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.

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[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.

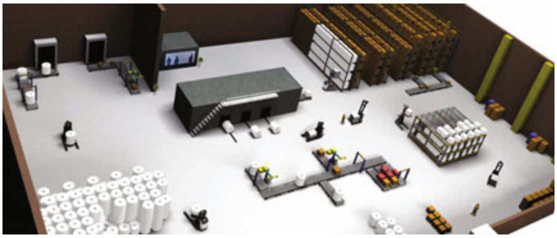

Fig. 2.1 An AGVS connects various processes in paper roll handling (Diagram, *Source* Rocla)

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).

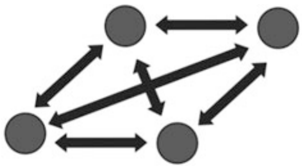

Fig. 2.2 Basic diagram of a taxi operation according to VDI 2710-1 (VDI 2710 Page 1: Overall planning of AGVS Decision-Making Criteria for the Choice of a Conveyor System. VDI 08/2007, Beuth-Verlag, Berlin)

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.

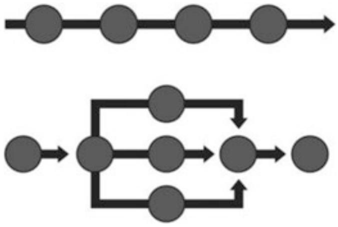

Fig. 2.3 Schematic view of flow line principle, linear and branched (in accordance with VDI 2710-1)

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.

[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).

[5] MTM = Methods-Time Measurement.

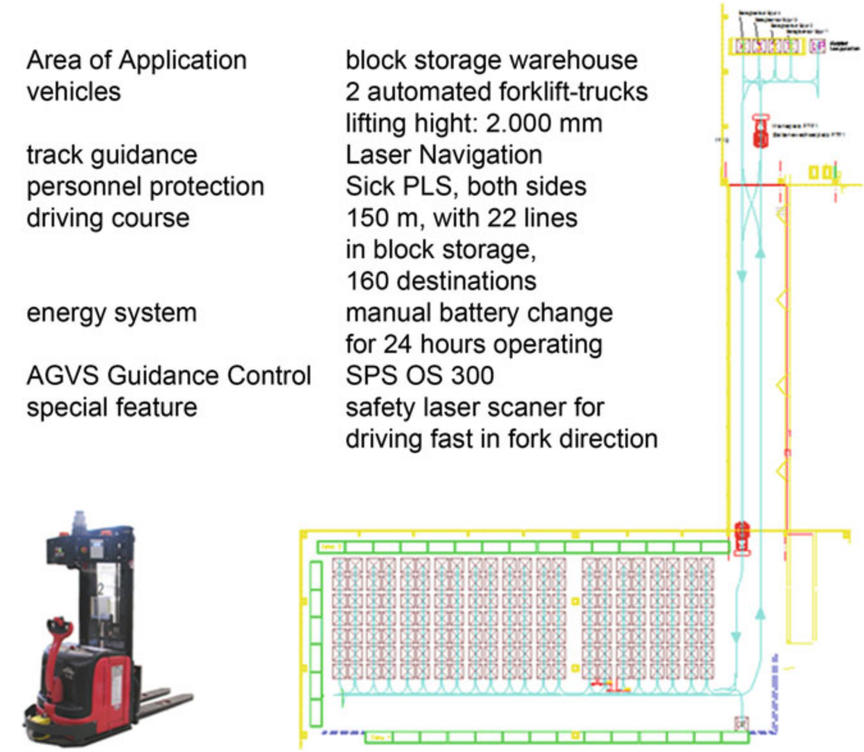

Fig. 2.7 Example of a floor-level block storage warehouse (*Source* E&K 2012)

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.

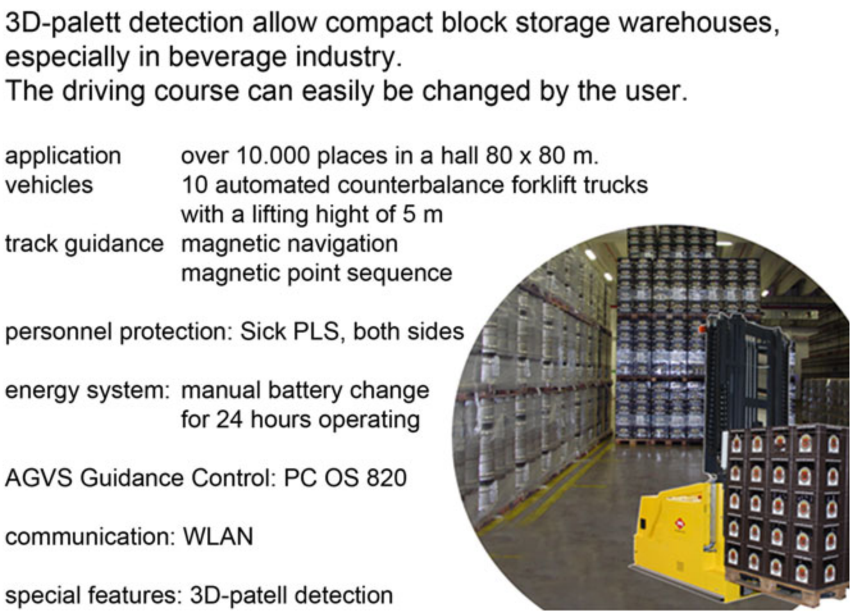

Fig. 2.8 Characteristics of AGVS with pallet recognition in block storage a warehouse (*Source* E&K 2011)

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.

[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.

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[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).

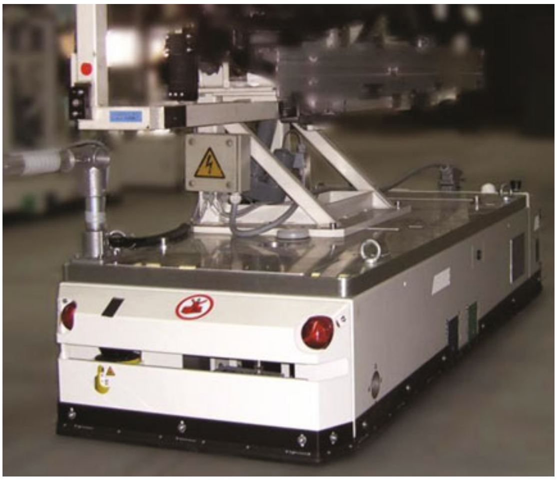

Fig. 2.22 Assembly vehicles at BMW in Dingolfing (*Source* dpm 2011)

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).

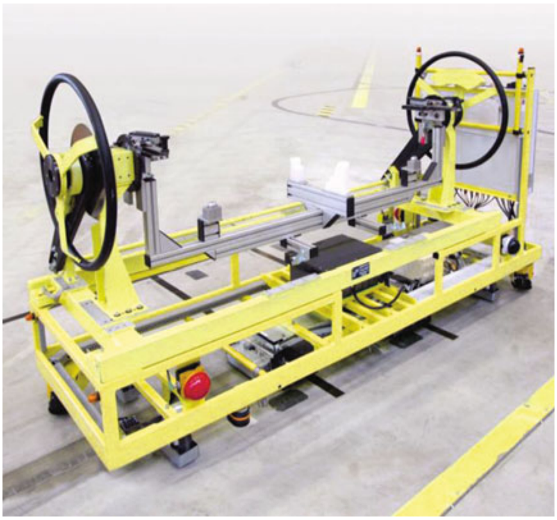

Fig. 2.27 AGVS for assembly and delivery at Daimler in Bremen (*Source* CREFORM 2011)

[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)

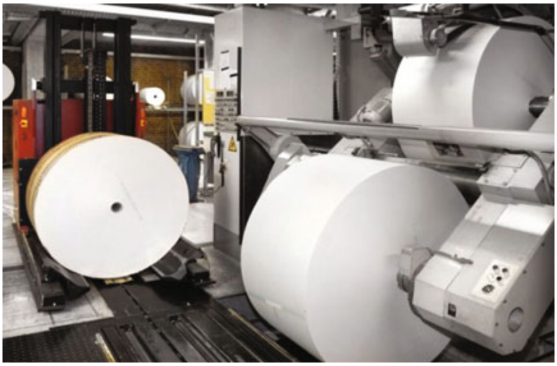

Fig. 2.33 An AGV supplies the roll changer at the printing machine (*Source* DS)

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

[12] HBS = high-bay storage.

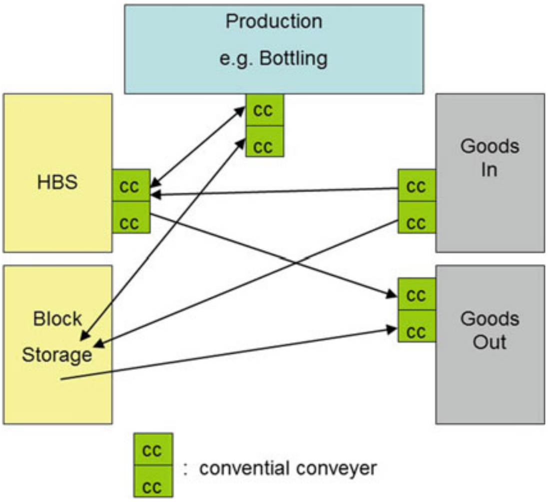

Fig. 2.37 Material flows in a typical brewery (*Source* Ott/Ullrich 2008)

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

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[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".

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[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)

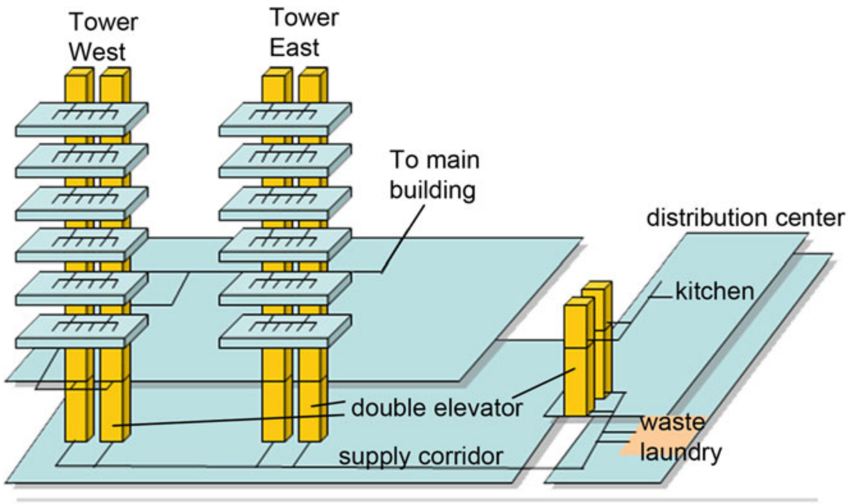

Fig. 2.57 Overview of the AGVS layout (*Source* DS 2010)

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).

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[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).

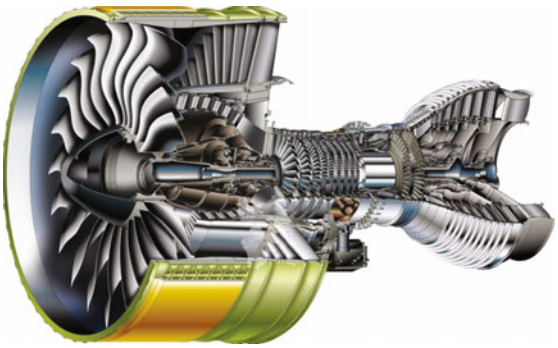

Fig. 2.70 Parts for the GP7000 turbofan engine are assemble in Munich on automatic vehicles (*Source* www.baisi.net)

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)

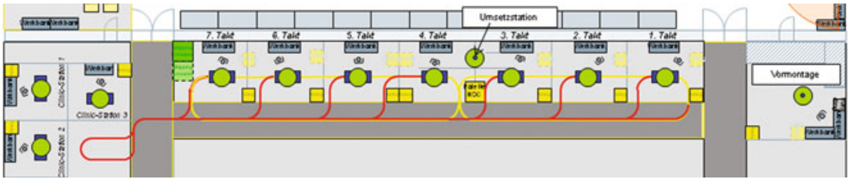

Fig. 2.72 The layout of the assembly line in overview (*Source* MTU Munich)

- 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).

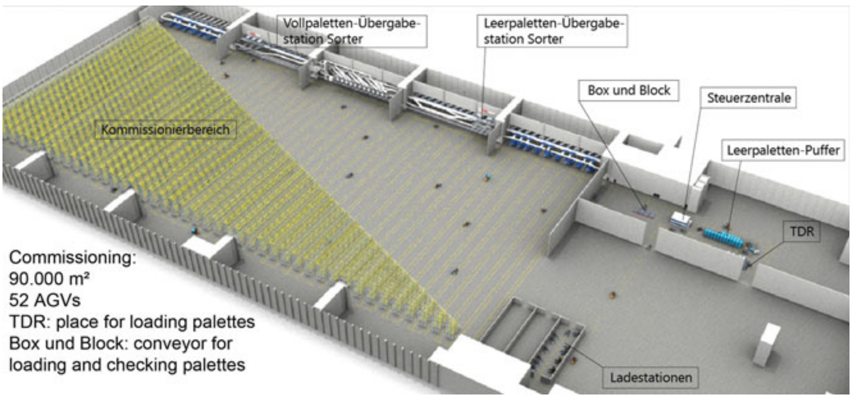

Fig. 2.76 Schematic overview of the AGVS layout (*Source* DS 2012)

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)

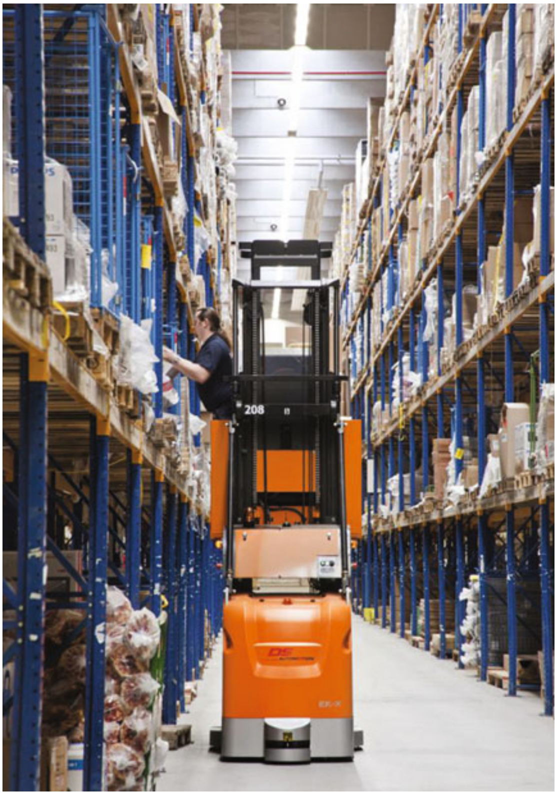

Table 2.5 Key figures for the two vehicle makes

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.

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