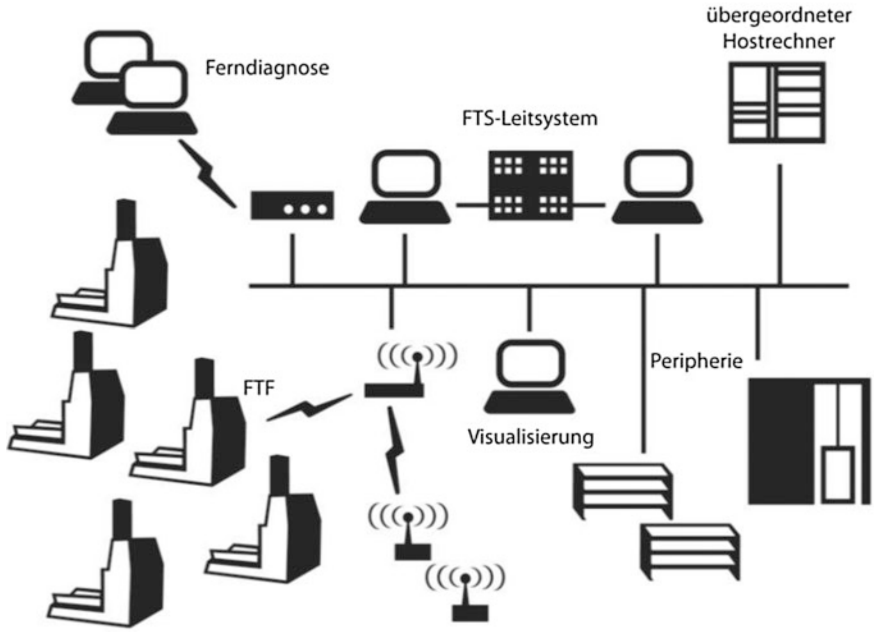


Fig. 3.23 System architecture of a complex AGVS (according to: VDI 4451-7)

Data transfer to the superordinated host servers usually takes place via local, Ethernet-based networks using the TCP/IP protocol. Such host servers can perform the following tasks:

- Material flow systems for production guidance (e.g. SAP)
- Production planning systems (PPS)
- Warehouse administration systems (WAS).

3.2.2 Users and Clients

AGVS guidance control can be called up by persons/employees or used for service purposes. Calling up the AGVS guidance control focuses on a central task of the AGVS, namely, fulfilling transport orders. In this sense, it connects all the persons and devices as users and clients that make it possible to fulfill transport orders using the AGVS guidance control system. These include:

- Equipment service and maintenance personnel, e.g. via terminal or monitor.
- Service technicians from the AGVS manufacturer, also using long-distance diagnostics.

- Operating data registering devices, including occupancy signalers, signal lights with activation or call buttons.
- Host computer systems such as production planning systems, assembly guidance systems or material flow computers.
- Automatic transfer stations, processing stations, loading or reloading stations, conveyor elevator stations, robots.

These clients provide the AGVS guidance control with its transport orders, using an ID, listing the source, sink and if needed with a priority and further information on the load. Additionally, the following information is exchanged:

- Status requests and reports
- Equipment guidance and status information
- Changes to transport orders
- Alarms and status reports on the vehicles and the layout.

The employee also has other convenient options: visualizing the setup, conducting statistical analyses and even simulations.

3.2.3 Functional Building Blocks of an AGVS Guidance Control System

Figure 3.24 shows the common functional building blocks of an AGVS guidance control system.

Here we refer to the VDI guideline "AGVS Guidance Control" and briefly describe the tasks that are assumed by the user interface, transport order processing and service functions:

3.2.3.1 User Interface

The user interface provides access to the AGVS guidance control system. On one hand, it comprises the human-machine interface (masks and input windows) as well as several machine-machine interfaces such as LAN and WLAN protocols (Fig. 3.25).

3.2.3.2 Transport Order Processing

Internal material flow control is a preliminary stage for transport order processing and is required when the transport orders are not clearly defined but have to be prepared. An order such as "need good A at machine B" requires processing along the classic lines of "pick up from C and bring to D". The AGVS-internal material flow control thus combines source and sink via the transport relationships entered

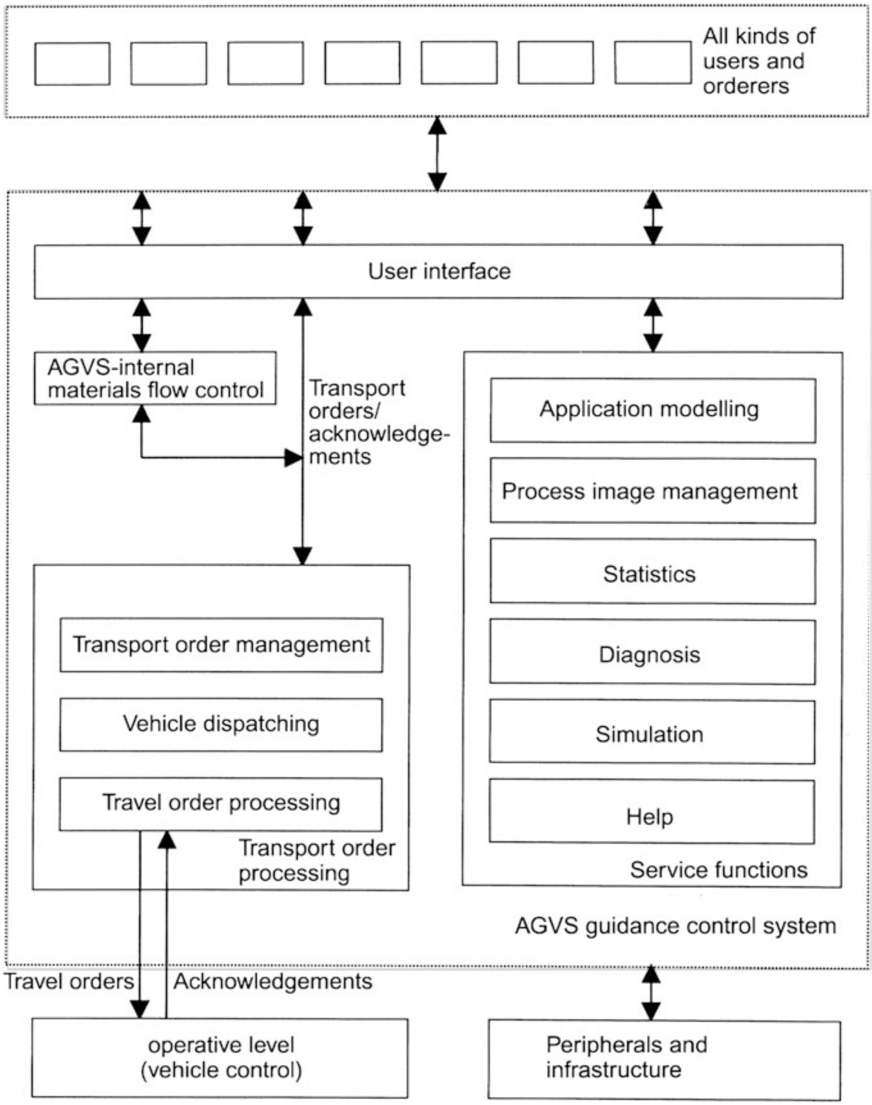


Fig. 3.24 Functional set-up of an AGVS guidance control system (*Source* VDI 4451-7)

for them into a transport order and then sends it to be executed by transport order administration. This sort of special generation of transport order can take place:

- During load transfer, the AGV scans and identifies the load; this load has a destination, or sink entered into the material flow control.
- Workers enter a materials order into a BDE terminal. The internal material flow control knows where this material is to be picked up and generates a transport order.

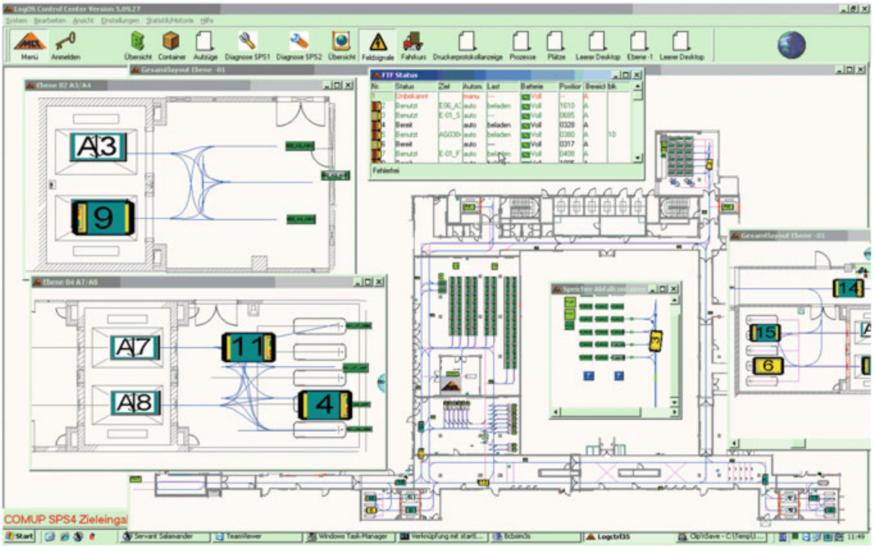


Fig. 3.25 Example of a user interface on the AGVS guidance control system (*Source* MLR)

- Load transfer stations can be fitted with sensors to signal when they are occupied, allowing demand to be recognized. The background information is found in the internal material flow control, which can use it to generate transport orders.

The key functions of transport order processing are:

1. Transport order administration
2. Vehicle dispatching
3. Travel order processing.

The travel orders form the final link of this chain. They are sent to the AGV, which processes them and reports back. In all three of these partial functions we see the operative equipment intelligence, which is decisive for the efficiency, and ultimately the profitability of the equipment. The guidance control system has to strike a balance between the quickest order processing time and the minimum number of vehicles necessary.

Transport order administration As a rule, transport order administration receives the transport orders as they were generated. In exceptional cases, the transport orders are issued in blocks with time scheduling, for example, from a superordinated production planning system. The transport orders are then ranked according to their priority or their scheduling and constantly checked for their feasibility. This is generally the case when materials are ready at the source and the sink is ready to receive them, but it can also be subject to other criteria.

If a transport order is ready to be executed, it is cleared for vehicle dispatching. Superordinated systems are informed of the status of the transport orders when necessary.

Vehicle dispatching Vehicle dispatching finds the "best" AGV for the transport order that has been cleared by transport order administration. Based on this decision, a travel order is passed on to travel order processing.

When determining the "best" AGV for the task, a number of strategies can be used. The simplest solution is just to call up a free AGV at random. In more complex systems, however, some of the following systems can be considered:

- The shortest time or distance to the source
- Avoiding possible blockages on the route
- The chance to pick up several loads from various locations
- Forecasts of the upcoming system status.

Further key functions of vehicle dispatching are the handling of empty vehicles and the battery charging strategies. When handling empty vehicles, each vehicle that has already processed an order and will not be receiving an order in the near future is given a transport order to proceed to a waiting area or battery charging station.

The battery charging strategy is principally dependent on the type of battery, the layout and the type of battery charging. Examples of battery charging strategies include:

- At the end of the shift, travel orders are generated for all vehicles to visit the battery loading or changing stations.
- Battery levels are constantly monitored. When necessary, travel orders to visit the battery loading or changing stations are generated.

Travel order processing Travel order processing generates sequences of driving or other activity orders based on transport orders. Travel orders are assigned a destination that is known to the AGV (activity orders can include load pickup, load drop-off or battery charging).

Travel order processing takes over the task of traffic guidance control. It ensures problem-free movement for all the AGVs, especially at intersections and high-traffic areas, and prevents collisions and blockages. As a rule, traffic guidance control is based on the traditional process used in railroad traffic, dividing the network into blocking areas (block sections). A vehicle is generally not allowed to enter a blocking area unless it is free from all other vehicles. After calling up and issuing a blocking order, no other vehicles are allowed to access this area. In addition, any doors, gates or barriers present are also activated.

3.2.3.3 Service Functions

Modern AGVS guidance control systems have a wide range of service functions. These can be classified as follows:

- Application modeling, e.g. for user-friendly changes to the layout or for (de) activating individual AGVs
- Process visualization administration (often called plant visualization) provides users with information on travel orders, vehicle status and positions

- Statistics, allowing access to useful data on plant capacity utilization, main sources and sinks, disruptions
- Diagnostics for efficient error recognition as well as aid functions to support operators
- Simulation or emulation, e.g. for analysis of system behavior.

Application modeling Application modeling creates a database for programming the overall system. Before an AGVS is taken into service, the layout on which the AGVs are to travel must be modeled. This includes such things as the drive paths with indication of direction, blocking areas, load transfer points, stopping points, charging stations, etc. Depending on the vehicles' guidance systems, further characteristics of the equipment such as the location of reference markers have to be modeled. Along with layout modeling, other important information must also be modeled. This includes:

- Vehicle models: describing the kinematics of the vehicle(s), installing of sensors, technical fixtures as well as logical behavioral patterns (e.g. behavior during emergencies or fires).
- Peripheral models: geometric description of their form and position in the area as well as logical behavioral patterns if needed. This particularly applies to load transfer stations; but all other peripheral facilities are included, such as elevators or traffic lights.
- Simulation models: Information on application-specific configuration of the simulation and visualization modules if needed.

During early project phases, the initial data flows into application modeling, where it is continuously adapted and enhanced. This modeling information is progressively entered into relational database systems, which support a consistent flow of data into the guidance computer.

Envelope simulation serves to graphically verify the layout for collision safety based on vehicle models. The standard for planning an AGVS is to conduct envelope simulations that determine whether vehicles can move along their paths without causing collisions. Based on the CAD layout of the operating environment, collision safety along the entire route can be checked.

Process visualization administration Process visualization administration establishes the time scheduling of the system status, provides a protocol and information. It controls and coordinates the types of operations as well as all system errors and disruptions. It supports error correction, either on-site or via distance diagnostics.

In some plants, a site administration is necessary in order to portray buffering sites. It represents a very simple warehouse administration in the sense of a site administration, integrated into the AGVS guidance control system. In doing so, it focuses on embracing the functions of the buffering zone and the buffering site administration. If needed, an external warehouse administration can be connected.

Statistics Statistics functions support analysis and optimizing of material flow operations and serve to assess the system capacity utilization. Statistics often provide the user valuable information on how to more efficiently operate the equipment.

Usually a small number of identically structured basic statistics are created in the AGVS, while other data are transmitted to other computer systems for further analysis via external statistics programs. The data are generally provided on the customer's own statistics servers (this can also be a simple workplace computer), so that the customer can conduct analyses on his own independently of the AGVS and the AGVS manufacturer.

Typical basic statistics are: error statistics, order statistics, throughput, system/vehicle capacity utilization, down times, transport route capacity utilization, buffer capacity utilization, order processing time, availability and energy balance.

AGV error statistics can also be used to derive diagnostic information. For example, if a sensor error comes up in one AGV significantly more often than in another AGV, this can indicate a defective or improperly adjusted sensor.

Diagnostics In order to quickly and safely identify and rectify problems, diagnostic systems have come to provide indispensable services. Distance diagnostics, especially in automated guided vehicle systems, offers an opportunity to being in outside experts to work on the system.

A system diagnosis is a diagnosis conducted by the user in dialogue with the diagnosis process. The user defines, configures and activates all diagnoses to be conducted. Based on that, automatic processes conduct the desired tests on the vehicle or the equipment and produce analyses of the test results. The user is able to influence, activate or deactivate the diagnostic process. The diagnostic functions, especially in more "standardized" AGVS guidance control systems, rely on troubleshooting diagrams.

In contrast to system diagnosis, self-diagnosis contains fully automated actions that check the system for errors or inconsistencies. The results are stored in the appropriate format and transmitted to the user. In the event of grave errors, the self-diagnosis either activates corresponding procedures to automatically correct the problem or demands a response from the user. At a minimum, those safety functions are activated that return the overall system or the affected components to a safe and useable condition.

Help functions "Always the right information at the right place" – this is the guiding motto for document and information management. In all processes, systems and platforms, each user can call up any necessary information in a multimedia format. Most of all, the Internet and HTML have contributed greatly to this development. The following areas of documentation can be distinguished:

- User documentation: This contains descriptions of masks, operating tips and a description of functions.
- System documentation: This contains information about system installation and operation. It is of great importance to the system administrator.
- Program documentation: This is available to the customer, it describes all programs according to their documentation standards.

- Installation documents: These are available for each plant installation and describe the specific characteristics of the equipment.
- Service and maintenance documents: Information compiled by the service technician about errors, repairs and maintenance performed.

Simulation/Emulation[10] Simulation has a number of various tasks. There are three different types of simulation that are relevant for AGVS applications. Functional system simulation tracks the influence of changes in the AGVS. This close coupling with the guidance functions allows estimates of system performance to be conducted which result in a great deal of safety when implemented. Real-time simulations or simulations in individually defined time intervals are rarely available. The guidance control itself serves as the basis for conducting the simulation, this process is also called emulation.

Material flow simulations are conducted using complex and abstract program packages, in which the emphasis is placed on the actual logistics tasks. The individual transport system – in this case AGVS – is in this case merely a means to an end. Commercial simulation systems can conduct any sort of simulation, the software is independent of the means of transportation at hand and its task. Slow-motion processes are the standard here, so that long-term estimates can also be made.

One unique and until now rare form of simulation is project support simulation. It offers functions for rough planning and determining the range of functions as well as determining the principal system processes. These simulation components are there to help sales technicians during the offering phase, but it can also be used to generate behavioral rules and system definitions. This information can then be used for a complete system simulation.

3.3 The Automated Guided Vehicle (AGV)

The designs of automated guided vehicles are as varied as their array of uses. The range of individual criteria is enormous in regard to such things as:

- the size of the vehicles
- the number of vehicles in a plant
- the complexity of the system as regards the functions, guidance, various navigation possibilities, load handling
- the various, sometimes extreme operating conditions
- the various industries.

Rather than simply cave in under the weight of all this variety, we will attempt to categorize them in this first sub-chapter. Then we will illustrate some of the key

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[10] The VDI Specialist Panel for AGVS is planning a guideline on the topic of "Areas of Use for Simulation of Automated Guided Vehicle Systems (AGVS)" for 2011.

points of the AGVS-specific vehicle components, such as the vehicle guidance, mechanical components and energy supply for the vehicles. The two core functionalities of navigation and safety have already been described.

3.3.1 AGV Categories

The best way to categorize AGVs is by looking at the loads that they transport. If we stick to intralogistics, then the first item is certainly the pallet (in the form of a Europallet or special types). But trailers, roller containers or rolls (of paper or metal) also need to be moved regularly. The following table categorizes the world of AGVs (Table 3.6).

Table 3.6 Categories of Automated Guided Vehicles

Pos.	Designation	Load	Description
1	Forklift AGV specially designed	Pallet	Floor-level load pickup, various heights, standard or special pallets or other fork-compatible containers, stackable, typical payload: 1 t. Conceived, designed and produced by AGVS manufacturers
2	Forklift AGV as automated serial vehicle	Pallet	As in 1, but: the AGVS manufacturer uses a serial product from a forklift manufacturer and automates it with the necessary AGV equipment
3	Piggyback AGV	Pallet	Usually limited to one transfer height (e.g. 1 m), side load pickup using roller tracks or chain conveyor, typical payload: 1 t
4	Towing vehicle	Trailer	"Tugger". Pulls multiple trailers, typical total weight of trailers: 5 t
5	Underride AGV	Roller container	The standard AGV in such places as hospital logistics. It underrides the roller container, and lifts it for transport. Typical payload: 0.5 t
6	Assembly AGV	Assembly object	Use in serial assembly, a substructure holds the pickup for the assembly object. Typical payload: up to 1 t
7	Heavy load AGV	Rolls, coils (paper or metal)	Transporting heavy paper rolls or steel coils up to 35 t
8	Mini-AGV	SLC	Use in large fleets, e.g. for commissioning.
9	PeopleMover	Passengers	For conveying passengers, similar to small or large buses
10	Diesel AGV	Diverse	Outdoor vehicles, usually diesel-electric or diesel-hydraulic drive. Typical payloads ≥3 t. Examples: Diesel forklifts, trucks, wheel loaders, harbor AGVs for ship containers
11	Special AGV	Diverse	Special solutions for special tasks. All AGVs that do not fit one of the above categories

SLC Small Load carrier, wide range of containers for small parts

The first seven categories are certainly the most common in the modern world of AGVs. The remaining four categories are not as obvious and not as entirely self-explanatory.

At this point we would like to point out that we are excluding the entire topic of “service robotics”. Service robotics will certainly grow in importance – that much is certain

- but previously, and we are looking at the third era of AGVS, the significance of service robotics for the world of AGVS has significantly lagged behind the expectations of the 1980s,
- and here we are describing the use of AGVS in intralogistics, where most service robotics applications do not play a role.

3.3.1.1 The Forklift AGV – Specially Designed

The range of uses for this vehicle is large. It centers on the pallet or forklift-compatible containers. The logistical tasks can be very straightforward (simple trips between two locations without diverging) or also quite complex (taxi operations). The vehicles can be used independently (stand-alone) or, managed by an AGVS guidance control system, working in cooperation with (several) other AGVs (Fig. 3.26).

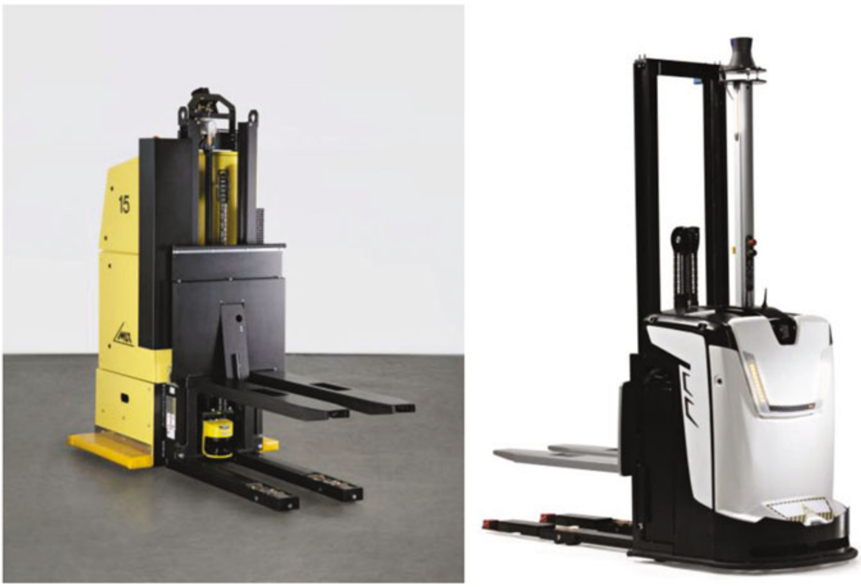

Fig. 3.26 AGV cat. 1: The forklift AGV – special design (*Source left* MLR and *right* Rocla)

3.3.1.2 The Forklift AGV as Automated Serial Equipment

In principle, the range of application for these vehicles is similar to that of vehicles in cat. 1.

The most import use here is for serially produced vehicles from forklift manufacturers' standard ranges which can be automated with the least possible effort. The AGV shown in Fig. 3.27 can still be manually operated even after being automated – that is its special advantage. There are pedestrian and seated vehicles.

The serially produced vehicle is enhanced with safety equipment, guidance and navigation components. For dead-reckoning navigation, the drives must be fitted with turning angle transmitters. To do so, the drive shaft of the motor must be extended outward so than an encoder (turning angle transmitter) can be attached. In addition, there must be enough room available to install them. This means that there are series that are easier to automate than others. Attention must be paid to the fact that in modern serial vehicles, electronic component groups for guiding sensors and actuators are included, rendering them predestined for automation.

There are two camps in the world of AGVS: those who prefer specially designed vehicles, and those who see advantages in automated serially produced vehicles. The advantages of specially designed AGVs (cat. 1) are:

Fig. 3.27 AGV cat. 2: The forklift AGV, based on serially produced equipment (*Source left* E&K, *right* dpm)

- Optimal integration on all additionally needed components (problem of insufficient room)
- Designed for permanent use and extended service live
- Accounting for an automation-compatible energy concept (automatic battery change or charging).

The advantages of automated serial vehicles are listed as:

- Cost advantages though serial manufacture
- Proven service and replacement part availability.

Serious AGVS manufacturers will always check when automating serially produced vehicles to determine whether there are further components that will have to be replaced to provide long-term, permanent use (such as wheels and electric components).

3.3.1.3 The Piggyback AGV

These vehicles also work with the traditional loading aids, such as pallets, containers or cage boxes. In contrast to the two previously mentioned categories, piggyback AGVs cannot lift the loading aids directly from the floor, but require a certain height, usually of more than 60 cm, which has to be maintained throughout the entire plant as the standard transfer height – we will not concern ourselves here with complex mobile or stationary facilities to adjust the transfer height (Fig. 3.28).

Fig. 3.28 AGV cat. 3: Piggyback AGV (*Source* Frog)

Fig. 3.29 AGV cat. 4: The towing vehicle (*Source* dpm)

The major advantage of these vehicles lies in their load handling: the lateral load pickup makes it possible to drive directly up along the stationary load transfer station without maneuvering – unlike forklift vehicles – and to pick up the pallet taking advantage of the high velocity of the conveyor (roller track, chain conveyor or similar). This can be done quickly and requires less space.

3.3.1.4 The Towing Vehicle

In the second chapter we addressed serial production and also discussed the possibilities for towing vehicles for commissioning and for transport (Fig. 3.29).

In the strict sense, we have to differentiate between specially constructed AGVs and automated serially produced vehicles. But since trailer-towing vehicles are considerably less common than forklift AGVs, we have not placed them in separate categories.

3.3.1.5 The Underride AGV

Clinic logistics were the topic of a previous sub-chapter, so that we need not describe this vehicle any in further detail here. It is important to note that along with clinics, they can also be used in an industrial setting (Fig. 3.30).

We also find previous examples from the automotive industry (BMW in Leipzig, see above).

Fig. 3.30 AGV cat. 5: The underride AGV (*Source* Swisslog)

3.3.1.6 The Assembly Line AGV

Vehicles used in assembly lines are very different in nature. The assembly object, its size and weight play a major role in determining the vehicle used. But the assembly stages also play a role in designing the AGV: Are purely manual assembly stages planned or are there also automatic stations? These call for a different degree of precision in positioning. And: How great are the forces that impact the object and the AGV during assembly activities? These also place differing demands on stability against tipping. In addition, the necessary access to the assembly object must be maintained (Fig. 3.31).

Such plant operations usually have much simpler guidance systems than taxi systems. Driving speeds are extremely low and the demands on personnel safety are often different. Workers constantly find themselves in immediate proximity to the vehicles. They should be able to continue to work without interruption, but nonetheless be protected against injury. This often has an effect on the use of a personnel safety scanner, in adjusting its safety and warning fields as well as the lateral step protection. The safety design must be conceived so that the workers can go about their tasks without constantly activating the sensory equipment.

3.3.1.7 The Heavy Load AGV

Here we would like to include the heavy load vehicles for indoor use. They are represented by the vehicles that transport rolls, either in paper production or processing (paper rolls with a weight of several tons) or in the steel industry: producers of steel coil, or in the automotive industry (steel coils usually weigh 30 t) (Fig. 3.32).

Fig. 3.31 AGVS for assembly and supply at Daimler in Bremen (*Source* CREFORM)

Fig. 3.32 AGV cat. 7: the heavy load AGV (*Source* Frog/Siemag)

Vehicles for such payloads place heavy demands on design and components. This applies to the drives, the energy supply and safety equipment. It is within their nature that the number uses for such extreme weights is comparatively low.

The extreme weight of the entire transporter determines the efforts of the developers to avoid accidents involving persons or objects at all times. That seems obvious at first, which is why we should expressly point out the direct comparison with AGVs of category 6, in which safety design plays a major role – but with an entirely different purpose.

3.3.1.8 The Mini-AGV

The eighth category has become somewhat rare in the current third era of AGVS. This involves numerous small, intelligent and flexible vehicles to perform tasks quickly. We nonetheless want to include them as a category, as the idea is not new, and there are – especially in the USA – a number of examples[11] (Figs. 3.33 and 3.34).

It is a vision which not only universities are pursuing: entire "swarms" of small AGVs working together intelligently. The vehicles should be able to communicate with each other – without their own separate AGVS guidance control, develop strategies and perform joint tasks. These areas of research are known as agent systems and swarm theory.

A number of unconventional uses are conceivable. The most prominent task lies in advanced commissioning, in which it is not the worker who seeks and collects the goods, but the goods themselves – with the aid of the mini-AGVs – make their way to the commissioners, aiding them in compiling customer-specific shipments.

Fig. 3.33 AGV cat. 8: The mini-AGV (concept)

[11] Example: KIVA Systems, 225 Wildwood Avenue, Woburn, MA 01801 USA, www.kivasystems.com.

Fig. 3.34 KATE (*Source* Götting)

The future of this technology will involve using intelligent designs and new components (electrical, electronic and sensory) to develop low-cost solutions. Personnel safety will remain a sticking point, as the current IA[12]-approved laser scanners would be prohibitively expensive.

3.3.1.9 The PeopleMover

Safely transporting passengers in public areas as well as in parking areas, parks, golf courses, inner cities, exhibition halls, airports, etc., as well as at a working plant, places enormous challenges on manufacturers, which is why very few firms have taken up this topic.

PeopleMover serves transporting personnel/passengers, whereby they are not by definition (according to VDI 2510) automated guided transport systems.

The background is that People Movers place special demands on personnel safety. They are generally used outdoors and in public traffic areas. This adds the problem of determining the question of responsibility. Neither the insurance associations nor the VDI guidelines offer binding information. It is also made more complicated by the desired vehicle speeds, which are generally higher than those in intralogistics uses. It is an area of use for automated vehicles which would go far beyond the scope of this book (Fig. 3.35).

[12] IA – insurance association.

Fig. 3.35 AGV cat. 9: The PeopleMover (*Source* Frog)

Fig. 3.36 AGV cat. 10: The diesel AGV, *left* wheel loader and *right* in a container harbor (*Source* Götting)

3.3.1.10 The Diesel AGV

This category includes all the various vehicles that are used in outdoor areas. These are usually larger AGVs, transporting loads of several tons. The outdoor use allows an internal combustion drive, usually diesel-electric or diesel-hydraulic (Fig. 3.36).

We have already mentioned the unique aspects of outdoor operations.

3.3.1.11 Special Design AGVs

This category embraces all the vehicles conceived and built for specific projects and do not fit into any of the previous groups (Fig. 3.37).

Fig. 3.37 An AGV of cat. 11: specially designed AGV (*Source* Snox)

3.3.2 Vehicle Guidance Control

In the traditional hierarchical guidance control structure of the third era of AGVS, vehicle guidance control is subordinated to the AGVS guidance control system. While the guidance control system in is charge of everything, namely from fulfilling tasks (processing transport orders), vehicle guidance control coordinates all the

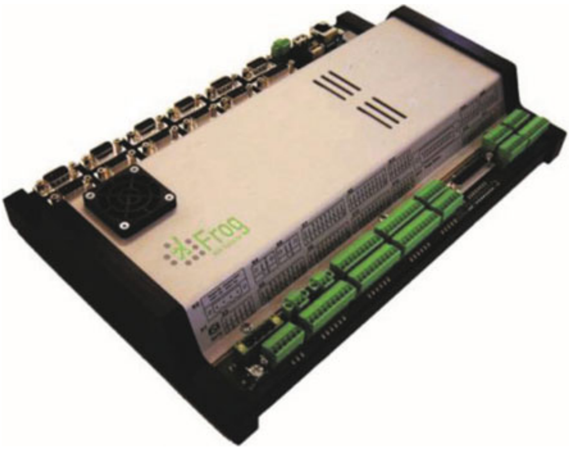

Fig. 3.38 A specially designed AGV guidance control (*Source* Frog)

actions of the AGV. This makes vehicle guidance control one of the key components in an AGVS, especially since it consists of both hardware and software.

The hardware can be highly varied, depending on the complexity of the system and the intelligence of the vehicles:

- Single-board computers
- Storage-programmable guidance systems
- Individually designed computers based on micro-controllers
- Multi-board computers (Fig. 3.38).

3.3.2.1 Requirements for a Vehicle Guidance Control System

The special requirements are derived from the use of the guidance in a vehicle. This means it must deal with voltage fluctuations in the mobile energy supply and be resistant to various forms of dust. From the mechanical standpoint, it has to function reliably despite shocks. If the vehicle is to be used outdoors, then climate-related demands can come into play. Under such conditions, the guidance control units are usually protected, as well as being cooled and/or heated.

Vehicle guidance control is of key significance in regard to safety equipment requirements. In line with the required safety categories corresponding to EN 954 or the safety integrity level of IEC 61508 for personnel safety, the functional interconnection of the vehicle with its electric/electronic components is to be established with great care:

- AGV guidance control hardware and software (personnel safety must be ensured)
- Choice of sensors plus evaluation unit (→ protected against breakdown)
- Electric design (→ 2-channel).

Fig. 3.39 An AGV operating panel: with 2 *black* stop switches (not emergency stops!), a round WLAN antenna, the junction box for manual guidance, an entry terminal, sensors and lights (*Source* dpm)

3.3.2.2 Vehicle Guidance Control Interfaces

Vehicle guidance control interfaces and the guidance control are usually physically connected by WLAN data transfer and logically by the travel order which the vehicle receives via the physical interface, which it replies to the same way after completing its task. The vehicle guidance control interfaces within the AGV affect the following vehicle components (Fig. 3.39):

- Safety system, especially the emergency stop circuit, personnel safety switch, switch plates, etc.
- Energy management, monitoring the battery charge level
- Load transfer equipment, the position of a lifting mast, or similar
- The mechanical drive elements, drives and steering
- The operator equipment, the operating panel and the hand operating device.

There can also be additional interfaces with external devices or equipment:

- Direct communication to other vehicles
- Load transfer stations
- Building facilities, such as personnel or freight elevators, automatic doors, fire doors, traffic lights, barriers, etc.

3.3.2.3 Classical Function Blocks

The very title already delineates the function blocks we are examining here, since the functional task assignment between a guidance control system and vehicle guidance control can generally be realized very flexibly. In extreme cases it is conceivable that all the function blocks for both guidance hierarchies could be run on the vehicle computer. But this is not commonly done to date; so we will limit ourselves to considering the classic division of function blocks as shown in Fig. 3.40. The photo shows the classical function blocks.

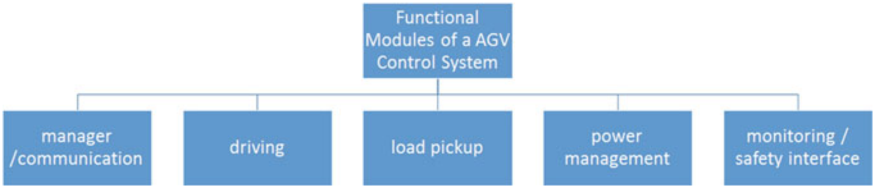

Fig. 3.40 Classical function blocks for an AGV guidance control

The **manager** function block breaks the travel order down into individual commands and activates the vehicle components such as the drive, steering, load handling device, safety equipment, etc. to fulfill the travel order. This makes it the equivalent of the central switching control in an AGV.

The **drive** function block uses the navigation process, performing dead reckoning and taking bearings in line with the possibilities discussed previously in combination with the mechanical driving equipment such as drive and steering actuators. All of the tasks of determining position, navigating, track guidance and determining location are run in this block.

The **load handling** function block assumes the coordination of the load pickup and dropoff. Depending on the complexity of the LHD,[13] sensory equipment is consulted and the actuators are triggered. If the stationary load transfer station happens to be active, this function block is also responsible for activating them.

The **energy management** function block has the task of maintaining the vehicle's energy system to ensure high availability. There are numerous possibilities for a mobile energy supply; in principle based on combinations of the following technologies:

- Traditional batteries, such as lead-acid and NiCd[14]
- Contact-free induction energy transfer
- Modern batteries, such as nickel-metal hydride (NiMh[15]), lithium-ion (LiIon[16])
- Double-layer capacitors
- Fuel cells
- Internal combustion drives, such as gasoline or diesel.

Depending on the technology used – combinations are also possible – energy management can be realized at various levels of complexity.

The **monitoring and safety** function block guarantees protection of personnel and property, which is why it is of the highest importance that it should fulfill its function. Safe guidance systems and/or safe switching design are required in order to ensure the function of the personnel safety features at all times. The safety

[13] LHD = load handling device.
[14] NiCd = nickel-cadmium.
[15] NiMh = nickel-metal hydride.
[16] LiIon = lithium-ion.

requirements are not quite as high for the second functionality of this function block: collision prevention. It is part of traffic control and ensures that the various AGVs within an AGVS neither collide nor block each other. To this end, the vehicles are either equipped with appropriate collision protection sensors or communicate with each other directly.

3.3.2.4 Types of Operation

The guidance structure of a vehicle guidance control can vary according to the type of operation selected. Along with "automatic" operation, there are other types such as

- semi-automatic
- manual
- diagnosis and service
- learning mode.

Manual operations allows the vehicle to be operated manually using the operating panel on the vehicle or on a manual operating device. The manual operating device is an external device, connected to the AGV via cable and plug, allowing the AGV to be driven using a joystick. Depending on circumstances, this device can also be used to pick up or drop off a load.

Semi-automatic operation is always part of a project-related special solution. It is usually a mix of automatic and manual operation. For example, if the AGVS guidance control breaks down or if the WLAN connection between the vehicles and the guidance control system is disrupted, it can make sense to allow the vehicles to continue to operate (to a limited extent). In addition, the travel orders can be entered manually on the operating panel to be automatically carried out. But if the interfaces to the AGVS environment are not operated directly from the vehicle but rather via the AGVS guidance control system, this intention quickly reaches the limits of its applicability.

Diagnosis and service operation allows service personnel wide access. New route information can be learned using the learning mode. This can be done by a one-off manual trip (teaching trip) or also via a download from the AGVS guidance control system. These trips are then saved in the vehicle computer and are available for automatic mode.

3.3.3 The Mechanical Moving Components

The vehicle categories described in Sect. 3.3.1 are no less varied than the technical solutions used to allow vehicles to move about. They include wheels (we are naturally only considering wheeled vehicles here), and a chassis, thus the number, type and mounting of the wheels as well as the drive and steering.

3.3.3.1 Wheels

Most AGVs – especially almost all indoor vehicles – have wheels with a plastic (elastomer) tread, usually Vulkollan® (Bayer) or polyamide. They are highly wear-resistant an leave very few tracks on the driving surface ("non-marking").

Outdoor vehicles use full rubber wheels or common truck tires (pneumatic rubber tires). The higher the elasticity of the wheels to insure such aspects as comfort (which can be important to protect the on-board electronics or the load) and/or floatation (on a bad road surface), the more difficult it is to navigate and accurately determine position.

3.3.3.2 Wheel Configuration

The wheel configuration describes the choice, number, mounting and actuation of the wheels of an AGV. If more effort is put into configuring the wheels, the mobility of the vehicle increases. Good mobility means less space and time are required when driving in a straight line, around curves, when maneuvering to pick up and drop off loads. However, every technical advantage also comes with an increase in price.

Technical necessity and the economic viability of a project determine the optimal undercarriage. The space required can be calculated by considering the envelope curve, which graphically describes the entire space occupied by a vehicle. This allows the plant payout to be checked in advance regarding the space needed for load handling as well as the curves and narrow sections along the drive path. If the manufacturer succeeds in designing a technically challenging undercarriage which allows the vehicle to operate faster and more efficiently, the higher vehicle unit price can be compensated by reducing the overall number of AGVs needed.

Figure 3.41 shows typical wheel configurations. Here we distinguish between linear vehicles with two degrees of freedom and free-moving vehicles with three. The envelope curve is not as favorable for linear vehicles as for free-moving ones. Thus the classical tricycle undercarriage is comparable to that of the familiar movement characteristics of a car, for which we know that you have to compensate for overshoot when parking or negotiating a curve. If our car were a free-moving vehicle with all-wheel steering, then parking would be a lot simpler.

The Mecanum wheel[17] allows a specially designed undercarriage. This creates an astoundingly maneuverable vehicle, which can perform almost any conceivable movement on a level surface. All four wheels work without any geometric steering lock. A number of individually rotatable "barrels" are mounted around the circumference of the wheel, which can turn freely. Each wheel has its own drive. The four differing rotation speeds allow for any sort of movement (Fig. 3.42).

[17] The Mecanum wheel was invented in 1973 by Bengt Ilon, an employee of the Swedish company, Mecanum AB.

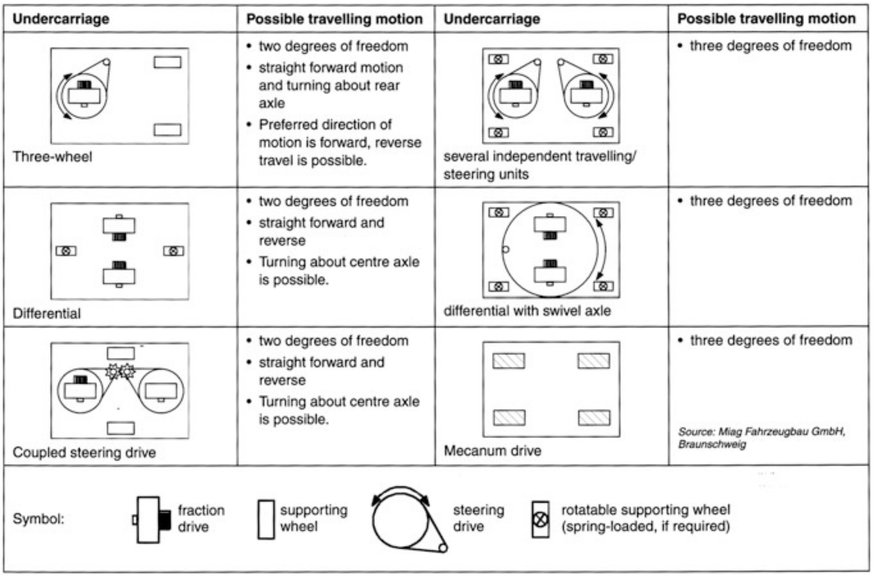

Fig. 3.41 Diagrams of typical AGV chassis (*Source* VDI 2510)

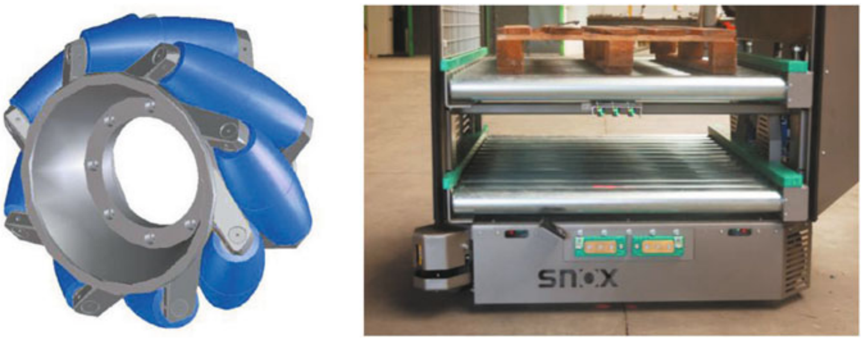

Fig. 3.42 *Left* Diagram of the Mecanum wheel, *right* installed on a piggyback AGV (*Source* Snox)

A further criterion for classification is the number and mounting of the wheels:

- Three-wheel undercarriage → triangular shape
- Four-wheel undercarriage → rectangle or parallelogram
- Five-wheel undercarriage → gable shape
- Six-wheel undercarriage → rectangular shape.

It is always possible to add supporting wheels to the required functional wheels to increase the payload capacity of a vehicle, which – usually with the aid of suspension coils – help bear the weight consisting of vehicle and payload.

An additional wheel can also function as a measuring wheel. Such a smooth running wheel is hung on a suspension and does not bear any weight, drive or breaking forces. It serves the sole purpose of "dead reckoning" for the vehicle to provide the "dead reckoning navigation" components with unadulterated values.

3.3.3.3 Steering

The steering function is based on the undercarriage kinematics. Here we want to point out only one key distinction: There are versions with and without geometrical steering lock.

An example for geometrical steering lock is a three-wheel undercarriage with one steered and driven front wheel and two trailing fixed wheels on the rear axle.

Undercarriages without geometrical steering lock include differential drives or undercarriages using the Mecanum wheel.

3.3.3.4 Drives

The range of voltage for electrical drives lies between 24 and 96 V. There are direct current as well as maintenance-free alternating current drives in use. Especially brush-free AC wheel hub drives are growing more and more popular, although they are more expensive than direct-current motors. Naturally, all AGVs are equipped with mechanical, hydraulic and/or electric brakes.

A typical drive consists of an electric motor, a wheel hub transmission, a running wheel with a Vulkollan® tire and an electromagnetic brake (Fig. 3.43).

We will not be looking at internal-combustion drives for outdoor vehicles. These are predominantly diesel-hydraulic or diesel-electric drives.

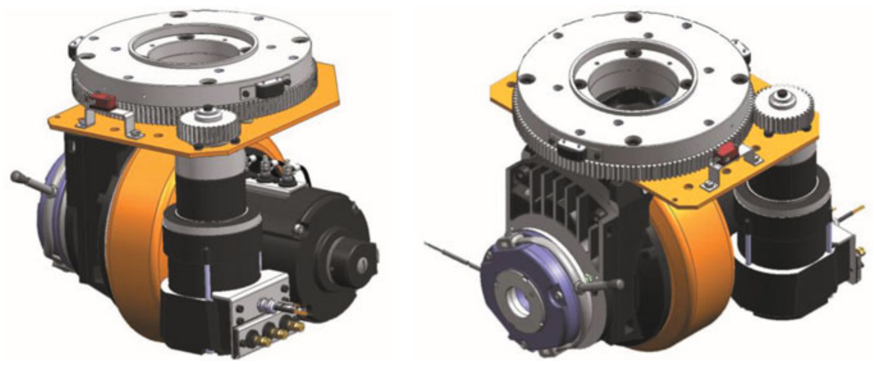

Fig. 3.43 A typical wheel hub drive for an AGV: The RNA 27 with integrated steering unit, 270 mm wheel diameter, 1,300 kg wheel load, available in 24 or 48 V, in DC or AC version (*Source* Schabmüller)

3.3.4 AGV Energy Supply

Automated guided vehicles have to be supplied with energy, for purposes of:

- vehicle guidance control, electrical, electronic and sensory systems
- the mechanical moving components
- load transfer equipment.

Outdoor vehicles – like trucks – usually have both a battery (lead battery) for the electrical components as well as a tank for gas, gasoline or diesel. We will not go into detail here. Under certain conditions, indoor AGVs can be supplied with power via a trailing or hanging cable, but this is not common and will not be pursued here.

At this point, let us concentrate on the three usual methods used by third-era AGVs and still in use today:

1. Traction batteries (electric vehicle batteries, or EVBs) (lead or NiCd batteries)
2. Non-contacting energy transfer
3. Hybrid systems: non-contacting energy transfer plus a small auxiliary battery.

All these technologies have their justifications; we will look at them individually and then differentiate them from each other, showing where they are most appropriate. Table 3.7 lists the previous possibilities in comparison.

Table 3.7 Comparison of current energy supply technologies

Technology	Characteristic
Lead battery	Low cost
	Can be used for capacitive operations (see below)
	Long charging times, the AGV must either be charged "overnight" on a charger or battery must be changed
	Heavy weight advantageous as counterweight or for stability
NiCd battery	More expensive than lead batteries, but longer service life
	Higher power density than lead batteries, so smaller
	Use in interval operations (see below)
	Quick-charging with high charging currents
Contact-free energy transfer	Appropriate for simple layouts, such as assembly lines
	Take up less space than electric vehicle batteries
	No wear or maintenance needed, reliable operations
	No need for EVBs and their disadvantages: limited service life, regular replacement costs
	Environmental protection: gasses, disposal
	Equipment can be simply switched off and on, whereas batteries must be serviced and maintained

(continued)

Table 3.7 (continued)

Technology	Characteristic
Hybrid system	Auxiliary battery helps cover short-term power requirements
	Auxiliary battery prevents shut-down, when the position of the vehicle over the double conductor is not optimal in places such as curves or when maneuvering
	Auxiliary battery serves as an energy source in case of loss of power or manual operation outside the driving track

Modern battery systems, such as nickel-metal hydride (NiMh), lithium-ion (Lilon), are certainly not part of the current technological standard,[18] and so – just as double-layer capacitors and fuel cells – will not be considered here.

3.3.4.1 Traction Batteries (EVBs – Electric Vehicle Batteries)

The EVBs commonly found in AGVS are:

- Lead-acid batteries (liquid electrolyte)
- Led gel or lead liquid batteries (bound electrolyte)
- Nickel-cadmium batteries (liquid electrolyte).

The choice of battery depends on such things as the type of vehicle operation. The following battery operating types are common in AGVS:

a. Capacitive discharge with and without battery change
b. Capacitive discharge with intermediate change
c. Interval operations

a. Capacitive discharge (lead battery)
   Capacitive discharge requires the battery to be fully charged at the start of the working shift. The battery capacity is scaled so that the operating capacity, that is up to 80 % of the nominal capacity, is available for the entire duration of the working shift. During the discharge process, certain parameters cannot be exceeded (current, temperature, etc.). After the operating capacity has been drawn down, a battery must have sufficient time to be fully recharged. As a rule, it takes as long to recharge as to discharge or drive (at least 7.5 h). Recharging is done either directly in the vehicle (usually single-shift operations) or in a separate charging area (usually for multi-shift operations).
   These systems are the simplest and least expensive of those considered here. They can be used for single or multi-shift operations, but they do require a relatively large degree of time and effort for changing and maintenance in multi-shift operations.

[18] At least not for AGVS. LiIon batteries have of course become standard for many common small electric/electronic devices.

b. Capacitive operations with intermediate charging (lead battery)
   Even with capacitive discharge using intermediate charging, it is assumed that batteries are fully charged at the start of the working shift. The battery capacity is scaled so that the operating capacity, that is up to 80 % of the nominal capacity, including the total capacity increased through recharging during the working shift, is sufficient. Recharging leads to an increase in energy turnover in the batteries and raises the temperature of the battery, decreasing the service life of the battery. Even here, recharging takes at least 7.5 h as a rule. This type of operation is usually found only in one-shift operations, rarely in 2-shift operations.
c. Interval operation (NiCd-batteries and to a limited degree, also lead batteries)
   For interval operations, the operating capacity of a battery is designed so that the energy reserves are sufficient until the next recharging. The battery is charged in or near the equipment, usually during the work process itself. There must be sufficient time at the charging station to replace the energy drained. The batteries remain in the vehicle throughout the entire working day and are only charged intermediately. There is no daily recharging or changing the battery. They are to be scaled based on the daily energy throughput. The especially well adapted NiCd battery is low-maintenance and usually used in three-shift operations.

This system is common for around-the-clock operations (24 h per day and seven days a week). The initial investment is higher than the previously mentioned systems, but the overall costs are lower (considering the useful life of the AGVS, also known as TCO or "life cycle cost") through a longer service life and lower maintenance requirements.

3.3.4.2 Non-contacting Energy Transfer

Non-contacting energy transfer involves the non-contacting inductive transfer of energy from a conductor mounted in the floor to one or more mobile users (AGVs). The electromagnetic coupling takes place across a gap in the air and is maintenance and wear-free. The primary circuit consists of only a single coil that is permanently installed as a "double conductor" in the floor, running along the route of the AGV. The secondary circuit is mounted at slightly less than 2 centimeters above the floor in the AGV, where the induced energy is made available to the users in the vehicle. The transfer frequency normally lies between 20 and 25 kHz.

This way of providing AGVs with energy is good for simple AGVS layouts, as are commonly found in serial assembly. It is difficult to realize for complex layouts in which the AGVS is moving about in taxi operations.

We will dispense here with the technical principles.[19] But it is worth having a closer look at the components needed and how the double conductor is installed.

[19] An in-depth book from Dirk Schedler: "Kontaktlose Energieübertragung – Neue Technologie for mobile Systeme", published by "Die Bibliothek der Technik", ISBN 978-3-937889-59-7.

Fig. 3.44 An AGVS with non-contacting energy transfer; the photos in the *middle* and *right* show possibilities for laying the double conductor (*Source* SEW)

The mobile components of such systems include the transmission head (secondary part, or pickup) and the attached mobile converter. Several pickups can be installed on the bottom of the AGV to deliver the needed power. A standard value for the performance of one pickup is 800 W. The pickup then converts the induced current into direct current, usually in a control voltage of 24 V and a voltage output of 500 V DC (Figs. 3.44 and 3.45).

The key stationary components are the supply switch, the switch-on module and the compensating condensers. The stationary converter converts the alternating current (50/60 Hz) into an alternating current with the nominal transfer frequency of 20–25 kHz. Output is typically 16 kW. The interface module then converts it into constant sinus-shaped alternating current.

3.3.4.3 Hybrid System

A hybrid system is an energy supply system for AGVs consisting of non-contacting energy transfer and an auxiliary battery. It is called an auxiliary battery in that it is considerably smaller than the typical EVB and fulfills only limited tasks.

There are numerous reasons for an auxiliary battery. The main points are:

- Not all areas of a layout can be equipped with a double conductor. Wherever there are special demands placed on the floor or the layout flexibility, the vehicle has to operate clear of the double conductor.

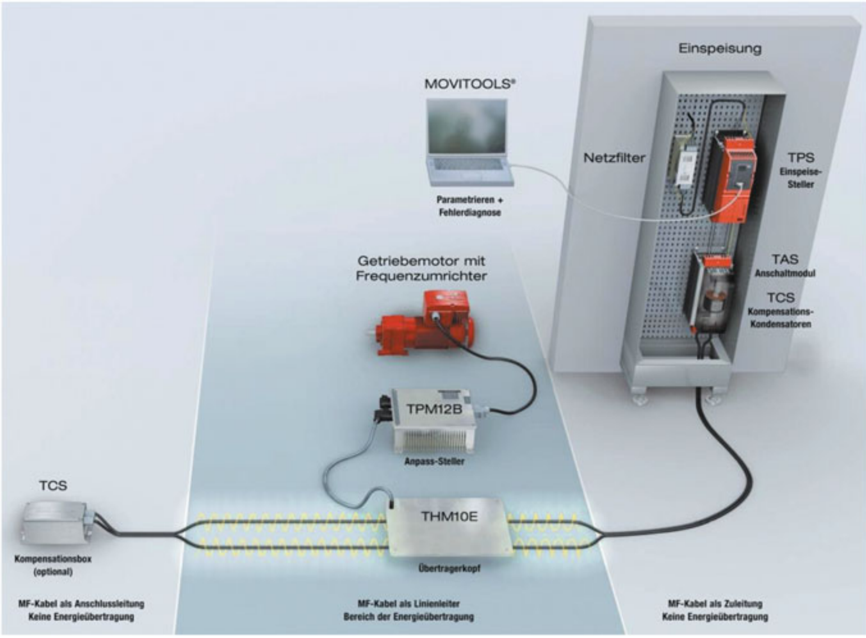

Fig. 3.45 System components for non-contacting energy transfer (*Source* SEW)

- Processes can result in peak demands from the AGV, which must be served by an additional energy reserve. High-performance condensers are naturally conceivable here.
- In the event of a breakdown, the vehicle can be driven off the layout using the battery in order not to disrupt the other AGVs.
- In special areas of the layout, e.g., in narrow curves, the relative position of primary (stationary) and secondary (mobile) circuits can be so poor that the energy transfer alone is not enough to power the vehicle, at which point the auxiliary battery would kick in.

3.4 The AGVS Environment

An AGVS is the flexible automatic means of conveyance. It can be integrated into almost any existing industrial environment. That means that when planning the equipment, the stationary setting must be analyzed so that the AGVS can be adapted to its surroundings and so that corresponding interfaces to the neighboring equipment can be created.

It must be clear to anyone that the significance of this integration cannot be underestimated. Many projects later find themselves repairing things that had been missed in the planning stage.

3.4.1 The Working Environment

On one hand, the working environment is determined by the surrounding climate and on the other hand by space restrictions. The climate is always to be noted wherever it varies from the norm, which is the case when the following conditions apply:

- Especially high or low temperatures, less than 5 °C and above 30 °C
- Large temperature fluctuations
- High humidity or extremely dry air
- Contaminants in the air, such as oil vapors, solvents, steam, paint particles, dust or aggressive gasses
- Electric or magnetic fields
- Explosive gasses.

This list applies only for indoor-use vehicles. Space restrictions can include limited overhead clearance or floor bearing weights.

If the above-mentioned conditions do not apply to any great degree, then the drive path and especially the condition of the floor must be checked. This is of principal importance for the safe and disruption-free operation of the AGVS. The best way to influence the surroundings is to install a new floor. This can then be designed to meet the respective norms and guidelines as they are to be found, for example, in the VDI Guideline 2510-1.

It would be going too far to give an exact definition of an "AGVS-friendly" floor. In general, the conditions can be met by observing certain standards in the following criteria:

- The compressive strength of the driving surface: a high contact pressure is important as well as high shear strength.
- Friction: The kinetic friction coefficient should be between 0.6 and 0.8. If it is any lower, proper emergency braking cannot be guaranteed; higher values lead to excessive wear on the wheels of the AGV.
- Evenness of the floor: this is all the more important when are high demands are placed on the precision of the load transfer, e.g., unloading into shelves.
- Uphill and downhill grades: the vehicle drives must be able to cope with uphill grades, and downhill grades harbor potential for problems in the event of emergency braking – vehicles must not be allowed to tip nor can slippage lead to extended braking paths. Sufficiently large transfer radii must be observed (on the scale of 25 m), so that the AGVs do not hang up with their frame on the slope, since the vehicles have a clearance of only a few centimeters due to safety considerations. Five to seven percent grades are usually no problem.
- Electric grounding capability: To avoid electrostatic charges, the floors should have a maximum resistance to ground of 1 $M\Omega$. Plastic floors are often used, which are both extremely smooth and highly insulating.

- Cleanliness: The floors must be regularly cleaned during AGVS operations; whereby it is important that the floors dry completely after cleaning, as wet floors can lead to unsafe driving maneuvers.

The traffic routes that are driven by the AGVs are generally not to be used by other traffic, such as pedestrians, cyclists or forklifts. They have to be clearly visually marked. The minimum width of the lane is based on the width of the AGV (including load), an additional clearance of 50 cm on each side and if needed, another 40 cm clearance for oncoming traffic. (Example: An 1-meter-wide AGV, using a two lane section – that means with oncoming traffic – needs a regular lane width of 2 × 1 m plus 2 × 0.5 m plus 0.4 m = 3.4 m)

If additional safety measures or equipment are needed because of restricted lane widths, this is to be determined in co-operation with the government work protection authorities (Trade Control or Worker Safety Administration) and the local insurance associations.

3.4.2 System-Specific Interfaces

The procedure used for **navigation and determining location** can require special markings (metal strips, metal bands, floor magnets, transponders, etc.) on or in the floor and/or also on the pillars and walls (reflectors, reflecting markers, locating beacons etc.).

A key system-specific interface is the one to the stationary **load transfer facilities**. These facilities can be active or passive. In the case of an active load transfer facility, there is one or more electric drives which need to communicate with the AGV, either directly or via a central control by way of the AGVS guidance control system.

Load transfer is a safety-relevant situation, which must be coordinated with the work safety authorities and the local insurance associations. In any case, danger to persons is to be avoided. The simplest approach is to restrict access to the safety-relevant areas, ensuring that nobody is present there.

Where this is not possible, special measures are commonly employed:

- Floor markings to designate danger zones
- Guard plates or guardrails at the entrance to the load transfer station
- Stationary safety measures according to Table 3.8
- Visual and acoustic warning signals on the AGV
- Special sensors to recognize persons and other obstacles.

In many plants the batteries have to be changed. This can be done manually or also in automatic battery changers. The AGVS manufacturers must plan and supply the interfaces for such automatic equipment. If batteries remain in the AGVs, then it is recommended to install **automatic battery charging** stations to which the vehicles are dispatched by the AGVS guidance control system for recharging. As a

Table 3.8 Stationary protection measures according to VDI 2510-1 purpose of use

Safety element/measure	Purpose of use
Parabolic mirror	Always useful in intersections with restricted visibility, especially when forklifts use the same routes as the AGVs
Traffic lights	For intersections that are not visible. As a rule, the AGV is given right of way and the light is changed in time so that it does not need to stop
Barriers	Barriers are useful when there is a large volume of pedestrian traffic crossing the route of the AVGs at certain times (change of shift, end of day, lunch break, etc.)
360-degree lights	To warn people of approaching AGVs in sections of the route with poor visibility
Light-activated barrier	e.g. for safety in warehouse passages
Suspended barrier tape or chains	To restrict access to areas
Further protective measures	Collision protection, fenders, switch mats, floor markings, swinging flaps

Fig. 3.46 Typical battery charging station: charger mounted on the wall and copper charging contacts set in the floor (*Source* DS)

rule, there is a central interface via LAN to the AGVS guidance control system (Fig. 3.46).

Since battery charging can release potentially health-endangering gasses, there are a number of regulations to be observed when designing the rooms for this purpose, which can all be found in VDI 2510-1. Essentially it is a matter of sufficient ventilation so that the gas concentration remains below allowable limits.

If the system is to be used in hospital logistics there is most likely an interface with **roller containers** (Fig. 3.47). These have to be picked up by an underride AGV, lifted and transported. When underriding, the exact position of the container must be recognized to allow it to be safely picked up. In addition, in the most cases, the container coding must be read which is located on the bottom of the container.

From the point of view of automated transport with underride AGVs, the following requirements arise:

- Clearance for the underride surface front side: 660 mm width × 365 mm height
- Total weight (filled) max. up to 500 kg

Fig. 3.47 A roller container in a hospital, right with an underridden AGV (*Source* Hupfer (HUPFER® Metallwerke, D-Coesfeld, www.hupfer.de))

- Four rotating rollers with a directional lock along the forward axis, of which two rollers with brakes and one or two rollers as anti-static wheels
- The rotating container wheels must automatically lock into place parallel to the vehicle when lifted, so that they do not collide with the side of the vehicle. This is usually done with a built-in spring
- High quality, smooth running rollers, ca 180 mm diameter
- Flat, even bottom, weight-bearing and sealed to the inside of the container
- A well in the middle of the bottom so that transponders, magnets or other ID tags can be installed there if needed
- Closed doors and hatches must "click" into place so that they do not accidentally open while driving
- Doors must open up to 270°; additionally, an arresting device so that the reverse side of the door can be washed
- CWA[20] requirements are supplementary (stainless steel, temperature-resistant, etc.).

The last of the system-specific interfaces to be mentioned are the devices needed for **data transfer**. Data transfer is needed between

- the AGVS guidance control system and the AGV
- the load transfer stations and the guidance control system as well as to the vehicles
- the guidance control system and the automatic battery charging station
- between the vehicles themselves
- the AGVS guidance control system and other peripheral units.

The data transfer between the AGVS guidance control system and stationary units generally takes place via LAN. For data transfer to (mobile) AGVs there are various possibilities: inductive, infrared, radio. Modern AGVS uses the WLAN

[20] CWA = container washer.

technology common to in-house and on-board communication. The entire AGVS should be fully covered by the network. A WLAN network is often provided during construction.

3.4.3 Peripheral Interfaces

The third group of interaction points between the AGVS and its surroundings involves the peripheral units, such as the doors, gates, lifts and other automatic conveyance systems.

3.4.3.1 Doors and Gates

Automated guided vehicles can pass through doors and gates as long as they open automatically. There are a number of possibilities:

- The AGVS guidance control system is able to activate them, this requires a LAN connection.
- The AGV communicates directly with the door via infrared or Bluetooth.
- The door is equipped with its own sensory equipment and notices the approaching AGV. Appropriate sensory equipment can be contact strips in the floor, photoelectric barriers on the walls or movement sensors.

In any case, it must be ensured that the door opens quickly enough so that the approaching AGV does not have to slow down or stop and wait. After the AGV has passed through the door, a signal can be given to close it again.

If the doors are also fire doors (or fire protection doors), these are operated as described above under normal circumstances. Fire doors are often left open permanently. They are closed automatically during a fire emergency, either by locally connected alarms or from a central alarm system. This automatic activation has priority over the command from the AGV or the AGVS guidance control system.

It must be ensured that the door does not close when an AGV is passing through, causing it to get stuck. That would prevent the fire door from closing completely, making it unable to entirely fulfill its purpose. For this reason, fire doors or their controls are usually equipped with a delay to give the AGVS around a half a minute to clear the door area after an alarm has been sounded.

3.4.3.2 Elevators

When an AGVS layout covers several floors of a building, elevators (lifts or vertical conveyors) are needed. The first question is whether these elevators are also used by personnel. If this is the case, the following issues must be cleared up in advance:

- Who will be using the elevators? Trained personnel, untrained personnel, visitors, children, patients, etc.?
- How often do the persons and the AGVs use the elevators?
- Can time windows be established to keep passenger and AGV traffic separate?
- Can the passenger elevators be encoded so that only trained personnel can use them?

Any combined operation (AGV and passengers) must be given consideration and may require special safety features in the AGVs (recognizing passengers in the elevator and "making room" if the situation arises, so that the passengers can exit the elevator).

The demands that an AGVS places on an elevator can be divided into mechanical and guidance control requirements. The mechanical requirements are:

- The depth and width of the elevator cabin must be calculated based on the largest length and width of an AGV (including lifted load) plus 1,000 mm. This leaves 500 mm clearance on all sides for an AGV which has entered the elevator. This value can be reduced to no less than 200 mm through special exemption from the local insurance association.
- Overhead clearance for the tallest AGV (including lifted load) must be at least 100 mm.
- The door opening width is based on the greatest width of an AGV (plus load) with 200 mm clearance on each side.
- The required floor quality must be of the same standard as that for an AGVS.
- The height difference between the cabin and the floor cannot exceed ±5 mm. The elevator cannot "sink" – if needed, it must be leveled.
- The gap between cabin and floor cannot exceed 30 mm.

The elevator interface is the connection between the AGVS guidance control computer and the elevator control. The AGVS uses it to call up a status report for an elevator. Information is transferred via potential-free inputs and outputs. The AGVS supplier provides a separate switching box for each elevator, in which the signals to and from the elevator are mounted on a terminal strip.

The following signals are typically given by the AGVS to the elevator:

- Calling up automatic operation
- Move to starting floor, that is, the floor where the trip is to start
- Move to destination floor, that is, the floor where the trip is to end
- Elevator door may not close.

The following signals are typically given to the AGVS by the elevator:

- Automatic operation
- Elevator has arrived at starting floor; door is open
- Elevator has arrived at destination floor; door is open
- Elevator status: available
- Elevator status: no fire alarm.

The following conditions are to be observed:

- During AGVS operations, the operating panel inside the elevator cabin cannot be useable.
- The elevator may not move, or open or close its doors when the AGV is entering or leaving.
- The elevator door must automatically open upon reaching the destination floor.
- In case of fire, the elevators must function without AGVS guidance control. In these cases, the AGVS guidance control does not assume control of the elevators.
- Local certifying authorities must determine whether the AGVS operation on the floors or in the cabin must be visually signaled (lamp or display).

3.4.3.3 Other Automatic Conveyor Systems

Under certain circumstances there can be other automatic conveyor systems operating in the direct vicinity of an AGVS. These can include crane equipment on the ceiling or a rail car or other tracked vehicles on the floor.

Cooperation between an AGVS and crane equipment must be checked with regard to overlaps in their working/driving areas. Dangling crane hooks or loads will not be recognized by regular safety scanners on the AGV! If loads are to be transferred to or from an AGV and a crane, the necessary interfaces between them must be coordinated for the specific project.

If the AGVs have to cross rail tracks or other sub-floor systems, a signals exchange must prevent any sort of collision. In addition, attention must be paid so that the demands are still met for the floor for dead reckoning sensory equipment as well as the braking path.

3.4.4 People and AGVs

And how do people interact with automated vehicles? That depends on whether there are interfaces, and if so, what people have to take into account. We will point out three separate cases.

3.4.4.1 Restricted Areas

There are rare cases of AGVS use areas being restricted or blocked off for access. Mechanical barriers such as fences or virtual barriers such as light curtains keep the AGVS layout free of unauthorized persons. The safety technology situation is comparable to the one that we are already familiar with from industrial robot working areas – as soon as a person enters or even puts an arm into these areas, an alarm is sounded and the equipment comes to a standstill.

This is rarely the case for indoor uses. Here "joint use" of the paths by AGVs is the standard. But it still makes sense to separate them to some extent. It could be possible to reserve certain routes for the AGVs so that they can perhaps cover relatively long stretches at "higher" speeds.

For outdoor use, it is much more common to create exclusive AGV sections or entire areas. We learned earlier that there are limitations to the use of AGVS because safety requirements cannot be met. In this case it is advisable to see if the routes cannot be kept separate. This allows operations without fully effective safety equipment, as demonstrated by the large-scale AGVS application (74 diesel-electric AGVs for ship containers) in the Altenwerder HHLA[21] container terminal in Hamburg.

In such cases there is no issue of human interface.

3.4.4.2 Employees

For indoor areas, it is taken for granted that automatic vehicles will share routes with employees. We have discussed applications in intralogistics where there are certain interactions with employees – especially with respect to topics we have addressed. Employees are mature, healthy adults who can be expected to work and act responsibly. They are instructed in how to interact with the AGVS and have grown used to automated traffic.

This means that intralogistics applications are also manageable with current safety equipment. The employees know how and where the AGVs move. The experience they gain in the first 2 weeks of working with the AGVS shows them convincingly that the safety sensors also react to them. During this period, there is a great deal of stop-and-go traffic, sometimes decreasing system efficiency. But after that, there are rarely problems in working with the AGVS.

For employees who are walking about, the AGVs display predictable and pleasant behavior:

- Standard driving speed is usually 1 m/s (= 3.6 km/h), the employees' usual walking pace. This means that employees are not surprised by a vehicle approaching unexpectedly from behind.

[21] HHLA = Hamburger Hafen und Logistik AG.

- The AGVs always follow the same routes and do not go around obstacles. When employees are occupying AGV routes, the vehicles gently come to a full stop and wait until the way is clear. Then they continue on their own.
- Experience shows that AGVs are more easily accepted when they are given nicknames. There are operations which have named their three vehicles Huey, Louie and Dewey. There are other cases of the AGVs being named after bosses.
- Electric vehicles are almost completely silent, which is not always desirable. One alternative to a nerve-wracking beeping signal is to install car radios in the AGVs. Then the staff just has to tune in a single station, and the vehicles create a pleasant atmosphere, offer information in unison and are easily recognized.

The situation is sometimes different for forklift operators. The automated guided vehicles are often seen as job killers. In such cases it is important to inform them in advance, that is long before the AGVS is installed, about the goal and purpose of the measures about to be taken.

"Cooperation" between forklifts and AGVs can function quite well if the forklift operators are "willing". Collisions can only occur when the forklifts gouge the AGVs, knocking out, for example, their expensive but sensitive personnel protection scanners. But – if sufficient care is taken – it is possible to work together without problems, especially since the forklift operator's raised seat position allows him to easily anticipate the movements of the AGVs.

3.4.4.3 Public Traffic

There are uses which involve groups of people other than trained workers and experienced personnel coming into contact with the AGVs. One example here is hospital logistics, where there are places in which there is recurring outsider traffic. The largest share of the routes in hospitals are generally driven away from the routes used by patients – but overlap cannot be fully avoided. Then the AGVs suddenly encounter freshly-operated patients with infusion racks or roller walkers and restricted mobility. Curious children or crawling toddlers also cannot be excluded.

Such situations place great demands on AVG safety equipment. Even personnel safety scanners approved by insurance associations are no longer relevant because their use lies outside of their scope of definition. Organizational and technical measures are needed here to guarantee the highest possible level of safety without greatly impacting the performance of the AGVS.

Chapter 4
The Fourth Era

In the two preceding chapters we have already described the "standard AGVS", both its technology and applications. But the world of AGVS has entered into a new stage of evolution, which will have enormous impact on both technology and new applications. This era will, however, not completely displace the previous one, but rather build upon its accomplishments. This means that the applications and technical solutions that were valid for the third era will remain in place!

The technological basis for the resulting changes are found in new, low-cost and intelligent sensor systems as well as software developments run via the Internet, which analyze these sensor systems.

The Internet has played a role in these developments in that a great deal of the developmental work in the field of image recognition is based on Internet applications. Google, for example, now owns hundreds of patents on these topics. They are not necessarily interested in recognizing a pallet – a basic task for AGVS – but rather people, faces, situations and other objects (city, beach, house, man, woman, etc.) The first examples in mobile systems can be found in automobiles. In the BMW 700 series, for example, the "speed limit info" and "night vision" options, which can recognize speed limits (on signs on the side of the road and above the lane) and people (at night with heat-imaging cameras),[1] are offered. Cars are doing things that were inconceivable 10 years ago: we are already familiar with the parking assistant from VW, "Park Assist",[2] which independently parks parallel or in a perpendicular parking space. Audi offers "Lane Assist", which recognizes when a vehicle drifts out of its lane and continuously eases it back in. Automatic clearance control (ACC) aids drivers in stop-and-go traffic. A sensor monitors a broad area in front of the car and maintains a pre-set speed, while accommodating the traffic ahead, and in a range of speeds from 0 to 250 km/h.

The examples mentioned or similar ones can be found in other makes of autos as well, there is no point in listing them all, "If there is anyone who still doubts that autos will be able to drive on their own, they should have a look at the new S-Class. Numerous cameras, sensors and computers can take over in the event of an

[1] Source: BMW 2010.
[2] Source: Volkswagen 2010.

G. Ullrich, *Automated Guided Vehicle Systems*,
DOI 10.1007/978-3-662-44814-4_4

Fig. 4.1 Driver assistance systems from Audi, Toyota and Volkswagen: *upper left* Audi active lane assist; *below left* person and ball recognition in a Toyota; *upper right* speed limit alert by Bosch; *lower right* parking assistant in a VW Touran. The boom began around 2010, about the same time as the fourth era of AGVS

emergency or a traffic jam. It sounds uncanny, but is to everyone's benefit – since autos can do more than the best driver", according to a report on the new Mercedes S-Class from Spiegel Online.[3]

Here we consciously avoid naming and describing the sensory and guidance systems used. Individual manufacturers use various combinations of laser, radar,[4] lidar,[5] infrared, ultrasound – and video systems. It is still unclear which technologies will prevail on their own or in which combination (Fig. 4.1).

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[3] By Jürgen Pander, SPIEGEL ONLINE dated May 16, 2013.

[4] RADAR = radio wave detection and ranging, uses radio waves.

[5] LIDAR = light detection and ranging, uses laser beams.

In any case, modern cars are able to move automatically to a great degree, even at high speeds. Naturally, auto developers undoubtedly have the advantage of being able to come up with safety concepts without the need to be responsible for safety. It is the driver who bears ultimate responsibility, and that will remain unchanged for some time.

There are two other developments in the automotive industry that will likely find their way into the world of AGVS over the short or long run:

First of all, there is communication in connection with localization. Automobiles determine their position via satellite navigation and can use radio to exchange data with peripheral facilities such as traffic lights, gates and traffic guidance computers. A wealth of potential applications can be found here, all with the goal of avoiding accidents, increasing the rate of traffic flow on roads and reducing energy consumption. Positioning also has advantages for automobiles, allowing the driver to find out the location of his vehicle, for example, after it has been stolen, or simply misplaced after a long night in a strange city or on a gigantic trade fair parking lot – a function that will be rarely needed in an AGVS.

Last but not least, alternative drive systems are being developed. Tried and true diesel and gasoline motors are being optimized for fuel use, and alternative energy storage and converters are starting to be used in autos. Innovative battery concepts (Li-ion) or fuel cell are mentioned here as examples.

This defines the main emphasis for the following pages, where we will concentrate fully on AGVS. The topic will be the functional challenges of the fourth era as well as new and old markets.

4.1 Functional Challenges

Functional challenges are the result of experiences with current systems. More will be expected in the future, which compels us to try new approaches. Table 4.1 lists several typical functional demands on systems of the future.

One or the other AGVS manufacturer will insist that some of these things have already been realized. This is true and praiseworthy – but there is nonetheless still

Table 4.1 Functional challenges for the AGVS of the future

Designation	Description
Truly autonomous driving	"Truly" autonomous driving means no artificial markers for navigation, but integrated safety and a greater ability to think along
Avoiding obstacles	Recognizing obstacles (object recognition) and avoiding them, reporting them if needed
Recognizing disruptions	Recognizing and managing disruptions while they occur: correcting docking position, driving to alternative docking stations, reporting. Dangerous situations must be mastered
Pallet finder	General function, in order to be able to lift a loading aid, even though it is not optimally positioned

(continued)

Table 4.1 (continued)

Designation	Description
Truck loading	Independent measuring of the cargo area and optimal loading. The first solutions are already available, but are still not very flexible and – in comparison with loading a truck with a manual forklift – too slow
Quick learning	Learning new tasks quickly, e.g., through a teaching trip, during planned or extraordinary layout changes, for a new AGV in the fleet
Moving traffic	Especially in outdoor uses, the ability to responsibly “go with the flow”. This includes adapting speeds, even high ones
Reacting quickly	Everything has to be done more quickly. This includes driving, load handling and communicating with peripheral facilities
Speech guidance	The operator must be recognized and his order must be understood: “Wait!”, “Where are you going?”, “Bring these pallets to the warehouse!”
Energy use and battery disposal	Environmental protection has also come to logistics. Energy use and especially the environmental compatibility of battery disposal have come to play a larger role

enough room to make these functions into safe, quick and reliable standards for the future. In combining the demands, one comes up with three key functional groups which will be developed in the future and described in the following sections.

4.1.1 DriveSafe: Integration of Navigation and Safety

The following illustrations (Fig. 4.2) of an AGV from the early days (first era) clearly show the components for navigation (a finger in a groove in the floor) and safety (wire frame as safety bale). In the following eras there were further developments along these lines, but today we still find the classical parallel/separate design of both systems. Classical: magnetic sensor strip for navigation and laser scanners for personnel safety.

In the end, navigation continues until a safety sensor tells the vehicle to stop. The AGVS is working in the world of blind robotics, just as a vision-impaired person finds his way through his immediate surroundings with a cane. Up to now, we have had very little perception of the outside world. The AGV simply follows pre-programmed procedures based heavily on internal sensors. It is hoped that the reader does not see this as an attempt to speak poorly of AGVS; in previous chapters it was shown clearly that today’s automated guided vehicle systems work reliably, safely and with high performance – but this chapter is oriented towards the future.

The laser scanner has come to occupy a major role in the world of AGVS. Almost every new AGV has at least one of these personnel safety scanners installed. This technology is proven and approved by insurance associations.

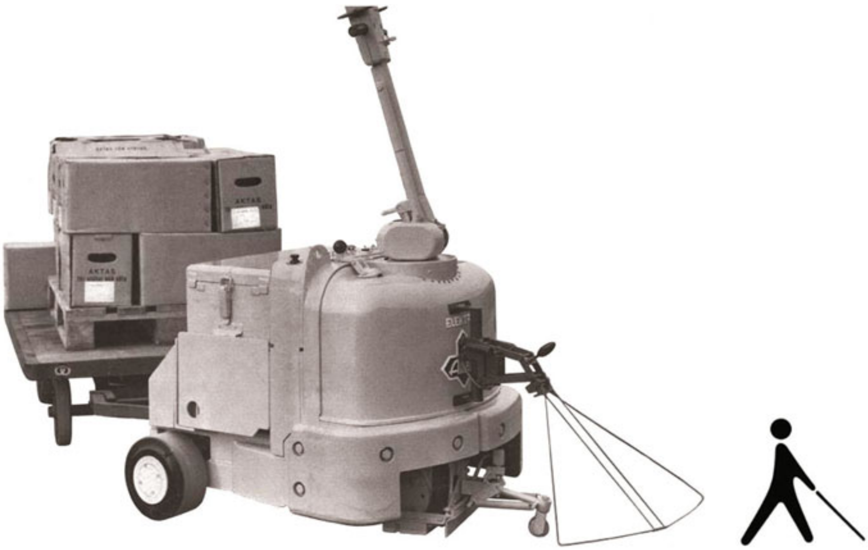

Fig. 4.2 Towing vehicle from the 1960s (*Source* E&K); analogous to a cane for the vision-impaired

Nonetheless: simply sensing the various individual levels of contact is and remains unsatisfactory. Loads that stick out into the AGV's drive path area above the sensor level are not recognized. An underride AGV in a clinic has no problem driving right through a hospital bed parked parallel without the scanner reporting an obstacle. It is not a problem as long as the AGV is not carrying a load!

DriveSafe, in the end, means opening the vehicle's eyes. Let us imagine what it would be like for a vision-impaired person to be suddenly able to see again. He could do without a cane and react entirely differently to the surrounding world. Let us come up with another metaphor for the same topic:

"**Taking direct bearings**" for automated guided vehicle systems (AGVS) Taking direct bearings is familiar from sailing. This is what a hobby sailor has to do as part of getting a sailing license, learning to assess the danger of a collision based on the course of another ship: when the approaching ship

- "swallows" the horizon, it will pass by the bow of your own ship,
- "spits out" the horizon, it will pass astern.

When the bearing "stands still" between the ship and horizon, that is, it does not change, then both ships are on a collision course! What does that have to do with the AGVS or the AGV (vehicle)? AGVs drive and navigate. Navigation is a combination of dead reckoning and taking bearings.

What does an AGV do when it is on a direct bearing, i.e. on collision course with another moving object? This other moving object can be a forklift, a worker on foot or on a bicycle, or something completely different – regardless, because current

AGV's do not notice the looming danger of collision. Today's AGVs navigate obstinately along until the personnel safety sensor is activated. The order to stop is given and the danger is averted.

Although this process is entirely safe and was/is sufficient for regulated settings in production areas, in which only adults and trained personnel are underway. Based on the fact that people learn to think and react, this sort of behavior is not sufficient for everyday situations. When we are walking downtown and note that another pedestrian with "direct bearing" is crossing our path, we quickly alter our course to avoid a collision with them. We either walk a bit faster or more slowly or change course to the left or right.

That is simple for people but impossible for today's AGVs. But why should an AGV be able to do that? The answer is that the areas of use for AGVS are changing. AGVS has been in common use in hospitals for 10 years, but in the meantime the vehicles are not just using the closed-off cellars, but are passing directly through the entryway of the hospital or across the hallways of the wards. Here the AGVs do not just encounter trained personnel, but thoroughly clueless people, especially sick and disabled persons, children at play or care personnel rushing about their business.

Or let us consider the ever-growing area of outdoor operations. Automated vehicles move rapidly around the plant premises, in the midst of outside visitors and truck drivers.

The preventively intelligent approach of direct bearing is representative of a new generation of intelligence, which we will call DriveSafe and, in the end, means an integration of the AGV functionalities of "navigation" and "safety" as well as newly developed sensor systems.

In the figurative sense, "direct bearing" is of significance to the entire AGVS industry. Let us image it as a medium-sized ship on course on the sea, encountering a giant ocean liner which is also steaming at a brisk pace – and bearing down directly! Here we are referring to the automotive industry, which has already put a lot of work into developing driver assist systems. Automated functions already available for every mid-sized limousine would work well for an AGV: automated parking, driving in column, maintaining clearance, maintaining lane, intelligent night vision and recognizing traffic signs and markings; these require the modern sensor systems and analytical software that we need for fourth-generation AGVS.

The AGVS industry must – in keeping with the metaphor – urgently change its course or gain speed in order not to collide with the giant ocean liner (the automotive industry) or to be flattened by the wave (of OEMs) coming up behind it! That means that the AGVS industry must actively turn to face the challenges of the future. It has to reinvent itself: it has to analyze external influences alongside the requirements of future customers. In the end it is a matter of securing their independence through clearly defined core competencies.

4.1.2 Automated Togetherness: Acting Intelligently

Today's AGVS are guided centrally/centralistically. The AGVS guidance control system assumes the central functions and calls up the vehicles. These are fed with only the information they need to perform their assigned tasks. The guidance control system is in charge of all coordinating tasks.

The more active intelligence we expect from an AGVS system, the more intelligent the individual AGVs have to be. If we want vehicles that can "see"[6] then they need to be able to obtain and assess all this necessary information. In addition, there will be more communication with peripheral facilities and between the AGVs themselves. The vehicles will exchange information, warn each other and if possible, also offer assistance.

For some time there has been research into swarm intelligence. This investigates how swarms of birds move forward, although the individual birds move back and forth across the swarm. Hives of ants or bees also work more effectively and successfully as a unit, whereas an isolated creature is unable to survive alone. It seems a bit daring to try to apply these considerations to an AGVS with numerous vehicles – although AGVS manufacturers would find the idea of swarms of AGVs appealing. Nonetheless, this sort of basic research provides us with indications on how to organize intelligence and decision-making authority in fleets of vehicles.

One concrete wish would be, for example, the ability to use an intelligent vehicle – let us consider a forklift AGV or a towing vehicle as a one-vehicle system – without a great deal of effort for installation. If a second or third AGV is added, this small group would be able to work together without adding an AGVS guidance control system of other superordinated functionalities. The vehicles could be so self-explanatory that the operator himself would be able to bring them into service without support from the manufacturer.

The predicted AGV behavior would only make limited sense in the previous/classical AGVS uses, but would more likely apply to new uses and perhaps even new markets. The use of small, intelligent vehicles was previously not possible, which might be a reason for the lack of uses. There will always be demand in the enormous field of service robotics, but also in intralogistics, especially wherever it is not a matter of large, fixed material flows, but rather constant, flexible "fetching and bringing"; for example, in commissioning, in which the workers do not move up and down endless rows of shelves, but rather have the goods come to them as needed.

We already discussed the future significance of a 3-D obstacle recognition sensory technology in the last chapter. There are numerous approaches to solving the problem, but to date none has been able to establish itself as the standard. The priority is to enable AGVs to recognize not only persons (based on their shins), but also objects such as crane hooks or the prongs of a raised forklift. Automated guided vehicles equipped with 3-D sensors offer considerably more safety.

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[6] The search for an AGV that can "see" does not necessarily mean focusing on stereo cameras and central sensors. It is irrelevant which technologies prevail.

One proposed solution: a line scanning camera with an integrated oscillating mirror is installed into the JEF500 contact-free measuring sensor (from SICK). This sends the laser beam from the red laser diode in a 45° angle and allows it to recognize objects in three-dimensional space. The angle position and the beam diffraction is used to measure distance and transmit these via the Ethernet interface to the vehicle guidance system, which can react promptly and automatically reduce speed or even stop the vehicle. Additional software allows the data gathered to be used additionally for 3-D imaging and other analyses. The class 2 laser has a range of 0.4 to 2 m (Figs. 4.3 and 4.4).

Fig. 4.3 Automated guided vehicle with JEF500 3-D laser sensor from SICK (*Source* MLR)

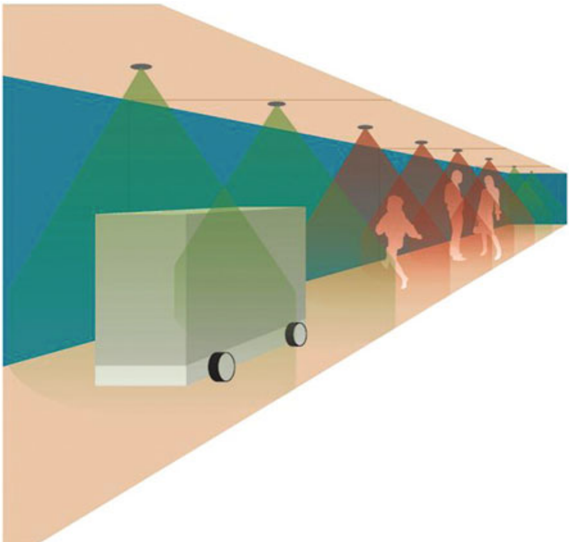

Fig. 4.4 A DriveSafe scenario with STS–to-I communication. (Ullrich, G.: Der steinige Weg zur autonomen Mobilität in and außerhalb der Industrie "The Rocky Road to Autonomous Mobility Within and Outside the Industry". Lecture held at the 4th Technology Forum "Automated Guidance Transport Systems (AGVS) and mobile robots – Opportunities, Technology, Economic Viability" at the Fraunhofer Institute IPA Production Technology and Automation, May 17, 2011 in Stuttgart)

Safety sensory equipment need not necessarily be mounted in the AGV. There will be uses in which active support from the infrastructure would make sense. Sensory systems of whichever type employed on the ceilings of the passageways collect information about people in the corridors and transmit this wirelessly to the STS. This means that the vehicle does not need to detect all the personnel movements, but is supported by the infrastructure (STS-to-I[7]). Such a system is particularly advantageous when it allows a vehicle to be aware of the traffic situation in the new corridor before turning into an intersection.

Both 3-D scanners and new STS-to-I communication will provide decisive impulses, not only to safety equipment, but also to navigation.

4.1.3 Energy Mix: Modern Energy Management

Within the boundaries of the technological standards of the third era of AGVS as documented earlier, it is easy to describe energy supply for the AGVs. The engineers working for the AGVS manufacturers employ relatively simple rules:

- Simple oval-shaped assembly system: Contact-free energy transfer possible
- Otherwise lead or NiCd batteries – with the characteristics described in Sect. 3.3.4.

Cooperation between AGVS manufacturers and battery suppliers works so well that predictable, functional systems are created. Problems might arise when there are no long-life batteries for certain constellations, so that they have to be replaced after only a few years. That is no unassailable hurdle – as long as the customer is aware of the need to replace batteries and it is already factored in by the AGVS supplier.

In the future, the energy situation will not be as straightforward. New technologies are making their way onto the market, promising higher energy densities or other potential uses.

4.1.3.1 Innovative Batteries

The lithium-ion battery is the main representative of the new battery technologies. For over 20 years, these batteries have been finding their way into our high-tech mini-devices such as mobile phones, Smart Phones, laptops, tablet PCs, photo and video cameras. Starting recently, their uses for electric mobility have been tested. There have even been initial tests in an AGV (Fig. 4.5).

The means of use influences the way the energy is drained and thus the possibilities and strategies for recharging. This is decisive for the service life as well as the performance and energy density of the battery. At this point it already becomes clear that there can be no simple rule governing the feasibility of such a complex energy storage device in an AGV.

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[7] STS-to-I: communication between STS and infrastructure.

Fig. 4.5 A Li-ion battery (*Source* Claus Ableiter, Varta)

It is clear that this battery needs to be maintained carefully, since errors in handling can have dangerous consequences. Potential errors are: mechanical damages, short circuits, too quickly loading or draining a cell. This causes the cell to become unstable, it can overheat and become an acute fire hazard.

Li-ion batteries need a reliable BMS[8] which handles each individual cell optimally, that means that charging and draining must be done for each individual cell. In any case, an acute fire hazard can arise when

- excessive mechanical strain causes internal short circuits,
- high external temperatures lead to a melting of the separator between cathode and anode,
- the battery comes into contact with too much water (defective batteries react strongly with water),
- the sensors for temperature and voltage monitoring break down.

It is still unclear how manufacturers rate these hazards and how they will be able to manage them. But this refers to several groups of manufacturers: first of all battery manufacturers, followed by automobile manufacturers and finally AGVS manufacturers.

It could be the case that this technology will not be used in the near future and that only NiMH batteries will be employed. Or manufacturers might wait for one of the many further developments, such as the lithium-polymer battery, the lithium-titanate battery, the Super Charge ion battery, lithium-manganese battery, the lithium-iron-phosphate battery or the tin-sulfur-lithium-ion battery.

At this point, we are reminded of a report on n-tv from July 29, 2013. It was reported that "Aviation experts are concerned about a component which might be the cause of a previously underestimated fire hazard in passenger and freight aircraft". This article traces numerous incidents in aviation in recent months to lithium batteries, which are an acute fire hazard.

[8] BMS = Battery Management and Monitoring System.

The question remains open: Are the advantages of this technology so great for an AGVS or an AGVS application that a medium-sized AGVS manufacturer could or should take these risks?

4.1.3.2 Capacitors

With the goal of wholly or partially dispensing with batteries, dual capacitors are a more commonly addressed topic. Their unique construction gives them a greater energy density than conventional capacitors. They are known under the brand names Goldcaps (Panasonic), Supercaps (WIMA), BoostCaps (Maxwell) or Ultracaps (EPCOS).

The double layer capacitor uses the effect described by Helmholtz[9] as early as 1856. A double layer forms when a current is fed into electrodes immersed in a conducting fluid. This is why these capacitors are also called electrochemical double layer capacitors. In an uncharged state the charged particles (ions) are distributed evenly in the conducting fluid, the electrolyte, which is located between the electrodes. When a current is applied, the negative ions migrate to the positive electrode and the positive ions to the negative electrode. A double layer is formed on both electrodes with a mirrored charge distribution.

Double layer capacitors are greatly superior to batteries with regard to their specific power density. They are constructed rather like a battery. A wrapped alignment is the best way to realize compact systems with minimal internal resistance. Their cyclic lifespan is high, as is typical for capacitors. Their characteristics and reliability could be considerably increased in recent years. This opened up possibilities for use in AGVs.

The key advantages of double capacitors over batteries:

- Short charging times: can be quickly charged via contact-free energy transfer and via recuperation[10] e.g. during regenerative braking
- Extremely long service life
- Very simple charging procedure: When a constant voltage is applied, excessive loading current is almost impossible and overcharging is not possible
- Good buffering characteristics for reducing battery weights (Fig. 4.6).

Development is not at a standstill here, either. Work is already being done in laboratories with "nanogate" capacitors[11] with an energy density ten times greater than current double layer capacitors.

[9] Hermann Ludwig Ferdinand von Helmholtz, 1821 to 1894, German physicist.

[10] Recuperation = current recovery.

[11] e.g., Japan AE Power Systems Corporation.

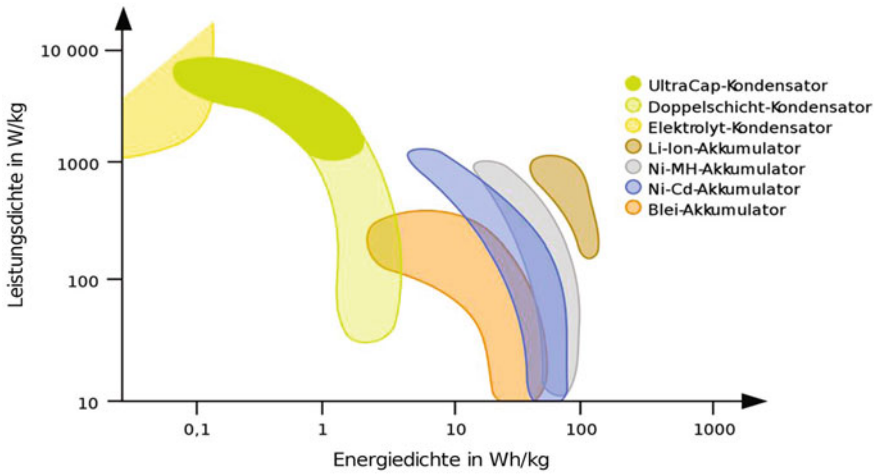

Fig. 4.6 Comparison of power and energy densities of various energy storage sources (*Source* MovGP0, Wikimedia Commons CC-BY-SA-2.0-DE)

4.1.3.3 Fuel Cells

We would like to limit ourselves to the most commonly used form of the concept of fuel cells, namely the hydrogen-oxygen fuel cell. In the strictest sense, a fuel cell is not an energy storage device – like a battery or capacitor – but rather an energy converter using hydrogen as a fuel to produce current. The technical principles would be too involved, so we will simply consider the AGVS-relevant characteristics with the goal of better divining future potentials.

The automotive industry[12] has been researching the use of fuel cells in automobiles for the past 20 years. They have come up with various approaches: while most manufacturers use the current generated by the fuel cells directly to power the electric drive, BMW, in its E68 (700 series) uses the hydrogen directly in an internal combustion motor and uses the fuel cell for generating the necessary on-board power supply.

We will not address the problems associated with manufacturing and storing hydrogen, although these topics directly affect the cost viability and environmental compatibility of the process.

Using them in an AGVS offers the following advantages[13]:

- highly effective with high overall energy conversion efficiency
- no dangerous emissions, only water vapor
- consistently efficient energy supply

[12] BMW, Daimler, Ford (until 2009), GM, Honda, Toyota, VW.

[13] ZBT – Zentrum for Brennstoffzellen Technik, (Center for Fuel Cell Technology) Duisburg. Prof. Dr.-Ing. habil. Gerd Witt.

Fig. 4.7 Fuel cell stacks with 24 cells and 500 W each (*Source* ZBT)

- highly reliable
- low wear, resulting in low maintenance
- long service life
- low-noise operation.

Figure 4.7 shows fuel cell stacks with 24 cells each. These packages have a polymer membrane and injection-molded bipolar plates. Their dimensions are (l, w, h) 22 × 14 × 16 cm and they weigh 3 kg. Their nominal output is 500 W.

The idea is to replace traction batteries with an equally powered system. Such a system consists of the following components:

- hydrogen reservoir
- fuel cell module
- compressor
- radiator
- intermediate reservoir
- base plate.

The battery is replaced by a system producing equal power. All of the system components are mounted in the available space and provide the same energy as the battery they have replaced.

It will depend on how general issues of the infrastructure for hydrogen supply are resolved to see if fuel cells will be successful in AGVS, especially for the traditional use in forklifts. AGVS applications are certainly predestined for large plants that already use hydrogen for their products and processes.

4.1.3.4 Energy Mix

If there are to be additional alternatives to current energy storage devices in the future, then more know-how is needed in order to more comprehensively address the question of energy supply for an AGV. It is made more difficult by the fact that in the future, there will be even more combinations of the energy technologies mentioned to produce an optimal energy system (energy mix). We have seen this development in automotive design: Not just simply diesel or gasoline powered

Table 4.2 Suitability of energy suppliers in AGVS for various performance areas

Technology	Standby	Driving	Peak
Contact-free energy transfer	–	+	–
Conventional vehicle batteries (lead or NiCd-batteries)	+	+	O
Li-ion batteries (representing all innovative batteries)	O	+	+
Double capacitors	+	–	+
Fuel cells	O	+	–

Explanation of symbols: not suitable−, conditionally suitable O, highly suitable +

autos are needed, but complex hybrid vehicles to meet all the various demands placed on modern autos.

The question of which possible combinations make sense is hard to answer at the present time, since we are at the very beginning of a new era of energy for AGVS. It might be helpful if we divide the energy requirements for a vehicle roughly into performance areas:

- Standby/resting
- Driving/base requirements
- Load handling/short-term peak output.

Table 4.2 gives an initial estimate of the various technologies available for these areas of performance. An initial assessment of the table leads us to several basic conclusions regarding reasonable combinations:

- Contact-free energy transfer really calls for support from small, innovative batteries or a double capacitor.
- Double capacitors will not be able to fully supply an AGV with energy, but will only be able to be used in a supporting role.
- Conventional traction batteries have demonstrated that they can cover energy supply for an AGV as long as there is room to install them. Smaller sizes can be used to support contact-free energy transfer.
- Innovative batteries are superior to standard ones when size and weight are important criteria. But price and safety factors weigh in against them.
- Fuel cells need an optimal operating point for which they are specially designed. In addition, they should be supported by a battery or a capacitor. Their greatest drawback: they require an extensive infrastructure.

The job of the engineer will consist of offering the customer an optimal combination or an individual solution. In doing so, it is indispensable to establish criteria for optimization. Today it is the case that technical feasibility is clearly the primary factor in the choice of an energy system, followed by the investment or the share of investment related to the batteries and charging equipment.

But users are slowly growing more interested in assessing not only the initial investment, but the overall costs for the time period under consideration. In this case, expensive, but long-lived technologies can be a worthwhile investment. And regardless of all that, the system prices for the new and innovative technologies presented here are changing much more rapidly than those for conventional traction batteries, so that a regular update of performance data and prices is recommended for AGVS manufacturers' design offices.

A further criterion for choosing logistics solutions in the future will also be relevant for AGVS: environmental protection and the sustainability of our decisions. If you enter a Google search under the heading of "green logistics" your computer will currently[14] generate 81.6 million results within 0.16 s. This means that more and more users are going to be placing emphasis on environmentally friendly, resource-efficient intralogistics, and will have a more critical view of current battery systems.

There are currently no recognized assessment schemes for a less emotional and more rational consideration of AGVS energy systems. This is where the VDI is called upon to actively offer assistance. Ways and means must be discovered to assess the relative performance of energy systems under green logistics criteria, while also clearly defining system limits. This means considering not just the environmental effects of the system while in operation (efficiency and potential emissions), but also their manufacture and disposal.

The optimization criteria for future energy systems are:

1. technical criteria (equipment performance requirements, available installation space in the AGV, weight)
2. the initial investment
3. the TCO over a period of observation
4. necessary infrastructure
5. hazards and maintenance requirements of the technologies
6. Target system "green logistics" in the sense of a sustainable company value.

The task of the AGVS manufacturer starts as soon as the potential customers have been evaluated regarding their way of thinking or when the supplier's flexibility is so great that he can begin doing project-based engineering together with the customer. To do so it is necessary to assess the required performance of the AGV over the course of typical and extreme cycles as closely as possible in order not to over or under-size the energy system – a challenging task!

4.2 Market Development

The first question that arises is one regarding the size of the AGVS market. Readers who expect a concise answer here will be disappointed. On one hand, the AGVS market is currently not clearly defined as it was, for example, during the second era of AGVS, and will be even less clearly defined in the future. Both the applications

[14] July 29, 2013, German search engine http://www.google.de.

and the suppliers are changing rapidly. On the other hand, every initial inquiry belies some motivation.

- This means that a potential AGVS user enquires about the market to find out if he is backing the right horse with his choice of system. In effect, he wants to know how other market players are using AGVS and where the trend is leading.
- The AGVS manufacturer asks himself if he can improve his own market position. This means that he also tries to compare himself with his competitors on the market – in this case with other AGVS manufacturers. In addition, he has the power to generate or at least develop markets through his own strategic orientation.
- Suppliers from the area of intralogistics want to look into whether it is worthwhile for them to enter the AGVS business. In this case, success is not just a matter of extrapolated market figures, but rather a matter of the product and how they go about their market entry.
- Component manufacturers want to know if there is sufficient potential demand for their products, which is why they are the likeliest to start up even though market figures are not highly promising.

Thus, we want to at least refer to the AGVS Equipment Analysis[15] published by the Department of Planning and Controlling of Warehouse and Transport Systems (PSLT) of the University of Hannover without citing its figures. Even limiting ourselves to the twelve members of the VDI Specialist Committee on AGVS and the AGVS Forum, these companies brought around 120 AGVS with an average of six vehicles each into service worldwide in 2009. If we assume an average price of €650,000 for one of these systems, then we arrive at a total sales volume of around €78 million. If we assume that these organized AGVS manufacturers comprise around 60 % of the market, then we come to a rough figure for the European market of €130 million. But it should be clear that these off-the-cuff estimates can be as misleading as they are correct and that they are of little value in determining the motivations named for the “market question” as mentioned above.

It is certainly reasonable to ask why the market is not bigger, especially since we saw in the Chaps. 2 and 3 of this book that AGVS is a tried and tested method for optimizing intralogistics. This is why we want to list the inhibiting factors, which certainly form part of the answer to the question. These factors can be subdivided and partially attributed to the markets. First of all, the general economic hindrances:

In principle, from a sales point of view, products are easier to sell when their prices are lower. This makes the initial investment a major hindrance to many projects. Alternative financing models would be desirable, especially those that result in calculable costs without risks.

[15] Annually published analysis of a survey of around 20 European AGVS manufacturers. Conducted by the Department of Planning and Controlling of Warehouse and Transport Systems in the Institute for Factory Equipment and Logistics at Leibniz University, Hannover.

The economic viability analysis usually determines that only 24/7 operations bring the best returns for an investment in an AGVS. In contrast, one-shift operations are often not economically attractive.

The maintenance and repair costs are often seen as too high. Compared to other conveyor systems, they can often be 50 % higher.

Many users' prescribed operating materials and quality standards make an AGVS expensive. It is much the same for European and customer-specific safety requirements (especially: personnel safety scanners, multi-channel electrical systems).

We would now like to turn to certain aspects of both traditional and the new markets and then ask the question of how AGVS suppliers will stack up in the future.

4.2.1 Traditional AGVS Markets

Here we want to consider technical shortcomings as the serve as the basis for future development potential. In general, we know that AGVS of the third era increasingly come into use as part of an overall project. This was covered extensively in the previous two chapters. Nobody has succeeded yet in selling automated vehicles as a product – but more on that later. The following table starts out listing the technical hindrances (Table 4.3, Fig. 4.8).

Outdoor use is still the exception; comparatively few outdoor projects have been realized. Here we must qualify that outdoor use means that the vehicles are driven unconditionally outdoors. If it is just a matter of short stretches, such as between

Table 4.3 Technical hindrances to market growth

Topic	Description
DriveSafe	Lack of intelligence: navigation also needed in complex surroundings
	Lack of universal/low-cost solution for 3D obstacle recognition and avoidance
	Safety requirements from the Machine Guideline are expensive, time-consuming and inappropriate
Guidance control systems	Guidance control systems are usually appropriate only for AGVS, but not for additional conveyor systems
	Various types of AGVs should be able to operate under a single guidance control system
	AGVs from various manufacturers must be capable of operating under a single guidance control system
	Lack of guidance control system flexibility for changes in the AGVS functionality
	Is a guidance control system even necessary? Key terms: swarms, multi-agent systems, Internet for objects
Energy supply	Higher-performance energy storage capacity required
	Service life of traction batteries is a factor – too short
	Charging batteries disrupts operations and "costs" additional AGVs

(continued)

Table 4.3 (continued)

Topic	Description
Load handling	Lack of safe, industrial-grade, standardized solutions
	Speed of load transfer is way too low (in an absolute sense – and compared to a forklift)
	AGVs still insufficiently flexible in use
	Recognizing the quality of the loading devices or special handling or rejecting “damaged pallets”
	Lack of multi-functional load modules
Start-up and Operation	Start-up must be simplified!
	Necessary training costs time and money
	Requirements for employee certification are too high
	Changes to drive path must be made simpler
	Service and maintenance must be further improved
Interfaces to other devices	The “AGVS-friendly floor” is a hindrance in itself because it is time-consuming to remodel
	Planning is still too complex
	No standard interfaces to peripheral installations
	Technical regulations, especially European norms, are lacking or too complicated
	Technical rules make things more complicated and expensive

Fig. 4.8 AGVs from seven different manufacturers under one AGVS guidance control system (openTCS – the open AGVS-guidance system. Opentcs = Open Transportation Control System. www.opentcs.org), currently only realized for the AGVS ballet at the Hannover Messe in 2009 (*Source* Forum-AGVS)

halls, which are partially protected or even roofed over, then it does not qualify as outdoor use. To make this distinction clear, consider an employee who is dressed for working outdoors in all weather because he will be completely exposed to the elements for a long period of time, and another one who simply puts on an overcoat to briefly go from one building to the next.

Additional hindrances to the "truly" outdoor use:

- Limited speed of AGVs
- Limited driving precision
- Limited load transfer precision
- Lack of safe, certified and inexpensive 3-D obstacle recognition
- No universal, low-cost navigation solutions.

Overcoming these shortcomings will allow manufacturers to generate competitive advantages through their own initiative.

The traditional AGVS markets will change. On one hand, a new generation of technology will offer new possibilities for AGVS; this was addressed in the previous section. Further changes will be brought about by trends in production technology:

- Increased flexibility
  In general, product variety and versions are increasing. Lot sizes are growing smaller, as are product life cycles. These developments call for production and logistics equipment that is just as flexible as the world of their products. Monthly or even weekly changes to production facilities will be commonplace.
- Process traceability
  Whether demands are external – even legal requirements – or internal is of subordinated importance. In any case, IT will continue to permeate all aspects of industry. Manual solutions (e.g. with manned forklifts) are possible only with well trained (costly) personnel and then still time-consuming and not always safely feasible. For these reasons, we expect that more and more industries will turn to AGVS.

4.2.2 New Markets

Right now there are not just industrial areas of application but also various potentials for use in public areas for automatic – or rather autonomous vehicles. The traditional AGVS manufacturers are making their first inroads into these new vehicle surroundings, to the extent that they are being used in the areas of health care and clinic logistics. The AGV's are encountering "outside persons" in various hospital projects, which fundamentally alters the technical, organizational and legal situation. If the classical AGVS in an industrial setting generally encounters only trained, healthy adults and employees, the public sphere is an entirely different story. Here they have to deal with untrained personnel, children or perhaps even patients.

Service robots (SR), which, in principle, have existed in very limited numbers for some time now, have always had to make their way in such areas. Previously, AGVS and service robotics hardly had any overlapping areas. But nowadays we come to expect that these product areas will be intermingling in the future and have come up with a simple formula:

Fig. 4.9 Two of the first STS products on the market: Use in a clinic, retirement home or hotel (*Source left* MT-Robot, *right* MLR)

$$\text{AGVS} + \text{SR} = \text{STS}$$

By crossing the traditional AGVS with service robotics (SR), we come up with service and transport systems (STS).

The world of AGVS contributes the latest developments in mechanical engineering to the product, which can move and carry materials. The service robot genes give it the intelligent EXTRAS (Fig. 4.9):

- extra object recognition equipment (3-D, sensor fusion)
- extra navigation, more safety (DriveSafe) in certain areas of use
- extra intelligence and more functionality
- extra flexibility (simplicity, ease of understanding) for start-ups/changes
- extra service friendliness (RFID/friendly sharing of information from core components)
- extra options for energy supply (combinations of technologies)
- extra data security and reliability (e.g. during data transfer).

In coming years we will see interesting markets develop in which the “service and transport system (STS)” finds its true destiny. These are automated guided

Table 4.4 Development tasks for the STS

Designation	Description
DriveSafe	An urgent vision of the future “Open your eyes!” (3-dimensional recognition of surroundings)
Image recognition	Objects, people, categories, situations
Video recognition	Interpretation of moving images, processes and gestures
Interacting with other participants in traffic	Assessing speeds, directions and intentions, “out-side” persons
Sounds	Recognizing and localizing
“Smooth behavior”	Sensitive coupling of sensory equipment and drive motors

vehicles that do not just transport but also are able to assume various service tasks; or in other words: service robots with a transport function. This makes them AGVs with expanded functions or slimmed-down SRs. Two typical examples are shown in the picture above, which can assume the most varied tasks in a hospital, retirement home or in a hotel:

- Food service
- Pick-up and delivery services for medications, beverages and documents
- Sub-mount for a mobile minibar in hotels
- Baggage carriers and guides

A number of developments demands are placed on this new genre of vehicles (STS): Table 4.4 summarizes the key points.

Under “new markets” we mean uses for automated driving beyond traditional intralogistics, as described in Chap. 2. Many of these uses come from the broad field of service robotics. Table 4.5 shows one idea of this not entirely new topic, but they are not taken up in detail.

Additional drawbacks for these new products, services and markets, especially for use in public traffic areas are:

- Lack of concepts and suppliers of small AGVs (max. 20 kg payload)
- Lack of integration between sensor and guidance equipment for the twin functions of safety and automated driving (DriveSafe)
- Safety requirements and responsibilities
- Lack of safe, certified and low-price 3-D obstacle recognition
- Necessary size and weight of moveable platforms
- Lack of standardized mobile platforms
- Autonomous navigation (without artificial markers)
- Robots on AGVs (mobile robots) – unclear: safety, certification, reliability, energy supply issues (Fig. 4.10).

Table 4.5 DriveSafe uses beyond traditional AGVS applications

Area of use	Description
Private	Service robotics: floor cleaning, lawn care, pool cleaning
	Personal companions (also for elderly care)
	Toys and hobbies, as well as trainers and teachers
Commercial	Airports
	Hospitals (goods logistics, automatic wheelchair and hospital bed assistant robots)
	Hotels (baggage carriers, mobile minibars, guides)
	Entertainment (PeopleMover and attractions)
	Security and monitoring services
	Façade, tank and pipeline cleaning
Agriculture	Milking
	Sowing and harvesting
Public	PeopleMover: urban logistics
	Service robotics: information, tour guides
	Automatic parking garages
Military and disaster services	Reconnaissance and intelligence gathering
	Information gathering and rescue services

Fig. 4.10 The mobile stage: Presentations and interviews right at the manufacturer's trade fair booth. Made possible by the freely navigating AGV at the Hannover Messe, 2010 (*Source* AGVS Forum)

Service robotics is an almost inexhaustible field in itself, one that we cannot and do not want to begin to approach in depth here. But we do want to note that this topic will not be completely lost on our existing world of AGVS and today's AGVS manufacturers. Figure 4.9 shows a combination of proven AGVS technology with innovative elements (navigation without artificial markers).

One key question remains in any case: What will be the role of today's AGVS manufacturers in the future? How do they want to and how will they position themselves?

4.2.3 Example of Uses from the New Era

AGVS makes adaptive clinic logistics possible. Modern concepts lead to massive savings in clinic logistics. In 2012, the next stage[16] of current AGVS uses in "large-scale logistics" for hospitals was developed. This will serve here as an example for new uses for new, intelligent vehicles (STS).

Since the start of the last decade, automated guided transport systems (AGVS) have established themselves in large hospitals (600 or more beds) and have taken over "large-scale" clinic logistics in the form of automated wares transport (AWT) systems.

The previous AGVS uses have all been similar in nature: usually they involve underride AGVs, which shoulder and transport stainless steel roller containers (Sect. 2.2.7). The roller containers are designed for food, laundry, trash, sterilized wares, medications or stores and be loaded up to a total weight of 450 kg. The large food containers can carry up to 30 trays.

Since the large hospitals naturally have long logistics pathways, 10 to 100 vehicles are commonly in use, always guided by an AGVS guidance control system which communicates with the AGVs via WLAN. The transports originate from the central supply areas such as the kitchen, laundry room, trash collection area, the apothecary and the storeroom. From here they visit the wards, which cannot be driven to directly, outside the wards there are normally so-called "train stations", where the AGVs drop off and pick up the containers.

These "large-scale" logistics solutions with large vehicles (up to 800 kg total weight, 2 m long and 1.80 m high) require long logistics pathways that are chiefly located in the sub-floors of the clinics and connect the central supply areas with the various wings in the cellar corridors. These solutions also then call for a considerable investment: for a system with ten vehicles which assume all the key logistics tasks of a 600-bed hospital, one can reckon roughly with at least one million euros (without accumulating conveyors and roller containers).

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[16] Drost, A., Ullrich, G.: *Transportlogistik for die Kleinen.* KTM – Krankenhaus Technik + Management (*Transport Logistics for Small-Scale Operations* – HTM – Hospital Technology + Management) 12-2012, pp. 36–40, Published by Dr. Wolf Zimmermann, Finning.

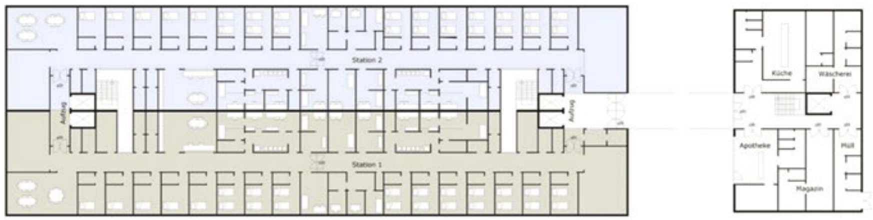

Fig. 4.11 Small-scale layout (*Source* MT Robot AG, Zwingen, Switzerland)

AGVS is now also found in smaller hospitals Such solutions are not appropriate for smaller hospitals because they require too many preconditions. Nonetheless, there are numerous small hospitals with enough potential for optimizing their logistics. A “small” hospital here refers, for example, to a specialist clinic with 150 beds of six wards with 25 beds each.

There are currently several planning projects underway. Naturally, each hospital is unique, but the differences lie in the details. In order to demonstrate the general potentials for optimizing clinic logistics with intelligent driverless transport vehicles, or rather: with new service and transport systems (STS), let us consider a fictitious example.

Figure 4.11 shows the layout of our imagined specialist clinic. On the right you can see the supply wing with central kitchen, apothecary, laundry, waste disposal area and storeroom. The building on the left is the hospital wing with three floors of two wards each (marked with gray and blue). In total, the clinic contains 150 (6 times 25) beds (Fig. 4.11).

The path from the supply wing to the elevator averages 50 m. The ground floor of the patient wing can be reached after 50 m without using the elevator. The upper two floors can be reached only with the elevator. The elevator is used by clinic staff.

There are two wards on each of the three floors. Each ward has a corridor 80 meters in length. There are ten double rooms and five single rooms along this corridor, distributed evenly. In addition, service areas, such as the nurses’ room, doctors’ room, treatment room, lounge, toilet, bath, stairwell, window area, storage area, etc. are located along the corridors.

We will assume that both wards on a floor are interconnected so that an STS can pass through the first ward and then, without having to go much farther, can enter the second ward through an automatic door, pass through it and then – without retracing its route, reach the elevator (“round trip”).

It has to perform the following logistics tasks:

- Delivering (and picking up) food, mornings, midday and evenings
- Removing waste from the wards and depositing empty containers
- Laundry delivery (and removal)
- Supplying wards with goods from the apothecary, sterile goods warehouse and the storeroom (sources are all in the supply wing)
- Special deliveries and express transports.

Fig. 4.12 *Left* the service and transport system; *middle* STS with a laundry module; *right* a view of the flexible laundry module (*Source* MT Robot)

The kitchen intervals determine the system performance To simplify our example, we will assume that the STS only delivers containers with food trays. The container is dropped off at the entrance to the ward on an MMW (mobile module handling wagon) (Fig. 4.12). The staff on the ward then distributes the food trays by pushing the loaded MMW through the ward and removing the trays. Individual trips are made:

- Bringing a filled container from the kitchen and delivering it to the ward.
- Picking up the container with dirty dishes from the ward and delivering it to the kitchen.

14 trays fit in one container. A ward needs a maximum of 25 trays per meal. Each ward needs two containers. In total, 12 trips are needed. If the meals for the entire clinic need to be delivered within 1 h, this means that the kitchen is operating at 5 min intervals. This means that the kitchen determines the performance of the entire system. The STS must be able to pick up the containers from the kitchen in this rhythm. This provides us with the total number of vehicles needed.

With the goal of limiting the number of STSs needed, a precise driving schedule must be worked out taking all necessary transports into account. This schedule provides for evenly distributed utilization of the vehicles over the course of the day. The food transports are the determining factor, and must be given priority. These then leave the free times in which other transports take place. Overall, the equipment is in use from 6:00 am until 10:00 pm. At night, the vehicles are parked at their parking places where they automatically dock and are recharged.

Additional transports Additional transports fill out the driving schedule with delivering and removing laundry, apothecary wares, sterile goods, storage goods, laundry and waste.

- Waste: Each station must be visited once daily. Combined transport: an empty load delivered, a full one removed. The destination/source is centrally located in the ward, i.e. 40 meters away.
- Laundry: Each station must be visited once daily. Small combined transports: Fresh laundry is delivered, the staff changes the laundry, the STS picks up the

dirty laundry later, resulting in two trips per station. The destination/source is centrally located in the ward, i.e. 40 meters away.
- Apothecary wares, Sterile goods, storeroom wares: Every morning, a transport passes through both wards on the ground floor and first ward on the middle floor (lower half). Another transport then covers the second station on the middle floor and both stations on the top floor (upper half). In the afternoon, one transport passes through the entire building.

The supplementary transports also include special delivery and express transports, which cannot necessarily be planned in advance. When planning, urgent attention must be paid to ensure that the number of STSs is sufficient to leave time windows for such. Many such special deliveries/express transports are to be made each day. Let us assume that there are around 30 such transports daily, which can have different sources and sinks.

Some of the transports, which normally fall under the category of special trips, are nearly scheduled in nature:

- Mail delivery (two trips through the entire building)
- Beverage crates (two trips per level/two wards).

The technical solution: The STS technology on which the calculations are based comes from Switzerland.[17] The centerpiece of this technical solution is an innovative vehicle; small, maneuverable and equipped with sensors which allow it to share the hallways with patients and clinic staff.

The vehicle can be combined with the various load carriers, the so-called modules. Such modules are available for food, laundry, waste, etc. The STS itself changes the modules.

The vehicle itself is highly maneuverable and light with a maximum payload of 200 kg. By automatically changing modules at the stations provided for that purpose, the STS independently re-equips itself for other tasks. This flexibility in the tasks it can perform makes it possible to greatly increase overall system capacity utilization. This, on one hand, guarantees a quick amortization, and on the other hand, other seemingly side tasks can be automated when utilization is low.

The combination of new technologies in the area of navigation, user interface and module changing system allows the STS to meet these requirements. It means that the user can alter and adapt the route. The integrated laser navigation system allows it to orient itself in familiar surroundings by learning the route on a teaching trip. This creates the free times in the schedule and the flexibility needed to actively promote the continuous improvement process (CIP).

In daily interactions it is important to be able to simply and intuitively assign new tasks. This serves to increase employee acceptance, reduces errors in daily interaction and improves workplace ergonomics. The STS's web-based user interface is intuitive in use, taking into account this change in society.

[17] MT-Robot AG, Zwingen, Switzerland.

Fig. 4.13 Picking up a food delivery module at a MMW (mobile module handling wagon) (*Source* MT Robot)

The STS is much smaller and more maneuverable than the previous AGVS solutions in hospitals. This is a noticeable plus, especially in crowded conditions; there is no problem with crossing thresholds of up to 2 cm. The sensory technology, especially developed for health care applications, consisting of tactile sensors as well as laser and ultrasound sensors, allows new areas to be opened up. 3-D monitoring of the drive direction as well as a recognition system for ramps and edges are the building blocks for allowing the vehicles to drive considerably more safely and to anticipate situations.

An absolute innovation has arisen in the form of the mobile module handling wagon or MMW. This delivers the modules completely flexibly but automatically to their destinations, and can be moved along by ward staff without major effort. This allows nurses to push the food delivery module through the ward on an MMW and distribute the trays. Figure 4.13 shows an STS picking up a food delivery module from an MMW.

Economic viability The scenarios are calculated using static simulation processes. In the case described above, 3 STSs are needed. The calculation covers the entire project, including:

- 3 STSs
- Guidance control system
- 3 battery charging stations
- 8 food delivery modules
- 15 laundry modules
- 15 transport modules (for apothecary, sterile goods and stores)
- 10 module changing stations
- 19 fire doors (refitted to function with guidance control equipment).

The total investment comes to around €600,000. The initial seemingly high price is relativized by the fact that the €120,000 for all the necessary containers/modules is already included. The alternative is to use a pickup and delivery service. This would require three people per shift for two shifts, meaning six people, with annual costs of €40,000.

An ROI analysis shows that the investment will pay for itself after two and a half years. If the investment is depreciated over 6 years with an internal interest rate of 7.5 %, the resulting savings over the depreciation period come to more than €700,000.

Summary and outlook The STS is smaller, more maneuverable and more intelligent than the traditional AGV. This offers even smaller hospitals the potential to automate their logistics, which creates a range of advantages. This technology is also something for larger hospitals, where the STS can be used to augment the existing "large-scale" AGVS solutions to round out logistics automation.

In the uses mentioned, computer-based planning tools were developed which can be used to analyze the layout, to calculate the number of vehicles needed and to evaluate the economic viability according to VDI 2710 p. 4. This provides the technical or logistics directors with valuable aids for planning and operating AWT systems.[18]

These solutions have filled out the offering, especially for smaller clinics and AGVS can continue to make advances in hospital logistics.

4.2.4 Key Supplier Competencies

During the recently ended third era of AGVS, the situation was clear: there were manufacturers of works vehicle, AGVS and robots. There was hardly any overlap. But the changes described above will lead to shifts and overlaps in the fourth era:

- Works vehicle manufacturers are starting to think about offering automated versions of some of their products. Major market players like Linde and Still already see themselves as AGVS manufacturers.
- Robot manufacturers see new potential uses if their products were mobile.
- Component manufacturers see themselves as able to completely automate vehicles, ultimately making them into AGVS manufacturers as well.
- Component manufacturers offer such complete system building blocks that inexperienced newcomers to the industry are also venturing to offer AGVS. Such complete system building blocks include the drive equipment, energy supply, track guidance and communication.

In addition to these shifts on the suppliers' side, there is growth in the user industries. This means that especially in the "new" industries, inexperienced companies, who have yet to build an AGVS but have proven themselves in related fields, will be offered opportunities. Traditional AGVS manufacturers will have a difficult time because they have limited experience in those industries.

[18] Specialist planning to fit these concepts: www.awt-kompetenz.de.

New players on the market will find it easier since the key AGV components available on the market are more complete and of improved performance. They usually come in well under the existing price level, even though the initial projects are not always technically or economically successful. Why are they afforded an opportunity? Because they already have a reputation in the industry (perhaps as a supplier of stationary, machine-related conveyor and delivery equipment), are familiar with the industry, and the price is right.

Industry focus Thus, it will become increasingly more difficult for traditional AGVS manufacturers to be successful in all industries and markets. Sales and marketing costs would be much too high. It is high time for them to concentrate on specific industries. Previously, very few AGVS manufacturers have clearly focused on a single industry (Table 4.6).

Focusing on an industry does not mean that an AGVS manufacturer can only process orders from their selected industry. It just means that their active marketing and sales efforts are limited to certain target groups. This is the task of key account managers who maintain a professional CRM.[19] Only then can a trustworthy relationship with a customer be established.

Table 4.6 Activity plan for industry-specific marketing

Key term	Description
CRM	Knowledge of industry and group interrelationships
	Knowledge of productions sites and people in charge
Industry database	Associations and affiliations
	Presentations: trade fairs, specialist conferences, regular meetings
	Publications, Internet portals, other bodies
Typical suppliers	Other industries with close contacts to target industry are potential partners.
	Establish and use cooperation with others with knowledge of an industry
Concrete marketing instruments	Photos, videos as basis for the following points
	Brochures, flyers, highly industry-specific!
	Internet presence – highly industry-specific!
	Using Internet portals such as Wikipedia, YouTube, Xing, …
	Specialist contributions and articles, advertising in trade publications
In-house presentations	Trade fairs, exhibitions
	Workshops and conferences
	Seminars and training sessions

[19] CRM = Customer relationship management.

Specialization There are other ways to specialize. For example, an AGVS manufacturer can specialize in assembly-line AGVs. This would also result in a focus on certain industries, since this type of serial assembly is not found in many industries.

Heavy loads or outdoor uses can also be a form of specialization. Or one could possibly concentrate on the low-price end of the market. The advantages of limiting oneself to one or only a few industries are:

- Better overview of the clientele, easier to care for.
- A company's own knowledge of the specifics of the industry can reach a level on par with that of the customer when it comes to seeking solutions.
- Marketing can be more efficient and better targeted. There is no question of which trade fairs, congresses and specialist conferences need to be visited.
- Only a share of the overall range of complex AGVS technology is actually required. This reduces the personnel resources in the technical departments of development, design and technical sales.

Center of competence: DriveSafe Another way to concentrate and specialize is to focus on the DriveSafe functionality. It is future-oriented, describes save driving and can be expanded into a core competence. Products from such DriveSafe suppliers would no longer be AGVS, but rather platforms or product ranges based on mobile platforms.

Companies that want to market solutions in the area of new uses (Sect. 5.2.2) can make use of these mobile platforms and base their applications on them. The DriveSafe supplier will make sure that the service robot

- is given an appropriate drive system (driving characteristics, space required, speed),
- is given an appropriate source of energy,
- navigates reliably and
- functions safely (in the sense of operating safety and legal requirements).

Project or product-oriented business It will be exciting to see who manages to be the first to understand AGVS not as a project-oriented business but as a product-oriented one, and as a supplement or sales alternative to project-based business. Project-based business is tedious: every request must be carefully worked out, conceived and calculated. Work is required not just in sales, but also in the mechanical and electrical design as well as project planning. The vision is tempting: customers purchase automated vehicles that can be built serially more or less off the rack and take them into service themselves.

Both established AGVS manufacturers and newcomers to the industry have come up with this idea. Traditional AGVS manufacturers are looking for new sales channels to expand their business, and the industry newcomers have picked up the scent of new business because the necessary equipment is available in the form of high-performance components. In the meantime, for example, optical track guidance for automated wheeled vehicles is available in every upscale Lego® kit.

Table 4.7 New marketing strategies for AGVs as a product

Sales channel	Description
Catalog	For factory use
	For tools
	For warehouse and loading devices
Configurators	In the Internet, configurators are commonly found on the sites of automotive manufacturers. Equally, the customer could see in an AGV configurator, if his use is suited for product-based business, as well as which functionalities he needs, with just a few clicks. In addition, he can find photos of the finished product with prices and order forms
Outlets	Factory sales, that is, direct sales from specialists in the manufacturer's affiliates
	Direct sales in selected locally active partnerships
External sales structures	Dealer network for works vehicles manufacturers
	Local partners for maintenance and service
	Home improvement retail chains

But the large manufacturers of manual, traditional works vehicles are also asking themselves if it is possible to sell their works vehicle series as automated versions (Table 4.7).

The technical preconditions and marginal conditions for such an approach are currently quite clear:

- The uses that marketing strategies are targeting have to be simple, which means working without a traditional AGVS guidance control system and complex layouts.
- They must also be simple with regard to the peripheral interfaces, or simply do away with them.
- Navigation must be simple – either entirely without artificial markers or needing nothing more than painted guide lines on the floor.

This means that there will soon be products that are AGVs by today's definition but are called something else: we cannot wait to see what sort of creative names they will come up with. At first, they will be simple vehicles to perform standard tasks, such as picking up and transporting pallets or pulling a trailer.

But then new ways of marketing will arise, whereby we do not mean entirely new ones, but ones directed entirely to the AGVS market.

Summary and outlook The world of AGVS and STS is growing more colorful. Not just for indoor uses, but for open-air uses as well. These outdoor applications remain a serious challenge. There are no weather-proof safety systems or methods of navigation. Even GPS can only be used to a limited extent. A lot of hopes are staked on the European satellite navigation system Galileo, which should be fully available sometime between 2015 and 2020.

One thing applies to all uses: the vehicles' own intelligence will increase. The abilities that are currently being promoted under the terms DriveSafe, Truly

Autonomous Driving and Smooth Behavior are going to leave their mark on the developments over the next 15 years. And the markets will grow – because automatic/autonomous driving will become key issue not just on public roads, but off the roads as well.

AGVS is and remains a fascinating technology. “Robot vehicles” that are guided as if by an unseen hand evoke an emotional response along with their purely technical and economic aspects. Even when we have all grown more and more used to automated systems, AGVS of the third era will become more intelligent and high-performance than their predecessors so that our fascination with automated guided vehicle systems will continue in the future – the world will grow more colorful!.

Chapter 5
Interdisciplinary Design of Automated Guided Vehicle Systems (AGVS)

First of all, we should note that the adjective *interdisciplinary* is used here consciously and in its proper dialectical sense. AGVS planning will be presented here comprehensively – as in the oft-cited VDI Guideline 2710[1] – all of the planning stages are to be addressed, starting with the preliminary considerations and ending with the decommissioning of the used equipment. Naturally, we will limit ourselves to the AGVS-related aspects – general descriptions of the topic of project management are available in great numbers.

In previous chapters, we have been familiarized with AGVS as a means of organization, one that plays an integral role in the intralogistics environment. Many points of contact arise – the technical and organizational interfaces – parallel, subordinated or overriding topics and workings, so that the planner notices quickly that he has to deal with a lot more than just AGVS technology.

Up to now – and here we continue to discuss the third era of AGVS – we have almost exclusively concerned ourselves with projects. Considerations have been made and continue to be made to market AGVS or at least certain AGV series as products, but they have not been very successful to date. No two systems are completely identical, experience has shown that even follow-up projects always differ. Planning automated guided vehicle systems is a multi-faceted, hands-on project. This should scare people off, but rather stress the significance of AGVS planning.

5.1 The Significance of Planning in AGVS Projects

Automated guided vehicle systems display varying degrees of complexity. The range of projects realized covers everything.

- from simple low-cost systems to high-end intralogistics solutions,
- from systems with only one vehicle to ones with well over a hundred,

[1] VDI 2710 "Interdisciplinary Design of Automated Guided Vehicle Systems (AGVS)".

G. Ullrich, *Automated Guided Vehicle Systems*,
DOI 10.1007/978-3-662-44814-4_5

- for both indoor and outdoor use,
- from simple functions (transport from A to B) to complex systems that perform other highly demanding jobs over and above simple transport tasks,
- from point-to-point connections to intelligent taxi operations,
- from very small to very large vehicles (payloads ranging from a few kilograms up to 100 tons).

The tasks presented by the user can vary from simple point-to-point transport to implementing comprehensive logistical operating concepts, whereby AGVS is just one component in a production, warehouse or distribution area. The depth of planning is also necessarily dependent on the degree to which it is incorporated into overall operations and the scope of the tasks at hand. With increasing complexity, a number of other issues arise along with pure AGVS functionality, such as modifications to buildings, warehouses, assembly lines, productions machines, etc.

In the end, the idea is to embed the logistical solution into the overall concept while considering various interfaces to parallel, subordinate and host systems.

As with every product, the economic considerations form the basis of planning along with purely technical, process and infrastructure-related aspects. Careful economic planning studies are needed for the necessary investments. Alternative financing models must also be weighed against each other.

In addition, the AGVS planner is often occupied with secondary matters that are otherwise uncommon in everyday planning business: the project's influence beyond the company itself (e.g. within the group or the entire industry) or consequences for the employees (local or labor rights issues), so that they must also be intensively studied from an outside viewpoint as well.

This is why planners must place emphasis on taking an interdisciplinary approach from the very start to ensure the success of an AGVS project. Their task is to consider all relevant aspects with the necessary degree of conscientiousness and to establish their causal contexts.

In the end, AGVS planning is thoroughly complex and demanding. Not every user has access to the necessary expertise or the capacities or resources required to aid in external planning support. All too often, the dilemma presented by the complexity of planning and the lack of resources leads to abandoning a reasonable AGVS solution in favor of a simple transport solution (e.g. one using conventional manual works vehicles), which always leads to missed opportunities to increase effectiveness.

5.1.1 Resource-Determining Criteria

How many resources does an AGVS project require? Optimal AGVS planning definitely depends on numerous factors. These include:

- Overall scope of the project:
  Is it a purely AGVS project in planning (stand-alone project) or is the AGVS just one component in a larger comprehensive material flow project? Is the bid

for the AGVS made separately or is the contract to be negotiated and awarded as part of a package with other systems?

- New project or modernization planning:
  The terms greenfield project and brownfield project are often encountered. A greenfield project refers to the new construction of an object (on a green field), while a brownfield project involves expanding or re-purposing an existing structure. These certainly depend heavily on the degree to which the neighboring systems can be adapted to the AGVS, or to the extent to which the AGVS can be integrated into existing structures.
- Budget:
  The amount of the project budget will also influence the planning. In the final account, the budget is also a key factor in determining the complexity of the project.
- Effects on intralogistics:
  What is the effect of the use of AGVS on operating procedures and on other systems? The more closely the systems are networked, the greater the demands on interdisciplinary planning.
- The significance of using AGVS for the logistics process:
  How greatly will it depend on the functioning AGVS solution? Will a breakdown of the AGVS lead to a production or delivery stoppage? Will the availability of the AGVS directly determine the performance of the entire production area?
- Previous experience with AGVS:
  In general, it is the case, that companies that are already using an AGVS find it easier to plan new systems. This is often a matter of personnel.

These criteria are used for assigning resources for planning. After all, careful AGVS planning is impossible without sufficient resources.

In this context, one must address the frequently asked question of how long an AGVS project is to last. Naturally, the "multidimensional extent" of the undertaking allows only a rough estimate. Six months are generally allotted purely for manufacturing, delivery and start-up of the AGVS. The bidding process, that is the time starting from opening page one of the product concept catalog, adds around three months, easily bringing the actual project time to nine months or more. In addition, there are "preliminary considerations", including conceptualization. As a general rule of thumb, one can assume a period of one year.

5.1.2 Organization of the Project Team

Then decisions on how to conduct and assign responsibility for the planning tasks are made based on industry or company-specific traits:

- Full company responsibility for planning with/without external support
  Planning is done by company staff or external staff hired by the company. In doing so, it is important to ensure that the employees have detailed knowledge

of all current procedures and internal processes, otherwise, time-consuming training will be necessary. Naturally, if they are assigned to planning, they will not be available for other activities, or only to a limited extent. For “large-scale projects” which are being approached for the first time, it is advisable to employ outside support.

- Supplier planning
  Planning can also be done directly by the AGVS supplier, whereby this approach harbors the danger that it will lead to a sub-optimal solution, as the manufacturer will rely only on his own range of products during planning. In addition, the supplier must be chosen at a very early stage. This sort of planning leaves it entirely up to the supplier to meet specific performance criteria and characteristics. In general, this approach is based on a so-called “functional offer for bids”, one which describes a logistical task but leaves the solution open except for certain key components or principles of transportation. Letting the supplier do the planning makes sense when this supplier has already delivered solutions for similar tasks for your company and has done a highly commendable job. His head start in experience is another argument for such a solution.
- General contractor project
  Another way to assign responsibilities can be to grant the project to a general contractor. This approach, which is recommended for more complex projects, involves transferring all sub-components of an overall project (e.g. construction measures, constructional steelwork, plant engineering and equipment, etc.) to a partner in charge of the entire project. This partner can then order sub-components from other suppliers. The key aspect is that only one contractual partner is responsible for providing the customer with the overall equipment and system for the project. The general contractor is then responsible for the interdisciplinary planning, but can bring external specialists into the planning process at any time.
- Mixed variants of the previously listed approaches.

5.2 Planning Stages

We will subdivide AGVS planning according to VDI 2710. First of all, since it makes *a priori* sense to work with the contents of an applicable technical guideline and secondly, since the author was a major contributor. It would otherwise be unconvincing if these pages varied from the guideline, since they were published only 18 months apart from each other.

The VDI 2710 is addressed to all interested parties, planners, operators and manufacturers and can be used as a basis for planning AGVS projects as well as serving to promote mutual understanding (Table 5.1).

Table 5.1 The planning phases of an AGVS according to VDI 2710

Position	Designation	Result
1	System conception	Decision made to use AGVS system. Economic validity is demonstrated
2	System planned out	Product concept catalog completed
3	Procurement	AGVS is installed and ready to operate
4	Operation planning	AGVS is reliably operated
5	Change planning	AGVS is altered
6	Decommissioning	AGVS is dismantled and disposed

As with any other project, realizing an automated guided vehicle system requires a step-by-step, fully transparent and coordinated approach.

It starts with all the considerations regarding the type and scope of the undertaking, the intended model to be realized, leading to the question of whether to take a completely new approach or to integrate and expand existing structures, as well as the financial and business framework.

A “screenplay” is completed and described for the envisaged project, which must contain all the networking points for operations along with the original tasks. Since problem-free operations cannot be guaranteed, especially during the initial project phases, it is a good idea to carefully consider the effects of breakdowns and develop alternative approaches.

If the project has been sufficiently outlined in advance by its initiators, the following steps should be directed at properly organizing the undertaking.

The project team should be organized based on the intended approach to planning, namely whether the company, the supplier or a general contractor is in charge of planning. In regard to the question of whether outside experts are to be consulted, this is determined by the degree to which the company staff is engaged and most of all on the choice of a competent group of employees.

The planning phases are set up logically. Only in rare cases will it be possible to work through the individual stages successively. Changes are often called for in previously completed planning phases. Such retroactive steps can include, for example:

- During technical detailed planning, the planner notices technical details that call the overall concept into question; example: explosion protection for the AGVs needed (5.2.2 ≥ 5.2.1).
- The economic and business considerations are not accepted by company management, the concept must be altered (5.2.2 ≥ 5.2.1).
- Market analysis does not conform to the product concept catalog (5.2.3 ≥ 5.2.2).
- The offers do not meet the accepted budget plans (5.2.3 ≥ 5.2.2).

- Operating costs are too high due to certain special technical details (5.2.4 ≥ 5.2.2).
- The calculated investments for replacement and expansion are unacceptably high (5.2.5 ≥ 5.2.1 or 5.2.2).

5.2.1 Designing the System

The goal of this plan is to reach a decision to use AGVS. If the results of the conceptualization turn out against AGVS and in favor of another means of conveyance, then AGVS planning ends right here. At this point, the criteria should be named which, upon assessment, speak "for or against" an AGVS.

5.2.1.1 Current-State Analysis

The primary goal of a current-state analysis is to generate preliminary data for planning as well as identifying weak spots. The information gathered from the current-state analysis serves as a basis for all the subsequent planning and realization stages.

To ensure that planning produces future-proof material flow systems and forms of organization, the highest demands are placed the current-state analysis:

- Delineating marginal conditions
- Recognizing existing potentials
- Plausibility checks
- Transparent portrayal of working procedures
- Providing key performance figures for optimizing material, information, energy and personnel flows
- Compiling information with the maximum information density
- Guaranteeing highest possible planning security.

The planning principles compiled from the current-state analysis provide the planner with a pool of vital performance figures, provided that the scope of the current situation is clearly defined, and that appropriate methods and aids are used in obtaining data.

5.2.1.2 Needs Analysis and Conceptualization

The need for a new solution arises from future demands, past experiences and the current-state analysis.

- The past: collected experiences
  This point does not play a role in planning new systems. Otherwise, extensive experience could be gathered from the existing, non-AGVS solution. These are

both quantifiable experiences that can enter into the current-state analysis as well as qualitative experiences related to the acceptance and relevance of the technology used.

- The present: current-state analysis
  The current-state analysis is an official compilation of the situation at hand and an important source of data for documenting the project.
- The future: Planning data for company growth
  Firstly, it is important to coordinate reliable planning data in the form of planning parameters. This must take place with all key positions in the company. It is often the case that technical planning is at cross purposes with the actual requirements, since planning data change as the project develops, making it important to note these at the start and during the course of every project.

And finally, each planning stage has a groundbreaking character. Various solution concepts are worked through and compared with each other. Typical questions posed are:

- Degree of automation
- Interval lines, island concept or flowing line
- Location of the materials, logistics concept
- Technical equipment for manufacturing facilities, loading devices.

A material flow simulator can be helpful here.

When planning foresees a significant increase in the degree of automation arising from the project, then the needs analysis should not hesitate to take on visionary aspects. These can include formulating overall goals which are initially not assessable in a monetary sense:

- The forklift-free factory (no damages caused by conventional forklifts)
- Cleaner, more orderly production area
- Process safety through controlled working steps
- Positive image for customers and partners
- Value added to location through improved quality, output and reliability.

5.2.1.3 Marginal Data

The AGVS checklist from the VDI[2] assists in collecting marginal data. The completed AGVS checklist serves to fully compile all relevant data required for the product concept catalog. It is divided into:

- General description and task designation
- Conveyed goods, conveyor aids and loading unit

[2] VDI 2710 Page 2. “AGVS Checklist – Planning Aid for Operators and Manufacturers of Automated Guided Vehicle Systems (AGVS)”.

- Load provision
- Layout
- Material flow with source/sink matrices
- Energy system
- Guidance control with analysis of information flows
- Surroundings
- Special requirements.

The AGVS checklist can be used to aid planning for operators and manufacturers of automated guided vehicle systems (AGVS). It contains a catalog of all relevant planning data to describe the planning task and the planning environment. This checklist contains all the information that the AGVS operator on one hand will need to compile later in order to achieve clarity on the planned use and organization of and on the other hand to give the manufacturer detailed information about the requirements profile of the conveyor equipment.

We refer to this guideline. Although it has been written for AGVS, it can be used for other technologies by adapting the details.

5.2.1.4 Choice of System

The data on which to base a choice of system are made up of the marginal data and the needs analysis. These aid the basic deliberations regarding the planned procedures. Examples of these basic considerations can be:

- Desired degree of automation
- Logistics concept
- Choice of loading aids.

Finally, the conveyor system must be selected. The choice is to be made based on both technical and economic considerations.

Technical system selection A further VDI guideline[3] helps in making the proper technical choice of conveyor system. It aids the logistics planner in the technical choice of a conveyor system. It guides the planner by disqualifying those types of conveyor equipment that do not fulfill requirements and lists all the conveyor systems that are appropriate. The guideline ensures that all current conveyor systems are taken into consideration. By describing the key traits, characteristics and suitabilities of the means of transport, it gives the planner vital suggestions for making the right choice, allowing the planner to assess all currently used conveyor systems.

The guideline also includes an Excel tool which converts all the tables found in the guideline, making it easier to use. The definitions and explanations of the principles by which they are interlinked as well as the relevant marginal data are

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[3] VDI 2710 Page 1. "Interdisciplinary Design of Automated Guided Vehicle Systems (AGVS) – Decision-making Criteria for Selecting a Conveyor System".

presented in the guideline. This Excel tool is amazingly simple, and is not just conceived for the experienced AGVS professional but also for those who are new to the topic, and is very well suited as a training tool.

Economic choice of system The VDI guideline VDI 4450[4] is also recommended to aid in the economic aspect of selecting a system: It is primarily addressed to investment planners whose task it is to make an interdisciplinary assessment of the economic viability of automated guided vehicle systems. The expanded economic viability analysis consists of an economic viability calculation section plus a cost-benefit analysis and an overall assessment section. It is suited for automated guided vehicle systems and other investment goods that are notable for high procurement costs, long service life and numerous qualities that cannot easily be assessed monetarily, if at all.

An overview names and explains various cost types for a detailed economic viability calculation, including aids in determining benchmarks for cost categories. An example is given of dynamic processes used in economic viability calculations. The cost-benefit analysis then integrates these criteria into the expanded economic viability analysis that cannot be qualified monetarily, or only at unjustifiably great expense. The guideline is structured so as to display them as such. Finally, it demonstrates how to make an overall analysis based on the results of the economic viability calculation combined with the cost-benefits analysis.

Since the expanded economic viability analysis requires a great deal of calculation, especially with dynamic processes, a computer program is included that independently performs the calculations once the data have been entered. Economic viability analyses of one to three alternative types of conveyor equipment can be enumerated and graphically displayed. They are divided into investments, direct and indirect costs, and additional benefits (see Tables 5.2, 5.3, 5.4 and 5.5).

Table 5.2 Investments in an AGVS calculation

Position	Description
AGVS	Vehicles, guidance control system, floor installations, project-related services
System periphery	Load transfer stations, buffers, to the extent that they are calculated as part of the AGVS and not the stationary conveyor equipment
Construction measures	Floor repairs, protective equipment, adapting fire doors, bridges and ramps
Integrating into existing structures	Interfaces to parallel, subordinate or overriding guidance controls, Integration of automatic scales, scanners, etc.

[4] VDI 2710 Page 4 “Analysis of the Economic Viability of Automated Guided Vehicle Systems (AGVS)”.

Table 5.3 Direct costs in an AGVS calculation

Position	Description
Maintenance	The steady and low-impact driving minimizes wear on wheels, batteries, drives
Energy	Basically the share of charging energy for the EVBs!
Operating personnel	Only as relates to transport system; guidance control personnel only
Taxes and insurance	–
Transport damages to product	Automated transport minimizes transport damages. Material, additional work and reworking, and customer damage claims are to be considered
Transport damages to plant fixtures	Such as loading aids, pillars, walls, shelves and gates

Table 5.4 Indirect costs in an AGVS calculation

Position	Description
Personnel costs in neighboring areas	If needed, forklift operators, personnel to make pallets available and for fine distribution
Warehouse inventory	Inventories can be reduced through improvements to information flow and high availability
Material inventories in manufacturing	–
Throughput time	Ordering time can be reduced and the order density increased – increasing effectiveness of production

Table 5.5 Additional benefits of an AGVS

Position	Description
Flexibility and Adaptability	Flexible use of space, adaptability to fluctuations in transport, material flow and layout changes
AGVS as means of organization	Guidance control provides optimal material and information flow, providing more transparency
Minimizing incorrect deliveries	Automation provides for absolutely reliable transports and a high degree of process safety
Safety	AGVS works safely and accident-free
Orderliness and cleanliness	Stress is reduced, leading to a pleasant surrounding atmosphere
Availability and Continuity	AGVS works unspectacularly, without interruption, and without bustle
Ecological benefits	Low noise level, no emissions, low energy use
Idea-based benefits	Exemplary manufacturing, positive internal and external image, technological advantage

In addition to the procedures used in VDI 2710 page 4, the following methods are also commonly used:

Return on Investment considerations (ROI) The concept “return on investment” (ROI) means, in financial terms, the relationship between the cost of capital for an investment and the income that it generates. This relationship can be related to a definite period of time or cumulatively for the entire lifespan of an investment. Other costs to be considered include those for dismantling and disposing of equipment, which can retroactively diminish profitability. When defining the ROI, the overall framework should be considered (time period, which costs are to be considered, etc.). Companies usually have their own internal guidelines.

In common use, “return on investment” applies to the payback period, that is, the time that it takes for the total income generated by the investment to cover its initial investment amount.

Total Cost of Ownership (TCO) When comparing various solutions to a technical issue, it has become increasingly necessary to undertake a deeper assessment of the costs. If, for example, only the costs are considered for two acquisitions with equal technical performance, then more consideration must be given to the monetary effect connected with the measure, in order to find an optimal solution based on all the indirect costs arising from the decision.

The “total cost of ownership TCO” method expands the point of view past the investment costs alone and makes it possible to define and quantify subsequent costs, as well as offering leverage points for cost optimization and contract negotiations.

When planning automated guided vehicle systems (AGVS), the relatively high level of investments means that the economic viability assessment for the system plays a decisive role. The arguments in favor of using an AGVS arise on one hand from the low operating costs and on the other hand from considerable additional benefits. These additional uses, such as the high degree of reliability in delivering the transported goods, are often impossible or difficult to qualify in a monetary sense. But since they are a key factor in determining the economic viability of the conveyor system, they cannot be excluded from an economic viability analysis.

Important: Once the system has been finally planned out, the results of the economic viability calculation should be checked again, as the degree of detail will be much higher than it was previously.

5.2.2 Planning Out the System

The goal of this phase is to plan out the project in detail and to produce a comprehensive product concept catalog as well as to adapt the economic viability of the system within the company and to re-evaluate. A simulation is helpful for complex systems. The AGVS-specific aspects will be discussed here briefly.

Planning out the system includes one key aspect that is unfortunately often neglected: promptly coordinating activities with insurance associations and trade supervisory authorities. The advisory authorities (internally and externally) should be drawn into the planning regarding work protection and safety right away.

5.2.2.1 Simulation

Simulation involves recreating a system along with its dynamic processes in a model that can be experimented with in order to gain knowledge that can be carried over into reality.[5] In contrast, static considerations use average values, e.g. throughput times, capacity utilization, speeds, etc. Dynamic simulations use much more complex distributions with temporary fluctuations and interactions. In addition, random number generators are used to recreate sudden and unexpected events.

A process simulation models the entire material flow process chain. It captures and presents useable results for the three following areas:

- Production planning: material flow and production guidance, setting intervals, working hours models and resource planning
- Works logistics planning: supply concept, layout and resource planning
- Supply chain planning: choice of suppliers, JIT/JIS concept, supply chain (Fig. 5.1).

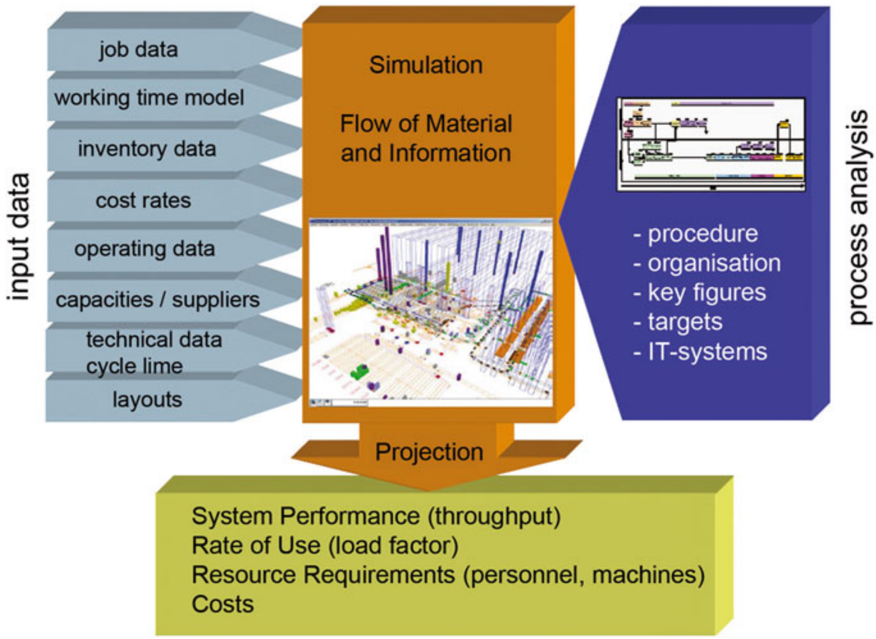

Fig. 5.1 Simulation of goods transport systems (*Source* SimPlan)

[5] VDI 3633: and VDI 2710 Page 3 Simulation of Logistics, Material Flow and Production Systems, March, 2000" and VDI Page 3 "Areas of Use of Simulation for Automated Guidance Vehicle (AGVS)".

Based on the AGVS, the simulation can provide the following results:

- Auditing the logistics concept (Performance and capacity utilization)
- Optimizing dispatching strategies in layout or guidance control versions
- Number of AGVs
- Scaling the load transfer and storage sites.

The advantages of a simulation in advance of realization are time and cost savings, increased planning safety, and thus reduction of the entrepreneurial risk. In addition, it also produces the following side benefits:

- Creating a common database for all parties involved in the project
- Transparent and verifiable bases for discussion during
- 3-D animation and to-scale overview of the entire system.
- Each simulation has its basic limits and weaknesses. Their results are determined by the initial entry data. If these are incorrect or incomplete, then faulty simulation results are pre-programmed. Not all eventualities or exceptional events can be considered. Thus it is necessary to warn against overinflated expectations at this point.

5.2.2.2 Technical and Organizational Delimitation of the AGVS

The so called worst-case scenario is a tested means of checking planning assumptions. It involves assuming disruptions of neighboring equipment and peak performance of production machines for a defined period of time. They can, on one hand, lead to a high demand on AGVS performance or, on the other hand, call for organizational solutions. This means that these exceptional circumstances can be countered with an increased number of AGVs or, for example, with a calculated number of buffer sites.

It is important to think through all eventualities, especially when the overall logistical process is highly dependent on the AGVS. This is the right moment to consider the possible breakdown of system components, not only the AGVS, but also its periphery.

It might sound a bit hackneyed, but it is true: an AGVS never breaks down. Electrical supply for certain operating areas might be disrupted, or a computer, or a computer network (LAN or WLAN), or an AGV. But never the entire AGVS.

The idea then is to enumerate the individual chances for a breakdown and to assess the consequences. If the consequences are too serious, then a plan B is needed. This could be, for example:

- A crashed PC (primary system), one which runs the AGVS guidance control (or parts thereof), needs a “warm standby” backup system. That means that there is another secondary computer that runs parallel in the background and assumes the tasks of the primary computer in the event of a disruption.
- Networks must be set up according to the rules of modern IT systems, which is a topic not exclusive to AGVS.

- The breakdown of an AGV should be planned in. In systems with multiple vehicles, the breakdown of a single AGV should not lead to the entire AGVS being unable to provide its required level of performance. Or an emergency strategy must be conceived – if needed, with support from manually operated forklifts.

In this case, it is up to the operator, that is the client, to verify whether or not the hardware for the guidance computer level as well as the networks (LAN and WLAN) should be provided by the company, since that would mean that its system and data security is integrated into the company's IT system and does not involve a non-secure parallel system.

In addition, the peripheral interfaces between the AGVS and the outside world must be considered. These include the active load transfer stations, elevators, automatic doors and gates, as well as all the IT interfaces, for example, from systems that provide the AGVS with its transport orders. All of these interfaces must have bypass strategy at this point in time.

5.2.2.3 Technical Detailed Planning

Technical detailed planning means going in and sounding out the equipment to be used. Numerous suggestions can be found in Chap. 3. The following section simply points out a few specific aspects of technical detailed planning.

Layout planning This involves defining the initially rough layout (see marginal data). In addition, the material flow relationships, the transport volume, the transport times and conditions in the production environment are to be considered. A layout should in any case be the basis of the invitation for bids, or it should be created by the supplier as part of his offer. It is advisable to define the direction of traffic.

Right-handed traffic is generally used so that the other participants in traffic can adjust more easily to the traffic movements. A good layout is noted for its simplicity. This means one-way traffic as well as organizational separation of works vehicles and visitor traffic, as well as a minimum of intersections.

Determining the number of vehicles For simple applications, the number of vehicles can be calculated based on the source/sink matrix, as already established in the marginal data. The VDI guideline 2710-2 describes a simple method for calculating the number of vehicles based on a transport profile. Along with the source/sink matrix, the number of working shifts, the operating times and the turnover times for transported goods are needed.

A simulation is a good idea for more complex applications. There are various systems and suppliers for this available on the market. To calculate the number of vehicles, the following conditions are to be defined at the start of the simulation: number of working shifts, operating times, break times, turnover times for the transport goods, possible conveyor speeds, degree of blocking, energy concept, operating concept, repair strategies and technical availability. The layout should be defined, and there should be an emergency operating concept. Depending on the operating concept, additional vehicles should be kept in reserve (repairs and maintenance).

Having too many AGVs increases the price and can even be the deciding factor against the AGVS project. Therefore it should be checked to see if

- peak performance times can be mediated through buffer sites or intelligent guidance and/or
- individual vehicle breakdowns can be compensated for over the short term by other means of conveyance.

One interesting question in this context relates to the person who determines or takes responsibility for the number of AGVs. This can be the user, the planner or the AGVS supplier. In order to compare offers, it is certainly helpful to establish a set number of AGVs. Then the user or planner is responsible for meeting the required level of AGVS performance. If meeting performance criteria based on a transport mix is a key component of the product concept catalog, then the AGVS supplier making the offer is responsible. Then the number of AGVs can vary from offer to offer. Wherever responsibility lies for each project, it is important that all involved parties are made aware!

AGVS-friendly building planning AGVS-friendly building planning can come in one of two possible versions: planning into a new building (greenfield) or integration into an existing building (brownfield).

In the case of greenfield planning, the needs of AGVS technology are to be met by integrating the demands as early as possible. The design of flooring, building pillars, building heights, facades, energy requirement, media, etc., can be adapted to meet the needs of an AGVS. In brownfield planning, the existing conditions can only be adapted to fit.

An AGVS-friendly floor is of principal significance for the safe and uninterrupted operation of an automated guided vehicle system. Its characteristics are described in Sect. 3.4 and are to be observed during construction of new floors. When existing floors do not meet all these criteria, this has to be coordinated with the AGVS manufacturer as a matter of immediate priority.

The following norms and guidelines are decisive in planning the traffic routes:

- Workplace Ordinance
- Workplace Guideline ASR 17/1,2
- DIN 18225 Traffic Routes in Buildings.

If the prescribed safety tolerances and security measures cannot be met, this has to be coordinated with the responsible insurance associations and/or the work safety/trade commission offices. It can be the case that special areas or rooms are necessary for AGVS operations. These can include battery charging stations, service and maintenance areas. Further details can be found in the VDI guideline 2510-1.[6]

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[6] VDI 2510 Page 1 “Infrastucture and Peripheral Equipment for Automated Guided Vehicle Systems (AGVS)”.

Table 5.6 Technical detailed planning for peripheral equipment

Position	Description
Demands on the application surroundings	Surrounding conditions
	Composition of floor (to be determined early on!)
	Traffic routes
Stationary facilities for navigation	Installation of guide lines on floor
	Installation of guide lines and primary conductors in floor
	Installation of floor marking points
	Installation of reflectors
Stationary facilities for load handling	Load transfer stations
	Safety-relevant aspects
Communications systems	Wireless data transmission, narrow/broadband radio (usually WLAN)
	Infrared communication
	Other
Stationary facilities for Electrical energy supply	Maintenance and care of batteries
	Stationary energy supply facilities
Stationary safety equipment	See Table 3.8
Peripheral facilities, building facilities	Doors and gateways
	Fire doors
	Elevators
	Lifts/vertical conveyors
	Crane equipment
	Track-mounted vehicles/sub-floor systems

Infrastructure and peripheral facilities More detailed information on this complex topic can be found in Sect. 3.4. Table 5.6 shows those places where AGVS-related demands are placed on neighboring equipment.

Especially integrating the AGVS guidance control into the periphery can lead to unexpected costs. The interconnection with fire doors and elevators is often not standardized and will require additional cost and effort as well as more administrative approval (Fig. 5.2).

Material flow guidance This refers to the interaction between the AGVS guidance system and the host level, namely the computer environment which provides the AGVS with transport orders. Material flow control means receiving and controlling the transport activities and processes with the goal of managing the transport volume using intelligent rules, but with the lowest possible number of AGVs. It is an important factor because it has an immediate influence on the number of vehicles needed. With an increasing degree of automation, demands on material flow guidance also increase. We refer here to Sect. 3.2 and the VDI guideline 4451 Page 7 “AGVS Guidance Control”.

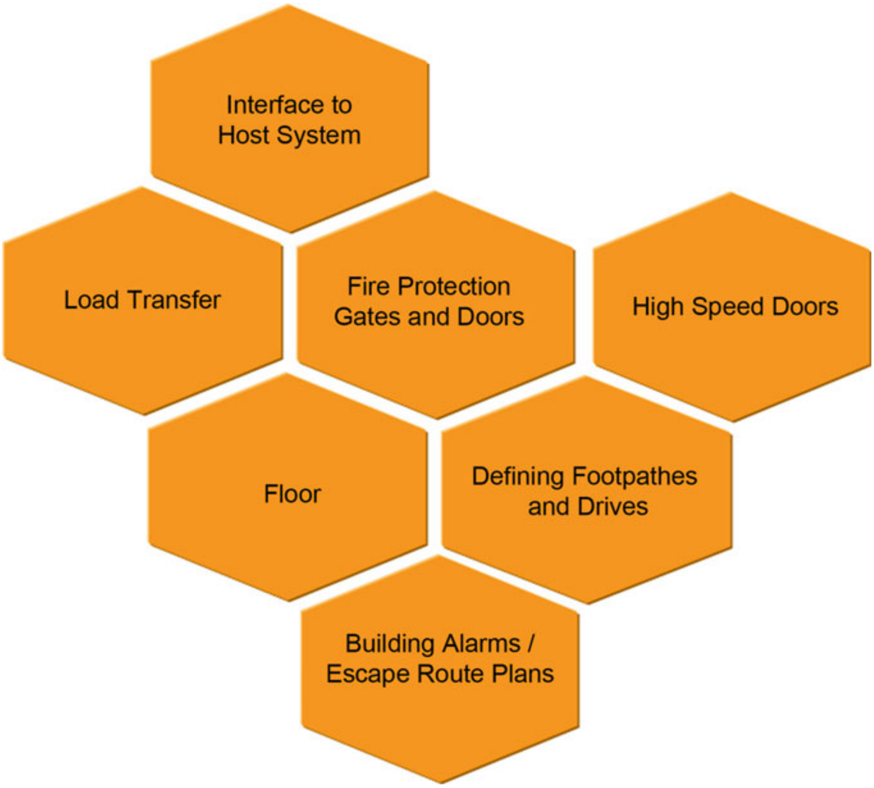

Fig. 5.2 Key interfaces as “mosaic pieces” of successful planning (*Source* Siemens [Kohl, H.: *FTS-Planung aus Sicht des Betreibers*. “AGVS Planning from the Operator’s Point of View” Presentation held at the Logimat Trade Fair, Stuttgart, March 5, 2009, Siemens AG, Industry Sector, Frankfurt am Main])

5.2.2.4 Product Concept Catalog

The product concept catalog is oriented on the results and describes all the required goods and services to be provided by a contractor. Basically, the client should be the one to formulate the product concept catalog. It then serves as the basis for an invitation to bid. In the meantime, the product concept catalog is also referred to as a bill of quantities (BOQ).

It is still common, however, that potential contractors prepare a product concept catalog themselves in coordination with the client. This has a great advantage for the contractor, making it possible for him to define the goods and services himself. But the client is then subject to the risk that the goods and services agreed on do not fully meet his own needs.

The product concept catalog should include the following points:

- Specification of the product to be supplied
- Requirements for the product's subsequent use
- Key conditions for the product and how services are to be provided
- Contractual terms
- Requirements for the contractor
- Requirements for the contractor's project team
- Acceptance procedures.

The formal procedure is for the contractor, after receiving the product concept catalog, to convert the results (requirements) into necessary activities (obligations) and then to prepare the so-called performance specification. The invitation to bid documentation contains a description of the goods and services to be delivered. The documents should reflect the commercial, organizational and technical requirements for the project.

- The commercial section regulates the following: general terms and conditions, basic principles of creating an offer, the form of the offer, pricing, terms of payment, invoicing, on-site measurements, cost auditing, contractual terms, property and usage rights, claims for defects, liability, scope of offering, etc.
- The organizational section should cover: procedural plan for project, project execution, start of project, approval phases, installation, electrical work, start-up, construction site setup, technical clearance, performance test, availability test, transfer of risk, test run, acceptance, safety, dates and schedule, etc.
- The technical section should cover: project-specific requirements such as operating times, intervals, equipment design, construction measures, project planning, scope of goods and services, delimitations between mechanical and electrical equipment, definition of interfaces as well as legal regulations to be observed, such as norms, guidelines (company) specifications.

In addition, we refer to the VDI guidelines 2519 page 1 *Vorgehensweise bei der Erstellung vonLasten-/Pflichtenheften*: “Procedures for Compiling Product Concept Catalogs and Performance Specifications” and VDI 2519 page 2 *Lastenheft/Pflichtenheft für den Einsatzvon Förder- und Lagersystemen*: “Product Concept Catalogs and Performance Specifications for the Use of Conveyor and Warehouse Systems”. See also Sect. 5.2.3.4.

5.2.2.5 Final Economic Viability Assessment

Along with the product concept catalog, the project documentation should also contain an economic viability calculation. The company has its own adapted calculation formulas and consideration that are to be used for the project. Specific key figures are calculated as a result, which have to lie within certain established limits. To the extent that these methods were already used in the “system selection” planning stage, they have to be finalized in line with the detailed planning.

We also refer to the section “Economic choice of system” in Sect. 5.2.1.4.

5.2.3 Procurement

Within the planning phase, an invitation for bids must be made and the AGVS has to be procured, then it is installed and started up by the contractor. At the end of the process, it is accepted, and the installed equipment is transferred to the operator.

5.2.3.1 Analysis of the Supplier Market

This planning stage determines whether the right suppliers are addressed. Usually there is no explicit planning process, but rather a project preparatory or project accompanying process. Trade publications are studied, major technical trade fairs (such as the Hannover Messe[7] or the Logimat[8] in Stuttgart) and conventions/congresses (AGVS-specialist convention[9] in Dortmund, the IPA Technology Forum, Stuttgart or The Material Flow Congress[10] in Garching) are visited, or research is done in the Internet. The pages of the AGVS Forum[11] website list the members of the European AGVS community.

5.2.3.2 Invitation to Bid

The basis of the invitation to bid is formed by the product concept catalog described above. The more completely and carefully it is compiled, the easier it is to assess bids and award the contract.

An established price list that covers all of the project components, categorizes and assigns individual pricing positions is helpful. A rough subdivision for an AGVS would look something like:

- Battery-powered vehicles
- Floor equipment and periphery
- AGVS guidance control system
- Project-related services.

After a market analysis has narrowed down the number of suppliers to approach, it is usual to try to obtain three independent offers. In this context, reference visits are recommended. The three suppliers on the short list are asked to organize a reference visit with one of their customers where there is similar or comparable system in use. Consultations with the operators are an important source of information.

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7 www.hannovermesse.de/industrial_automation.

8 www.logimat-messe.de.

9 www.fts-fachtagung.org.

10 www.materialflusskongress.de.

11 www.forum-fts.com.

Table 5.7 Positions in a bid assessment

Position	Description
Technical section	Overall solution (weighted)
	System components
	General contractual requirements
	Vehicle technology (AGV)
	Transfer stations/parking places
	Battery charging stations
	Functionality of the AGVS guidance control system
	Interfaces to host systems, infrastructure and future systems
	Service
	Options
	Project management
	Schedule
Commercial section	Investment
	Total cost of ownership and/or ROI calculations
	Energy costs
	Spare parts prices/fixed prices
	Terms of payment/sureties, guarantees
	Warranty period and conditions
	Transfer of operating safety risk (emergency strategies)
Soft skills	Style of response to invitation to bid
	Reference visits
	Supplier ratings
	Low-impact load transport
	Operator concept
	Appearance of product
	Innovation

5.2.3.3 Bid Assessment and Awarding Contract

Key points for assessing bids and awarding a contract are listed in the following Table 5.7. The client's own situation is the essential factor. The table serves to help make the bids comparable and to achieve a uniform assessment. In doing so, both the technical and commercial aspects of the scope of offering are evaluated.

The process for awarding a contract can vary, depending on the industry or the company itself. In most industries, negotiations are common before awarding a contract, for public institutions, bids must be submitted. Bidder interviews are becoming more common. Alternatively, online bidding events are held.

After a contract has been awarded, the order is formulated in the form of a contract and accepted with a notice of confirmation from the contractor.

5.2.3.4 Functional Specifications

These terms are defined and further suggestions are given in the VDI guidelines VDI 2519 page 1 “Procedures for Compiling Product Concept Catalogs and Functional Specifications Documents” and page 2 “Product Concept Catalogs and Functional Specifications for the Use of Conveyor and Warehouse Systems”.

The product concept catalog (see also Sect. 4.2.2.4 “Product concept catalog”) lists all the client’s requirements regarding the scope of goods and services to be provided. It describes the user-side requirements including all marginal conditions. The product concept catalog answers all questions regarding WHAT and WHY. The functional specifications gives answers to questions regarding HOW and WHAT IS TO BE USED.

The functional specifications describes how the requirements in the product concept catalog are to be met. The contractor lists the conditions given by the client in detail and offers conditions to realize them. While the specifications for the requested AGVS form the key component of the product specification catalog, the functional specifications describes how the contractor is to provide the services. This makes the project structure plan the less critical component of the functional specifications. It should include the scheduling and resource plans. For time-critical projects the scheduling forms a binding part of the contract (contract time schedule).

It is advisable to divide the functional specifications at least into a legal/organizational section and a technical/specialist section. Functional specifications and product concept catalog should be integral parts of the contract between the client and contractor.

For large-scale projects with multiple partners, the product concept catalog and the functional specifications should be signed by all partners involved. For critical projects, it is recommended to have the documents notarized so that any issues arising later can be resolved with clarity.

In many cases, presenting a functional specifications catalog is seen as the first task to be completed during the realization phase. The problem here lies in the fact that a project “lives and breathes”, meaning that theoretically the contents of the functional specifications catalog need to be continually adapted. Here a clear deadline must be set, one that lies no later than 6 weeks after the start of the project.

5.2.3.5 Realization

The project can start after a written order has been issued by the client and written order confirmation has been received from the contractor. A project meeting is to be held at the start of the project, at which the client and contractors present their project managers and project organizations. Organization procedures for the projects, established deadlines, communications channels, protocol procedures between client and contractor are to be coordinated. The coordinated comprehensive schedule is to be discussed and approved.

The procedure for technical resolution with approval documents, sampling, procedures for broadening or narrowing the scope, change services or version management (drawings), creating a technical specification document, CE[12] documentation, hazard analysis, determining layout, integration into surroundings and the production area are to be defined.

For more complex systems, it is recommended to plan and construct models and test equipment. As part of an FAT (factory acceptance test) it makes sense to hold the pre-acceptance of vehicles at the contractor's, the subsequent SAT (site acceptance test) at the client's site.

For fixed technical equipment, the construction site phase is then divided into mechanical assembly, electrical assembly, start-up and test operations. Depending on the equipment used, when installing an AGVS it can be a lot easier when, for example, the supplier provides complete and ready-to-operate vehicles so that mechanical installation is reduced to merely "unpacking".

Start-up Start-up follows directly upon completion of mechanical assembly and electrical installation. At this point the contractor should request that the client compile a list of defects. The following measures are conducted during start-up: functional testing (such as E/A tests), aligning software, setting software parameters step-for-step, starting up individual components of the overall system, equipment operating instructions, initial safety equipment start-up, safety instructions for all participants.

Once start-up has been completed, a functions test of the equipment under production conditions should be conducted. By this point, all CE documentation, including the declaration of conformity, should be completed, as it comprises a key component of the documentation.

The functions test is then followed by test operations. During test operations, the AGVS is used for the first time under the client's production conditions using the actual goods to be conveyed. This is then followed by the start of production.

Approvals Approval planning must in principle commence much earlier. The corresponding requirements should already be present in the product concept catalog and subsequently in the technical specifications document. In any case, many necessary certifications are only granted after operations have started, so that the planning step is described at this point. The marginal conditions for AGVS safety are determined by the following laws and regulations etc.:

- Machine guidelines, DIN norms, VDI guidelines, VDE provisions
- Safety guidelines
- Workplace regulations and workplace guidelines
- Guidelines from commercial insurance associations
- Guidelines from the Property Insurers' Association

[12] CE F03D Conformite Europeenne: in conformance with EU guidelines, a part of EU conformity according to the Machine Guidelines.

The applicable organizations and institutions are responsible for ensuring observance of the laws, regulations and guidelines etc. This applies for acceptance of the equipment and monitoring operations. In Germany, the following institutions are chiefly responsible:

- Government oversight authorities
- Commercial insurance associations
- Technical monitoring bodies
- Independent experts.

The development of provisions for safety equipment is made more difficult by the rapid changes in technology and the highly varied nature of AGVS. This makes it all the more important to involve the responsible work safety organizations in the planning process. This makes AGVS accident safety a task for the vehicle manufacturer, the planning team and the operator. The goal should be to work in a coordinated manner.

The existing guidelines must be considered in the planning phase and not put aside until the realization phase. Anything missed out will have to be changed retroactively with additional cost and effort. This is why the performance specification should contain a detailed description of the vehicle and plant-related safety package. At the same time, the applicable regulations, laws, guidelines, etc., should be included in the process.

For automated guided vehicle systems, the infrastructure for works vehicles, especially DIN EN 1525, should be sufficient. This regulates things such as the requirements for the works vehicles (stability, warning systems, recognizing persons on the drive path, emergency stop equipment), start-up testing and operating information. Certification may be required for fire and explosion protection, emissions protection or construction permits. These are to be verified in individual instances.

At this point we must take the liberty to point out that the AGVS project must achieve CE conformity, which takes the AGVS with its entire surroundings into consideration. All interfaces, especially those to stationary conveyor equipment, must be subjected to a risk assessment and integrated into the CE conformity.

Acceptance The guarantee period for defects claims commences with formal acceptance according to the BGB.[13] Standard practice is to accept the equipment only after

- significant or function-impairing defects have been corrected
- CE documentation including the CE declaration of conformity has been presented for the entire system
- performance and availability tests have been conducted
- an additional/reduced cost report has been compiled
- all official certification and approval has been granted.

[13] BGB = (German Civil Code).

The acceptance protocol which covers all this is to be signed by all participants. Further specifics for acceptance of automated guided vehicle systems are described in the VDI guideline 4452 *Abnahmeregeln für Fahrerlose Transportsysteme* (*FTS*) “Rules for Acceptance of Automated Guided Vehicle Systems (AGVS)”, which is referred to here. It describes the scope of acceptance as well as the process and the concrete manner of execution.

The appendices to the guidelines are certainly of interest: they provide a schematic diagram for equipment availability as well as an acceptance protocol form.

5.2.3.6 Operation Planning

The goal of this phase is the careful planning of uninterrupted AGVS operation. This includes involving employees in the early phases of the planning process. All employees who will later work with the system should be informed and their concerns heard. Only then will they come to except their automated “colleagues” – a precondition for successful use of an AGVS.

In addition, selected employees must be trained and qualified so that they can later correct problems on their own. These measures must be repeated regularly – especially for new employees.

These training measures also involve mastering emergency strategies. These apply when extraordinary events (such as a fire alarm) arise, but also when equipment that is vital for maintaining production breaks down. These emergency strategies are very application-specific and must be established in advance.

The following points are to be planned and have corresponding budgets put aside for them:

Repair/maintenance Maintenance embraces all service measures that are necessary to maintain or restore the functioning of the equipment, especially repair, inspection and overhaul. This means regular vehicle checks and cleaning as well as replacing worn parts. The service intervals depend on how the client uses the AGV. They are established individually by the suppliers and should be already mentioned in the bid.

Maintenance can be performed by the operator, by the AGVS supplier or by third parties. If the supplier or a third party assumes the maintenance, this is usually regulated by a service contract with a set reaction time. A service contract can, depending on the customer’s wishes, be concluded as a full or partial service contract.

Spare parts supply In order to be able to replace defective parts quickly in the event of a breakdown, an operable spare parts ordering and supply system is needed. The risk of breakdown and disruption for each vehicle, along with its vulnerability to failures, availability and deliverability is established. Based on the assessment, the individual parts are present in various types of warehouses:

- Operator's spare parts warehouse for the most important parts
- AGVS supplier's consignment warehouse at customer's site with high-end parts (optional)
- Supplier warehouse with all standard parts
- Subcontractor's warehouse (OEM warehouse) with all parts.

Safety testing The cyclical safety tests prescribed by accident prevention regulations are also to be conducted by the AGVS operator. If he is not able to do so, then he is to contract the supplier or an external company.

5.2.4 Change Planning

This planning stage is concerned with changes while the equipment is in operation. These can be necessary upgrades to the operating software and hardware or procuring of replacements upon expiration of service life, or also necessary optimizations or expansions such as additional vehicles, expanding the drive routes or integrating new transfer stations, etc.

Changes can be made necessary by the AGVS itself, or also by conditions of use:

Need for change arising from AGVS The rapid development in the area of data processing/guidance/microelectronics requires software updates, SW and/or HW upgrades and/or adaptations to the guidance control. After a certain period, spare parts and know-how are no longer available to the service personnel. At that point, components will have to be switched out.

Need for change arising from conditions of use No matter how professional the planning and system design, changes to the planning data will always arise. Production can be changed or extended, and the AGVS operating area can be expanded. This is truly the hour of the AGVS: in contrast to most other conveyor equipment, such changes to the system can be resolved technically without problems, usually without interrupting operations.

5.2.5 Decommissioning

This planning stage applies to the end of the AGVS. The technical service life usually ranges from ten to twenty years. It depends on how the system has been serviced and the extent to which guidance technology components have been kept up to date. When the end is approaching, company and legal provisions must be fulfilled.

Common reasons for decommissioning are:

- System is outdated: performance/availability/economic viability is not up to standards.

- Maintenance and repairs can no longer be performed rationally. Retrofitting would not be economical.
- There have been major changes to the area of use in the plant, e.g. production has ended.

Before decommissioning it should checked to see if the AGVS cannot be used in another area. Another alternative is to sell or transfer the vehicles to another AGVS user or back to the supplier. Parts of the system can sometimes still be used. Dismantled parts can be used as spare parts for another system.

Basically, Article 49 of the Recycling and Waste Management Act (*Kreislaufwirtschafts- und Abfallgesetz § 49*) is to be observed in storing, transporting and disposing of equipment and components. There is generally no problem with disposing of AGVS components, as there is almost no dismantling work required. They can be disposed of by the company itself, the AGVS supplier or an external company. When this is done by an AGVS supplier, they are most likely to have appropriate concepts for recycling available. The individual materials must be disposed of in accordance with environmental compatibility guidelines.

The following applies for disposal or recycling of batteries: Lead-acid batteries can be subjected to a regeneration process. Nickel–cadmium batteries are only partially recyclable. Both systems must be returned to a special disposal system. The choice of recycling or disposal will depend on the current state of regulations for battery disposal.

5.3 Planning Support

More and more companies are discovering intralogistics as a worthwhile area of activity to optimize quality, processes and costs. Personnel capacities and resources are being increased and experience with intralogistcs projects is growing. On the other hand, there has always been a demand for information and support. Here we would like to list the places to find information and support.

The role of the manufacturer during planning In the age of the Internet it is easy to simply generate a long list of AGVS suppliers who can be contacted by potential customers to request brochures and offers. Is it a sign of a serious AGVS supplier that he always presents a concrete offer?

We have seen that AGVS is no trivial matter and must take into account a wealth of project-related marginal conditions and specifics. If an AGVS supplier starts immediately by requesting all this information, then it would be professionally correct, but might scare off one the other potential clients. If he is quick with an offer for an AGVS guidance control system, a certain number of vehicles and a fixed price for project-related services, then he might meet the initial expectations of the interested client, but would not be giving the matter all due consideration.

In addition, most engineers find automated guided vehicle system technology interesting or even fascinating. This is certainly one reason for the fact that there are more requests than realized projects. The AGVS suppliers – especially the sales and project planning departments – have to carefully husband their resources. This is not an easy task for AGVS suppliers, especially since their product portfolio is more or less limited. Potential customers will always wonder if the products being offered are entirely optimal for their own projects or merely for the supplier.

In any case, a serious AGVS supplier has years of planning experience. He can make best use of them for the following tasks:

- His work is based on collecting marginal data, which are needed to evaluate his project. For this there is the VDI 2710-2, which can be used or adapted if necessary by manufacturers. Such data collections are especially useful for the customer to fix his start of planning so that he can recognize or demonstrate changes during the planning process.
- Choice of vehicle: The loading aids used by the customer as well as the layout and other criteria determine the type of load pickup, and thus the type of vehicle. A classic choice for transporting pallets is between automated forklift vehicle and a piggyback vehicle with lateral pallet pickup from a roller track. Both vehicles have their advantages and disadvantages.
- Calculating the necessary number of vehicles: The number of AGVs needed is a key precondition for an economic viability calculation. It also influences the traffic situation in the plant payout. For this calculation, the AGVS takes the customer's transport and route matrix and uses his know-how about the movement behavior of the vehicles as part of a static spreadsheet, which quickly provides information on the degree of utilization of the equipment based on differing numbers of vehicles.

VDI-Guidelines Since the start of 1987, the Association of German Engineers, *Verein Deutscher Ingenieure* (*VDI*) has had an "Automated Guided Vehicle Systems (AGVS)" specialist committee. This committee has set itself the goal of strengthening the AGVS industry by bringing manufacturers and operators together and serving as a neutral and recognized institution to bring potential users in closer contact with AGVS. It provides basic guidelines with the goal of giving the industry more freedom of action and planning security (Table 5.8). This should make better use of current potentials for use and open up new areas of application (Fig. 5.3).

Reliable and current regulatory guidelines should exist. These are subdivided into the following key points:

1. Describing the current state of the art
   Current regulations are continuously adapted to the state of the art and completed.
2. Creating planning security
   Using the definition of integrated systems planning, the user gains security. He receives assistance in the form of initial consulting, basic information, guidelines, tools and aids.
3. Active Market Communication

Table 5.8 VDI guidelines on the topic of AGVS[a] (equipment and planning)

Guideline number	Title	Date published
VDI 2510	Automated Guided Vehicle Systems (AGVS)	2005–10
VDI 2510 page 1	Infrastructure and Peripheral Equipment for Automated Guided Vehicle Systems (AGVS)	2009–12
VDI 2510 page 2	Automated Guided Vehicle Systems (AGVS) – AGVS Safety	2011–10
VDI 2710	Interdisciplinary Design of Automated Guided Vehicle Systems (AGVS)	2010–04
VDI 2710 page 1	Interdisciplinary Design of Automated Guided Vehicle Systems (AGVS)	2007–08
	Decision-Making Criteria for Selecting a Conveyor System	
VDI 2710 page 2	AGVS checklist – Planning Help for Operators and Manufacturers of Automated Guided Vehicle Systems (AGVS)	2008–08
VDI 2710 page 3	Areas of Use of Simulation for Automated Guided Vehicle Systems (AGVS)	2012–09
VDI 2710 page 4	Analysis of the Economic Viability of Automated Guided Vehicle Systems (AGVS)	2011–07
VDI 2710 page 5	Acceptance Rules for Automated Guided Vehicle Systems (AGVS)	2013–03
VDI 4451 page 2	Compatibility of Automated Guided Vehicle Systems (AGVS)	2000–10
	Energy Supply and Charging Equipment	
VDI 4451 page 3	Compatibility of Automated Guided Vehicle Systems (AGVS)	1998–03
	Drives and Steering	
VDI 4451 page 4	Compatibility of Automated Guided Vehicle Systems (AGVS)	1998–02
	Open Guidance Structure for Automated Guided Vehicles (AGV)	
VDI 4451 page 5	Compatibility of Automated Guided Vehicle Systems (AGVS)	2005–10
	Interface between client and AGVS	
	Guidance control system	
VDI 4451 page 6	Compatibility of Automated Guided Vehicle Systems (AGVS)	2003–01
	Sensory equipment for navigation and guidance control	
VDI 4451 page 7	Compatibility of Automated Guided Vehicle Systems (AGVS)	2005–10
	AGVS guidance control system	

[a] www.vdi.de/FTS

Targeted information such as presentations, publications, lectures, Internet presence and advertising measures help to make the broad public more familiar with AGVS. This includes the AGVS Specialist Convention,[14] which has been held every 2 years since 2012, currently at the Fraunhofer Gesellschaft IML in Dortmund.

[14] www.fts-fachtagung.org.

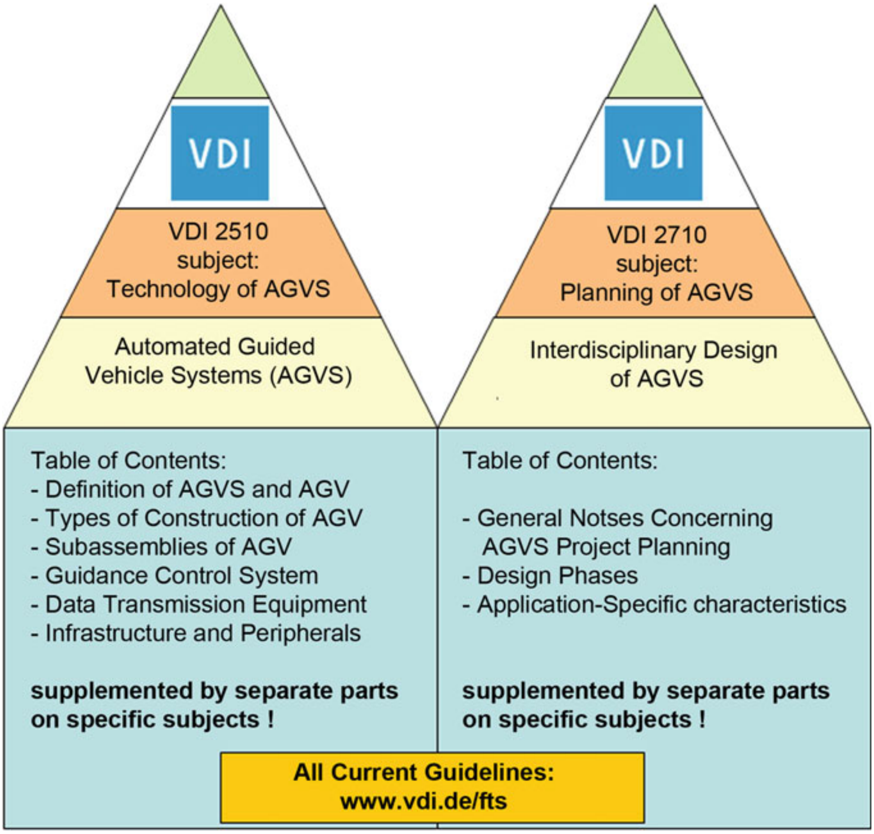

Fig. 5.3 Key topics addressed by the VDI "Automated Guided Vehicle Systems (AGVS)" specialist committee

Forum-FTS (http://www.forum-fts.com)

All of the AGVS manufacturers organized in the VDI founded the AGVS Forum in 2006 as a community of interest for the automated guidance vehicle system industry. The group currently consists of 13 members from five European countries. The AGVS Forum sees itself as a neutral consultant for (potential) users with a neutrally maintained Internet presence.

The AGVS Forum presents itself at trade fairs and exhibitions and undertakes to maintain a voluntary code of honor in its internal interactions and with customers. In the end, membership in the AGVS Forum is a guarantee of quality.

The AGVS Forum's information and consulting offering is not just useful for inexperienced interested parties, but also for experts, since the market is constantly changing:

- AGVS manufacturers vary their profiles
- new technologies appear on the market
- technical guidelines are constantly in a state of flux.

One special offering is an initial AGVS consultation. For a moderate price, it offers initial findings on technical feasibility and economic viability of an AGVS project under consideration. It allows an efficient and neutral start for the project.

AWT Competence (www.awt-kompetenz.de)

AWT is a synonym for "automatic wares transport" – this abbreviation is used exclusively in hospitals and clinics. Modern AWT equipment often uses automated guided vehicle systems (see also Sect. 2.2.7). The AWT Competence Initiative was founded in 2009 for this special, international market; it is a loosely cooperating community of interest made up of four companies which concern themselves with interdisciplinary, manufacturer-neutral planning of AWT systems. This initiative has been registered as a limited partnership (GmbH) since the start of 2013 and has been providing specialist planning for clinic logistics. They are already noted for their sometimes entirely novel approaches and solutions.

And they, too, like the AGVS forum, offer an initial AWT consultation. In addition, they provide all stages for information, planning and realization (Fig. 5.4).

Seminars and training (www.fts-seminar.de) Basic information on the topic of AGVS can naturally be found in this book. But additionally, there are the most varied formats for continuing education. Please refer to the AGVS seminar

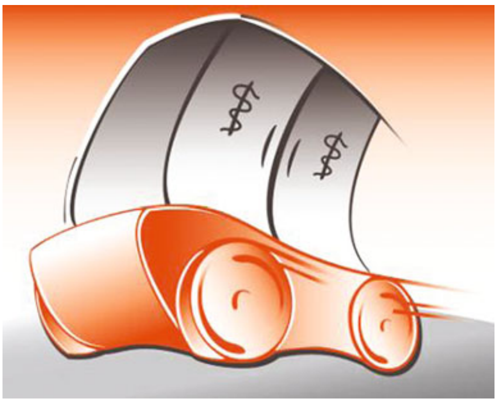

Fig. 5.4 The eye-catcher of the AWT Competence as a dynamic motivator

homepage, which contains a number of suggestions. Here you can book all sorts of seminars, lectures, training sessions, workshops and specials forums. Individualized topics, scheduling, locations and dates are also possible.

Consultation and planning (www.fts-kompetenz.de) And last but not least, the author would like to mention his own consulting activities, which are specialized on the topic of AGVS, and not just potential users (consulting, planning and realization) but can also be of interest to systems or component manufacturers (technology monitoring, market strategies).