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Automated Guided Vehicle Systems: a Driver for Increased Business Performance

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***Abstract*—The automation of transportation in the production, trade and service sector is a key point in the optimization of logistics. Automated Guided Vehicle Systems (AGVS) provide several benefits to fulfill this task. This paper provides an overview on AGVS technology, points out recent technological developments and describes results of research performed by the Department Planning and Controlling of Warehouse and Transport Systems (PSLT) e.g. statistical analyses, characteristic curves and new approaches.**

***Index Terms*—AGVS, Transportation, Automation, Technology, Development, Characteristics**

I. INTRODUCTION

One of the most important aspects of logistics systems is the handling of material flows in industrial environments. Despite the high throughput rates realized by steady materials handling technologies such as roller or chain conveyors, the vast majority of industrial applications rely on common lifting or hauling trucks as transportation system. The reasons are manifold: Besides cost related aspects one of the main advantages is the unmatched flexibility regarding integration in an existing or changing environment.

Fig. 1: Automated Guided Vehicle (TMS Automotion GmbH, Austria)

Extending these advantages of industrial trucks by means of automation technology results in increased reliability and reduced operating costs. The outcome is the so called Automated Guided Vehicle System, abbreviated as AGVS. AGVS are capable of performing transportation tasks fully automated at low expenses. Applications can be found throughout all industrial branches, from the automotive, printing and pharmaceutical sectors over metal and food processing to aerospace and port facilities. The increasing interest in AGVS is reflected in the sales figures which reached a new peak in 2006.

By now AGV-Systems are known for more than fifty years, a time in which various technical advances have been made, ranging from improved actuators and energy supplies to entirely new sensor concepts. The enormous progress of computer systems induced enhanced control strategies. The following sections introduce the main components of an AGVS and provide a summary of recent achievements in AGVS related technology.

II. SYSTEM OVERVIEW

AGV-Systems essentially consist of vehicles, peripheral and on-site components as well as the stationary control system. Only the faultless interaction of all these components ensures efficiently working plants.

A. Vehicles

Vehicles are the central elements of an AGVS as they perform the actual transportation tasks. The vehicles have to be designed individually according to the specific conditions of the environment they are used in [1]. This concerns load handling equipment, the navigation system, the drive configuration and other aspects.

Stationary control system | On-site system components | Peripheral system components | Vehicle

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B. Stationary control system

The stationary control system covers all superordinated control components. Its task is the administration of transportation orders, the optimization of schedules, the communication with other control systems via predefined interfaces etc. This system is also in charge of the customer interaction and often provides auxiliary functions such as graphical visualizations and statistical analyses.

C. Peripheral system components

Peripheral system components represent the counterparts to various on-board equipments of the vehicles. Examples are battery loading stations and load transfer mechanisms.

D. On-site system components

Aspects of the site's structural design that affect the AGVS as for example the ground, gates, lifts and so on belong to the category of on-site system components.

III. Technological Developments

The past years are characterized by significant technological advancements. They contributed to increased attractiveness of AGV-Systems for the users and essentially concern modularity, standardization, energy concepts, navigation systems, automation of series vehicles and safety systems [2].

A. Sensor and Safety Systems

A new promising approach is to equip an AGV and other vehicles with a collision avoidance system. This system will determine each vehicle's position and instantaneously broadcast it to other vehicles in order to forewarn drivers or the central navigation system to avoid collisions at an early time. This will significantly reduce the number of collisions between Automated Guided Vehicles and manual trucks.

Laser range scanners have proven an indispensible potential as security equipment and laser navigation technology. It is only a question of time when the currently well-established two dimensional planar scanning will be extended by the third dimension to provide the necessary data for radically enhanced precision and accuracy [3, 4].

An important step considering laser navigation is to achieve independence of reflection markers. Besides reduced installation costs this will allow to overcome the limitations of the current triangulation laser navigation method, developed more than ten years ago.

B. Inductive power transfer

A technical innovation used increasingly in the field of AGVS is inductive power transfer also known as inductive coupling. This technology transfers electrical power between two circuits through a shared magnetic field. In terms of AGVS the primary circuit is a conductor embedded in the ground whereas the secondary circuit is a pickup attached to the vehicle's lower surface. By energizing the conductor a magnetic field is generated inducing a current in an inductor inside of the vehicle's pickup.

Two basic principles of inductive power transfer are to be distinguished.

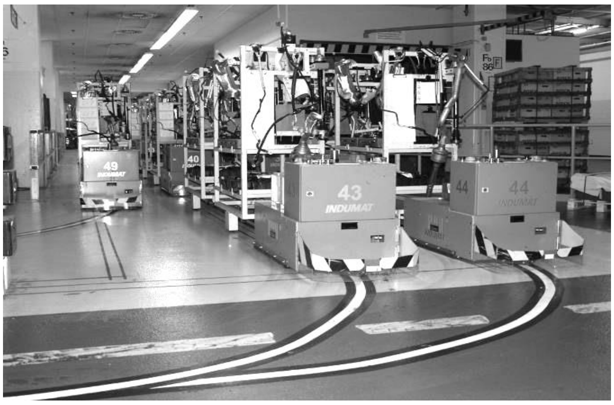


Fig.2: Inductive power transfer (Paul Vahle GmbH & Co. KG, Germany)

The first supplies the vehicle continuously at all times with energy. This requires the primary conductor to be installed on the entire driving course. The advantage is that no battery on board the vehicle is needed [5].

In the second case the vehicle is equipped with an on-board battery and can thus compensate an interruption of the inductive power supply. The battery of the vehicle could be charged inductively at one point, at multiple points or at a defined section of the course.

Inductive power transfer broke ground for new operational areas of AGVS, which were predominated by other conveyor technologies so far. However, on complex or strongly branched out driving courses and on grounds that cannot be millcut or contain a high amount of metal, the battery will remain the preferred energy concept.

One target of the development is to realize power transfer as well as data communication and inductive guidance over one single wire to reduce the expenditure on ground installation. Today the inductive power transfer represents an alternative to the conventional battery loading station. About 8 % of all AGVS put into operation from European producers 2006 were supplied with energy inductively.

C. Modularity and Standardization

Modularity is a common strategic production method to reduce both production costs and delivery times. Customers of AGVS can profit from an additional important advantage that the standardization of AGVS brings along: The currently inevitable commitment on lifetime to one AGVS manufacturer is abandoned, since customers can contact competitors in the context of modernizations or extensions [6, 7].

Cost reduction in the stages of development and realization of AGVS is essential for all manufacturers in order to survive in the competitive market. A common point to start from is to introduce a standardized component system. Each manufacturer would develop its own components based on this system. This will drastically reduce the variety of parts as similar components will become interchangeable between different vehicle types and manufacturers.

At the same time modularity will increase the availability of parts, simplify the logistics of replacements and reduce the capital lockup of the manufacturer.

D. Navigation and Communication

The transportation task of AGVS requires efficient and intelligent routing. The majority of navigation systems sold currently can compute these aspects in very short time. Usually these systems are also capable of handling priorities and time schedules.

Static routing is a well established standard in navigation. This routing technology is based on fixed course sections. AGV-Systems with static routing are similar to the railway system with course sections corresponding to tracks and the central navigation system relating to the railway control center. Sections are marked as occupied whenever a vehicle is entering and remain blocked until the vehicle has left again. This behavior can result in deadlocks, e.g. two vehicles trying to enter the same section on both endings at the same time.

With laser navigation flexible paths become feasible. Vehicles can leave their assigned path to perform evasive movements in order to solve deadlocks or avoid collisions. The consecutive calculation of the best path considering a certain time-frame with respect to the changing environment is known as dynamic routing. This strategy can also increase the flexibility of the whole production system.

Other proven navigation systems utilize either magnetic or radio transponders embedded in the ground. This allows vehicle movements from point to point. To achieve guideline-free characteristics transponders can be spread evenly throughout the AGVS's operational area.

E. Automation of Series Vehicles

The automation of series-production vehicles represents a further line of development. That concerns equally industrial trucks and motor trucks . The series vehicles are automated by the AGVS-manufacturers. Industrial trucks are preferred in particular if both manual and automatic handling has to be realized. To increase the flexibility the AGV can be equipped with more than one load handling attachment.

The automation of motor trucks has an increasing impact on the market of shuttle transportation between different buildings of one plant. Naturally the truck can be used during the daytime shift manually to increase the driving speed and in automatic mode during the rest of the time [8].

Fig. 3: Automated motor truck (Götting KG, Germany)

IV. APPLICATIONS

AGVS can be found in virtually any area of industrial production, trade and service. The main application areas are connection of different work areas, order picking, warehousing and assembly. The realization of the material flow processes in the warehousing and order picking sector is characterized by high volume of traffic from defined sources to defined destinations [9]. This is a standard application area of AGVS which usually demands high loading capacities. The load units are usually standardized pallets, therefore the vehicles are equipped with standard loading devices. Due to the requested performance, these systems often consist of more than 100 vehicles [10]. This demands a sophisticated central controlling unit and optimizing approaches for routing and path-finding.

Another area with a high application rate of AGVS are assembly lines. In this sector the load is inhomogeneous and changing. Therefore the loading devices must be fitted to the specific application. The vehicle sometimes not only transports the load from one assembly station to the next, but represents an assembly station itself. In this case the vehicle can be considered as a mobile workbench [11]. Another assembly application is the pick-up AGV which has the work piece mounted on it and virtually represents a conveyor for both the worker and the work piece.

In contrast to expanded, complex systems with a high investment, small and comparatively low priced systems can be found in many environments. Systems with only one or very few vehicles can be realized without any central controlling unit. These systems stand out by low investments and simple maintenance.

New developments at the PSLT are techniques that enable AGVS to follow a designated person. The basic requirement for human-robot interaction is the system's ability to distinguish between the person and its surroundings and moreover to identify the person. This can be achieved by using sensors such as digital cameras or laser range scanners. The main focus is centered on computer vision and its practical integration into an AGV-System. Experimental results show good performances of the system. Logistic operations like order picking would immensely profit from such a function. An interesting perspective is a warehouse with employees focusing on picking while trolleys are following automatically. When they are fully loaded the trolleys will carry their load to the destination point. Empty replacements are provided by the central control in time.

The system was presented at the AGV Conference 2006 which is conducted by the PSLT at the Leibniz Universität Hannover every two years.

Many more new applications for AGVS can be found in the logistics sector. An example is the implementation of an AGV to a stationary pallet stretch wrapping device. Thereby manufacturers can eliminate the use of pallet conveyors, reduce labor costs, increase plant ground safety, and eliminate product and conveyor damage caused by human errors.

Fig. 4: "AnGiV" at the PSLT´s AGV-Conference 2006

V. Operating Costs As Scale Of Economy

Contrary to man-operated industrial trucks the operating costs of AGVS are only marginally affected by the development of the labor costs. From this it results that relating to the labor costs a high calculative planning reliability can be achieved in the long-term. This is a general advantage of all automated material flow systems. On the assumption that the labor costs will rise even more strongly in the future than in the past, AGVS will increase above average in comparison to personnel intensive material flow systems.

The development of the labor costs, as for example a start-up financing for the creation of a job or a shortening of subsidies, may not remain unconsidered. Each of these factors can either promote or restrain the development of the AGVS-market.

The investment in a plant with an AGVS is usually higher than for a plant with man-operated industrial trucks. That has consequences on both the cost-accounting interest and the height of the depreciation. For AGVS higher cost-accounting interests result. The height of the interest rate has to be oriented at the development on the capital market. If the interest rate decreases, the profitableness of AGVS is affected positively.

The depreciation has to be regarded under two criteria, namely according to tax law and cost accounting criteria. It has to be an aim of the plant operators to estimate the economic lifetime of the plant as short as possible. Therewith it should be reached that the depreciation of the fixed capital can be made valid for taxation as promptly and completely as possible.

The labor costs, the interest trend at the capital market and the amortization period belong to the substantial economic factors, which determine the development of the AGVS-market. The development of these factors cannot be affected by the AGVS-manufacturers, the factors affect the market from the outside.

The amortization period defined by the technical lifetime is applied to the cost comparison method, thus for the system decision. A long technical lifetime affects the system comparison positively. The technical lifetime is specified internally considering the tasks and the operating conditions. For the success of the European AGVS-manufacturers on non-European markets the rates of exchange are relevant. With a low US-Dollar price per Euro the European AGVS-manufacturers can make attractive offers for the international market. In the year 2006 about 23 % of the AGVS by European producers were installed outside of Europe.

VI. AGVS Statistics

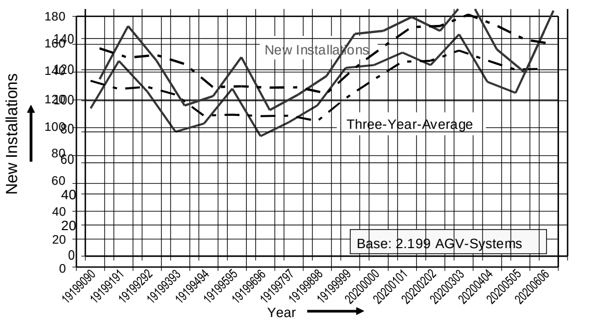
The increasing interest in AGVS is reflected in the sales figures which reached a new peak in 2006 with a volume of 200 Mio. EUR according to a yearly survey among European AGVS producers carried out by the PSLT. The current developments promise that automated transport systems will be of high relevance in the future as well.

The trends of the different markets and thus the development of the AGVS-manufacturers are also of particular importance for investment decisions of customers. Customers have to ensure that the acquired technology is future-oriented and that the manufacturer will be available at the market segment of AGVS in the long term [12]. The selected AGVS-manufacturer should be available for service and support of the system as well as for spare part logistics for a long time.

In comparison to the year 2000 about a quarter of the AGVS-manufacturers are on the one hand "new" vendors. On the other hand the "old" vendors offer new and different achievement profiles today. Both aspects point out the dynamics on the vendor side, which offers with more than twenty five European AGVS-manufacturers a large variety.

A substantial indicator for the market tendency of AGVS is the annual number of AGVS put into operation. The key number for the European manufacturers is issued by the PSLT based on the information of the AGVS-manufacturers.

The number of AGVS put into operation world-wide by European AGVS-manufacturers sums up to over 3.300 new systems with about 27.500 Automated Guided Vehicles in total.



Source: Database „Worldwide AGV-Systems of European Producers "
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Fig. 5: AGV-Systems in openings of European AGVS-manufacturers

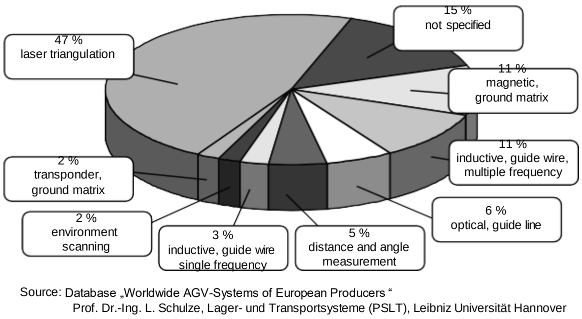

Fig. 6: Guiding technologies in AGVS put into operation by European AGVS manufacturers in 2006

After an intermediate flattening related to the number of the Automated Guided Vehicles and AGVS put into operation a significant growth can be registered from 1999 until 2006. Thus in the three-annual average the level rose in the mean-time over 140 new systems per year. In 2006 a new peak with 169 AGVS was reached.

A similar process is determined for the number of Automated Guided Vehicles put into operation. It is also a trend that the average system size measured in vehicles per system rises. The average number of vehicles per system amounts now again over six vehicles. As the complexity systems increase, the requirements on planning, engineering, project management, realization and putting into operation rise. This trend is also pointed out by the fact that the average equipment price allocated on the vehicles increased.

In 2006 a considerable number of about 6 % among all AGVS in Europe was realized within the outdoor sector. These applications of AGVS within port facilities for the containerization and as shuttle transportation already proved their fitness to practice [13].

Some characteristic numbers clarify the different requirements for operators in Europe, Japan and the USA. Comparing to Japanese and American Automated Guided Vehicle Systems, European systems have the largest average number of vehicles per system while Japanese systems have the smallest number. Most AGVS are operating in Japan, but the majority of these systems are to be considered as rather “simple“ from the technological point of view. This is also reflected in the installed navigation systems. In Europe laser navigation was realized in about 47 % of the systems in the year 2006 whereas in Japan the magnetic procedures predominate.

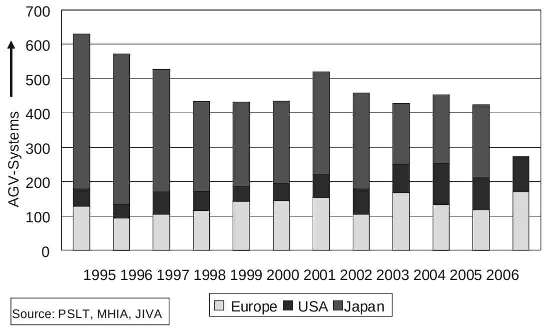

Fig. 7: Worldwide openings of AGVS of European, American and Japanese manufacturers

As of today there are a moderate number of AGV-Systems operating in China. The application in the tobacco industry is the widest where about 20 enterprises have used AGVS so far. Most of them are using laser guidance technology.

Increasing popularity and superior results of current AGVS now encourages more companies and institutions in China to start research on AGV technology [14]. This concerns for example the order management, route design and communication systems.

VII. Conclusion

Significant technological advancements contributed to increase the attractiveness of Automated Guided Vehicle Systems for the users. They essentially concern the modularity, the standardization, the navigation system, the energy concept, the automation of series vehicles and the safety system [15].

For manufacturers of AGVS internationalization and globalization represent new challenges. China and other newly industrialized countries offer chances for the future. The first systems were already put into operation in these countries. Great efforts are undertaken by European vendors to install reference assets. In this connection long-term export possibilities for AGVS-manufacturers are of particular interest. In addition China itself is currently developing AGVS for their own market.

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