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## **THE APPLICATION OF AUTOMATED GUIDED VEHICLES IN LOGISTICS**

Economic and human factors forced the need for the application of automated transport vehicles AGV. The area of application each year is getting bigger and bigger, going far beyond their original industrial applications. To this expansion contributed the advances in technology and an increase in the cost of human labor. In the paper there were presented the main areas of applications of this type of vehicles as well as the simplified calculation for the economic viability of this type of transport.

### **1. INTRODUCTION**

In the 1950s of this century in the U.S. industry centers emerged a trend towards a reduction in the costs associated with the activities of the company. These trends forced boards of companies to a thorough analysis of the costs of production. In the total costs one of the most significant components were costs associated with the flow of materials. Another factor that forced major changes in transportation and material flow was the development of modern manufacturing techniques known as flexible manufacturing systems. This was true for both transport between machining stations, assembly lines and also transport carried out within the stores. In the first stage these changes consisted in the elimination of the human from the production cycle focused on a production of large series. It was possible by the introduction of automated transport based largely on factors such as: conveyors, roller conveyors or automated carts running on rails. Transportation system based on these measures over the years proved to be stiff, prone to all sorts of failures and unsuitable for the production of small and medium series which required considerable flexibility. The first successful attempts to introduce new transport systems [3] providing considerable flexibility were launched in the U.S. in the 50s. These systems were based mainly on new means of transport [1] such as AGVs (Automated Guided Vehicle). The first system which used these measures was installed in 1954 in the factory of Mercury Motor Freight in Columbia, South Carolina. The turn of 60s and 70s was a setback in the development and industrial applications of the transport system in the United States. A new stimulus contributing to the development of transport systems occurred early 80s. The great contribution to this had European companies and the development of computer technology [4] used to control the system and control of the materials flow. The

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leading model solution was a new assembly plant of vehicles Volvo in Kalmar in Sweden [5]. This plant was launched in 1974. This plant gave up of a rigid assembly line and was used to transport car body to fit mobile terminal platform. It was also introduced a new organization of teamwork. The success of this approach was the impetus for further development in this direction. Innovative achievements of European companies were also recognized in the USA. In 1981, in the John Deere plant in Waterloo, Iowa, it was used an automatic transport system between the warehouses and production departments. The next significant step in the development of these means of transport was used in 1984 by General Motors – the first in the U.S. flexible assembly system. At present, the use of such vehicles is quite wide and develops to a large extent beyond the sphere of production [2,7] and is located in the wider area of logistics.

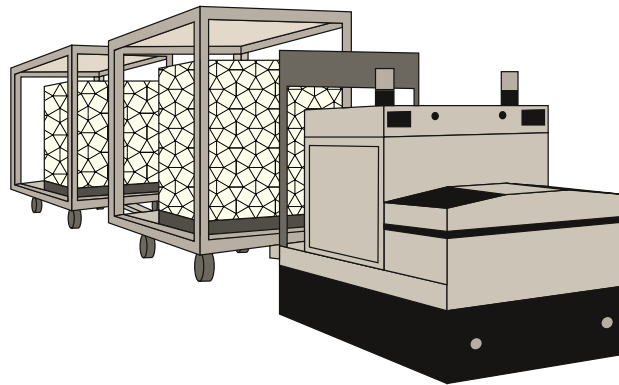
## 2. TYPES OF AUTOMATED GUIDED VEHICLES

The first vehicles of this type appeared in the 1950s and were used mainly to support the production process. The dynamic development of this type of transport in recent years helped extend the use and is currently used in many other non-productive areas related to human activity.

The variety offered by AGV manufacturers around the world is so great that they can perform various tasks. Among the whole set of autonomous transport vehicles, there can be distinguished the following types of vehicles:

- Towing vehicles (Fig. 1) - tow trucks and trailers weighing from 4 to 25 tons. AGV dimensions depend on the permitted capacity and working space and the destination;

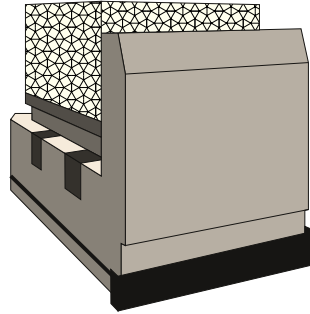
Fig. 1 Towing vehicle



Source: own study

- Unit load vehicles - to transfer to any area of the various elements, e.g. pallets, reels, boxes (Fig. 2). The robot selects the item that should be loaded;

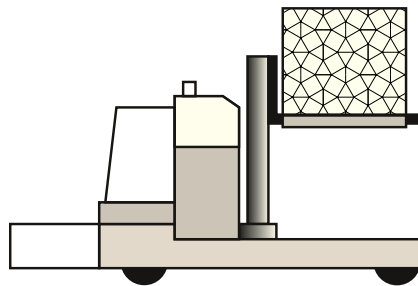
Fig. 2 Vehicle for transporting pallets



Source: own study

- Fork vehicles - used to transport loads horizontally and vertically (Fig. 3);

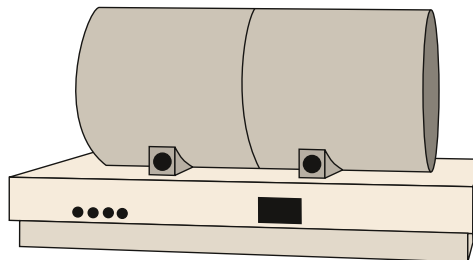
Fig. 3 AGV forklift



Source: own study

- Office vehicles- to carry small items weighing less than 250 kg and small dimensions. They work in a bright and clean rooms and are used e.g. for the distribution of mail in the office.
- Heavy Burden Carrier Vehicles - for the transport of elements with very large dimensions and heavy weight, e.g. metal bars, coils and arrays of more than 100 tons (Fig. 4).

Fig. 4 Heavy Burden Carrier Vehicle



Source: own study

Besides the above there are a number of specialized vehicles such as construction container carriers at sea ports and large storage warehouses.

### 3. THE EXAMPLES OF INTERNAL TRANSPORT VEHICLE APPLICATION

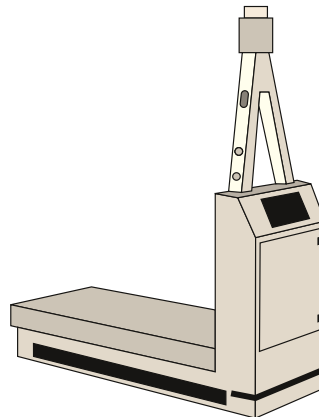
The purpose of the creation of automated transport vehicles is to eliminate dangerous, heavy and repetitive human labor. At present, the vast majority of these vehicles are used for transportation inside the factories [6], warehouses, office buildings and closed areas. Some auto transport vehicles fitted with additional equipment can often perform a number of very complex operations, such as land identification, disarming explosives or manipulation of cargo transported. In various application areas there can be distinguished automatically routed vehicles such as industry, transport (towing vehicles, automatic forklifts, automated cargo platform, automatic mounting platform), medicine (automatic nurses, self-propelled wheelchairs), defense (patrol vehicles, vehicles to disarm explosives, fighting vehicles equipped with the appropriate devices).

Below there have been discussed three examples of the application of automatic guided vehicles. Vehicles are manufactured by JBT Corporation [8]. The discussed examples include the applications in such areas as health care, warehousing and chemical industry.

#### 3.1. Health protection

In 2004 in the medical center of St. Joseph in Ann Arbor, MI in the USA [8] there were introduced twelve AGV vehicles of Atlas Lift Deck (Fig. 5) to transport the trucks with bedding, food and supplies. These vehicles use laser navigation. They move at a speed of 1.2m/s, and each weighs 545 kg. The carts with linens and supplies are transported from the receiving dock to the elevators and then to the different branches of the hospital. However, food trucks are transported from the kitchen to the hospital elevators, and then they are distributed to the various hospital departments. Automatic vehicles are also engaged in the transportation of bed linen and dishes from the hospital departments to the collection points (the hospital laundry, kitchen).

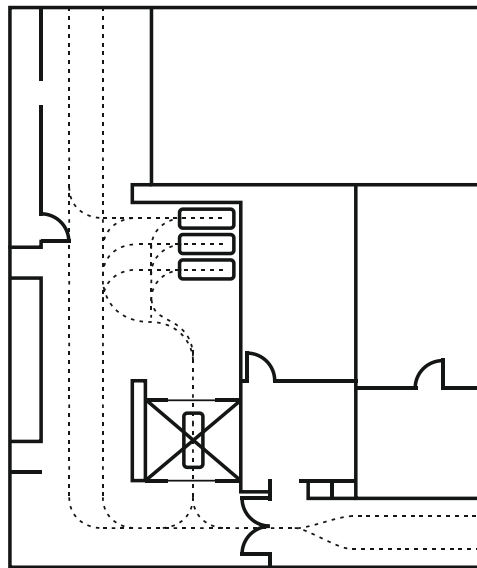
Fig. 5. The automatic vehicle of Atlas Lift Deck



Source: own study

Installed in the designated areas photocells as well as the applied network of I/O allow to monitor the collection points from which there are taken and transported by a vehicle trucks transporting the material. For the special displacements the operator uses the available control panel. The benefits of AGV are primarily the reduction of labor costs, the increase of personnel safety, reliable and timely delivery of goods. The example part of the route within the hospital is shown in Figure 6.

Fig. 6. An example of part of the route within the hospital, the dotted line marks the vehicle route

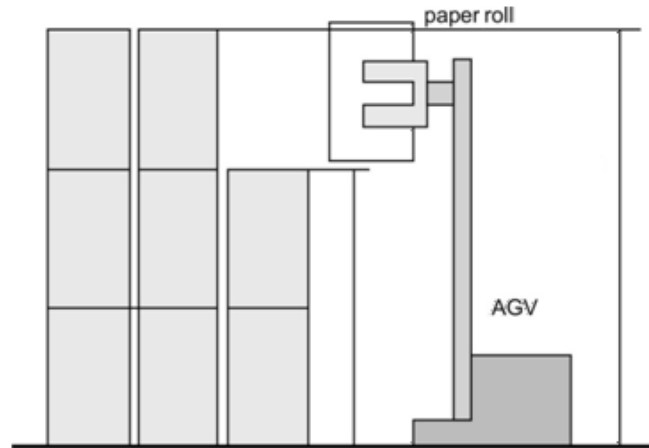


Source: own study

### 3.2. Warehouse management

An example of the use of automated vehicles in warehouses is the company P-Well GmbH [8]. Vehicles which work there are used for collecting the rolls of paper from the warehouse, transporting them to the assembly line and putting-positioning with the precision in the corrugator. There were used three vehicles with hydraulic lift and rotary jaw clamp. Each vehicle uses a laser navigation and is designed to carry a paper roll of maximum diameter of 1500mm, maximum width of 2500mm and a maximum weight of 3500kg. Rolls of paper are stacked in piles in the warehouse. The software applied in the vehicles provides them with information about the width and diameter of the paper roll, and the exact location of the roll in the warehouse before the vehicle is sent to the selected roll. The vehicle is equipped with a mast whose height can be adjusted automatically. In this way the vehicle is able to remove and place the paper roll at different heights as shown in Figure 7 The rollers are moved vertically.

Fig. 7. Warehouse scheme with paper rolls



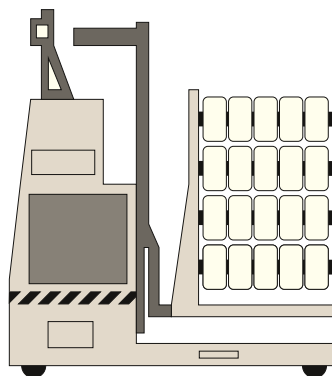
Source: own study

Approaching the corrugator the vehicle depending on the wind of the roller rotates it by  $+/-90^\circ$  to the horizontal position and places it in an assembly stand. Since the beam diameter of the vehicle is known, therefore the AGV control system calculates the ending position of the vehicle in such a way that the roller axis lies exactly above the horizontal axis of the assembly stand. After such a positioning the roll is lowered on the assembly stand. The benefits of automated transport vehicles in this example are mainly less damage to the rollers caused by moving, reduction of labor costs, the increase of storage capacity and the increase of safety.

### 3.3 Chemical industry

Another example is the use of automated vehicles in the chemical industry. Vehicles were introduced in 2006 in a factory of chemical fibers Eastman (Kingsport, the USA) [8]. There were used five vehicles using laser navigation.

Fig. 8. View of the vehicle transporting fiber rolls



Source: own study

Automatic vehicles transport from the warehouse raw material of the acetate fiber roll to the lab or to the final assembly line. The transported rolls are carried in special racks (fig. 8) equipped with pins. Automatic vehicles carry also the empty racks from the assembly line to the warehouse. The benefits arising from the use of these vehicles in the factory are: increased productivity, reduction of the amount of running operations, reduction of the labor costs, minimal control system, safe and reliable delivery of material to the final assembly line.

#### 4. EXAMPLE OF RETURN ON INVESTMENT (ROI)

By automating the whole or part of the process impressive cost savings can be achieved in logistics operation. The payback time of an automated system is very short, especially when working on shifts. Labor costs can be reduced, or workers can be released to more productive tasks.

The application of a survey of installed systems, an estimate of total system cost can be derived based on the number of vehicles in the system and the level of system functionality and complexity. Per vehicle cost estimates (fully burdened) are provided for systems for 1 vehicle; for 2-4 vehicles; and for 5 or more vehicles, all with three levels of complexity each.

The examples of complexity level as used in the tables [9] are:

Level 1: Simple – Manual Vehicle Dispatch, Load/Unload, No Central Controller, No Host Interface.

Level 2: Medium – Automatic Vehicle Dispatch, Load/Unload, Central Controller, Product Tracking, Multiple Path Options.

Level 3: More – Automatic Vehicle Dispatch, Load/Unload, automatic coupling/uncoupling (applies to tuggers only), Central Controller, Complex Host Interface, Ethernet Link, Product Tracking, Multiple Path Options Multiple Transfer Heights, etc.

Total system cost can be estimated by multiplying the projected number of vehicles by the unit costs shown in the following table 1.

Table 1. Cost per vehicles [9]

NUMBER OF VEHI- CLES	UNIT LOAD VEHICLES UP TO 3000 kg CAPACITY					
	COMPLEXITY - \$ (thousands) PER VEHICLE					
	1		2			
	Low	High	Low	High	Low	High
1	50	250	100	300	150	350
2 to 4	50	200	115	225	130	325
5 and up	50	160	100	200	100	300

There are a number of items that should be reviewed when deciding to purchase an automated guided vehicle system and Return On Investment (ROI) is one of those items. This section is intended to give some tips while implementing an automatic guided vehicle solution for the company.

However, sometimes costs aren't so obvious. The quickest way to calculate ROI is by calculating: annual wages per position multiply by the number of positions divided by

the price of the AGV system. The problem with this is that there can be missed some key costs (direct and indirect) that significantly impact return on investment calculations.

Direct costs: hourly wages, overtime, insurance benefits, vacation, sick time, equipment, etc.

Indirect costs: damaged product, utilities (AGVs are more energy efficient than forklifts), etc.

The simplified calculation example contains only direct costs:

X Company operates 24/3 and has 9 forklift drivers (3 per shift), each \$15 per hour. Employee benefits equal 30% of the base hourly rate. Overtime is paid at 1.5 times the base hourly rate and each forklift driver is averaging 5 hours of overtime weekly.

X Company has 4 forklifts and will not need 3 of them after the AGV system has been installed. X's forklifts have a life cycle of 5 years with each new forklift costing \$25,000.

Calculation inputs

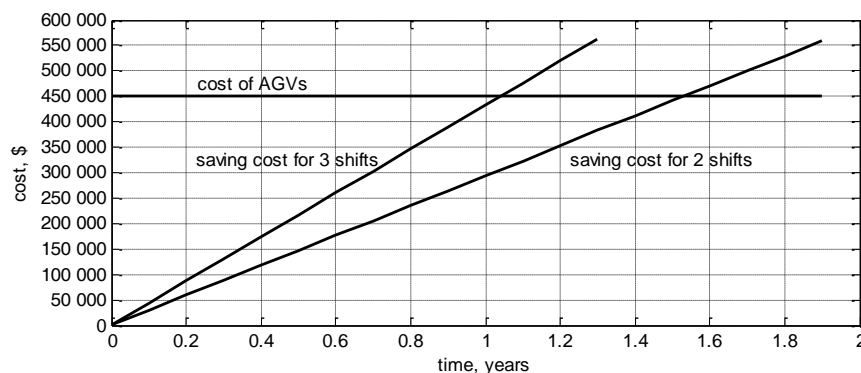
A	Total Number of Positions Replaced	9
B	Annual Base Hourly Cost Per Position (burdened with benefits)	\$40,560
C	Annual Overtime Cost Per Position	\$5,850
D	Cost for New Forklifts (total every 5 years)	\$75000
E	Cost of AGV System	\$450000

Calculation results

Total Annual Position Savings (B + C) x A	\$417690
Annual Forklift Cost Breakdown (D / 5 yrs)	\$15000
Total Annual Costs (total annual position savings + annual forklift cost)	\$432690
Years to Break Even (E cost of AGV system / total annual costs)	1.04 Years

By using the same procedure and the same assumptions additional calculations for two-shift operation were carried out. Subsequently, the same company repeated the calculations for a system of two and three shifts assuming an hourly rate equal to \$ 7. This type of rate is closer to Polish conditions. The calculation results are shown in the graphs in Figures 9 and 10. Payback period from the investment for the rate of \$ 15 is shown in Figure 9 and for the three-shift system it is 1.04 and for the two-shift it is 1.53 of the year.

Fig. 9. Comparison of the costs of system purchase and savings at an hourly rate of \$ 15

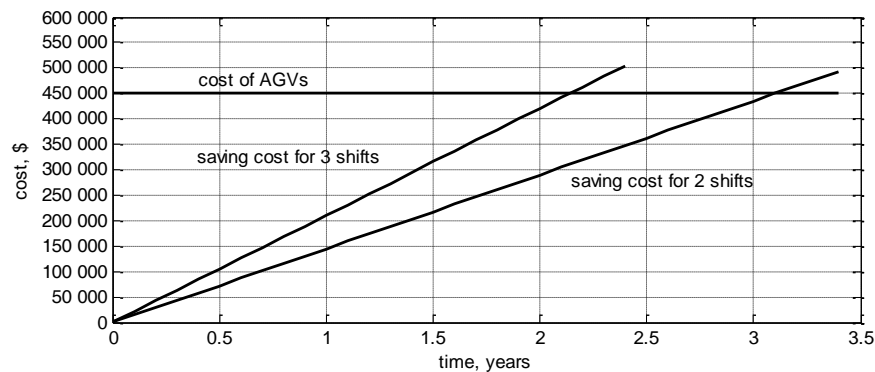


Source: own study



Payback period from the investment for the rate of \$ 7 is shown in Figure 10 for the three-shift system it is 2.14 and for the two-shift it is 3.104 of the year.

Fig. 10. Comparison of the costs of system purchase and savings at an hourly rate of \$ 7



Source: own study

The calculations are simplified, the variable costs are not included in them. However, it was assumed that the costs associated with the operation and maintenance of the system are comparable in both cases, that is why they have been omitted. As one can see from the preliminary calculations the determining factor is the cost of human labor. In Polish conditions, with an increase in the cost of human labor it can be expected an expansion of this type of automated transport systems.

## 5. CONCLUSIONS

Economic activities need to be constantly adapted to changing conditions. One of the main criteria for determining the success of a project is the payback period of the investment. As shown in Figures 9 and 10, with an increase of the rate, the period becomes shorter. In addition to the economic factors for the expansion of systems using automatic means of transport are also responsible other important factors which include inter alia:

- very high availability,
- the ability for easy and quick modification of the development of transport routes,
- low costs for development and redevelopment,
- very good adjustment of the transport frequency to the requirements,
- a small space occupied,
- a possibility to use unmanned transport in the conditions harmful to humans,
- elimination or substantial reduction of the economic losses associated with the transport of goods,
- a possibility of monitoring-tracing the flow of goods and loads.

Automatically routed internal transport vehicles due to the dynamic development of technology can perform ever more complicated tasks.

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## ZASTOSOWANIE AUTOMATYCZNIE KIEROWANYCH POJAZDÓW TRANSPORTOWYCH W LOGISTYCE

Czynniki ekonomiczne oraz ludzkie wymusiły konieczność zastosowania automatycznych pojazdów transportowych AGV. Obszar ich stosowania z każdym rokiem staje się coraz większy, wychodząc daleko poza ich pierwotne przemysłowe zastosowania. Do tej ekspansji przyczynił się postęp technologiczny i wzrost kosztów pracy ludzkiej. W artykule przedstawiono główne obszary zastosowań tego typu pojazdów oraz przedstawiono uproszczoną kalkulację ekonomiczną dotyczącą opłacalności stosowania tego typu środków transportu.

DOI: 10.7862/rz.2012.zim.18