Simulation modelling of material handling using AGV

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Abstract. Modern production systems are mainly characterized by, among others, the use of automated transport systems. One of the components of such transport systems are automated guided vehicles (AGV). These vehicles are primarily used in the material handling due to their greater efficiency, flexibility and lower operating costs. The main aim of the article is to present the possibility of using simulation modelling in the analysis of internal transport operations using automated guided vehicles.

1. Introduction

At the present time, the vast majority of AGVs are used for transport work inside factories, warehouses, office buildings and in closed areas. The main area of application of AGVs are warehouses, but they are also more and more commonly used in the production environment. The constant desire of enterprises to increase their production efficiency and systematize material flows causes an increase in interest in automated transport systems. Automated guided vehicles are increasingly used in modern enterprises to transport material goods on production lines. The result is an increase in productivity through the improvement of internal transport.

AGVs are vehicles that move during the transport of load along a designated route. These vehicles are equipped with an appropriate driving system enabling movement from the starting point to the end point along a predetermined and physically designated route or along a virtual route generated by a computer. In a true trajectory navigation system, the vehicle follows a strictly-physically defined route. This route can be determined by means of an induction loop, an optical loop or a magnetic loop. In the navigation system using virtual trajectories, the vehicle has its own extensive control system with a sufficiently large memory. The memory includes the map of the area and the route along which the vehicle is traveling. Using data from appropriate sensors, the control system determines the current position of the vehicle and further motion parameters. The basis for determining the position in this type of navigation is odometry - computational navigation [1, 2]. This method of determining the position of the vehicle is burdened with many errors. Additional systems are used in modern vehicles in order to correct these errors. Most often, in the conditions of industrial halls and buildings with well-known architecture laser methods are used, less often magnetic or optical. In the open space the GPS method is most often used for navigation but very often additionally supported by laser methods, mainly used to detect obstacles. Most often, AGVs are used in warehouse processes to transport box containers, rolls of materials, pallets with the product or for picking goods and shipment. They are also often used on assembly lines to transport components and entire machines between construction stations. AGV vehicles come in many types and can be equipped with load grippers, conveyors cooperating with the automation of production
lines and with warehouse infrastructure. Usually they are also connected with WMS systems, which makes work in the warehouse more flexible. The performance of transport tasks by AGVs in warehouses and production plants is becoming more and more common. Their use means that employees do not have to perform repetitive tasks in the field of internal transport and the stability of the processes is ensured.

The selection of the appropriate AGV vehicle takes into account the time criteria, the degree of repeatability of the processes, the frequency of transport operations, the maximum load of the vehicle, but also the features of the environment in which the vehicle will operate. AGV vehicles perform very well in conditions where they perform the same activity periodically. AGVs that move completely independently and are equipped with a number of safety systems can operate between people. Their application in the area of internal logistics translates into timeliness, no downtime, and the implementation of the Just-in-time concept. Using appropriate systems that ensure communication between AGVs and the possibility of automatic loading AGVs can transport materials without interruption while maintaining optimal operating parameters. Another advantage of AGVs is the possibility of using them in places that are dangerous for humans, for example near dangerous machines, places with increased temperatures.

Computer simulation methods are very helpful when choosing the optimal solution of the transport system consisting of AGV. Simulation tests on a properly designed system model are much cheaper and safer than tests carried out in real conditions. Most often, simulations of transport processes are carried out on a virtual map of a warehouse or production plant [3–7]. The model reflects the actual traffic in the warehouse or production plant. Computer simulation of the AGV system takes into account the selected navigation routes, the number of vehicles and other parameters that may affect the optimization of the AGV system. Simulations allow the user to observe changes in the system inputs and outputs in real time, giving the possibility of optimizing the AGV system in terms of current and future needs. Simulation tests can be carried out for different speeds depending on the load and route. Thanks to this, it is possible to determine the demand for AGVs, indicate bottlenecks in the process or necessary changes to the system [8].

The aim of this article is to present the possibilities and benefits of using software for modelling and simulating transport processes using AGVs.

2. Methods and software supporting modelling and simulations

The computerization of all industries has resulted in, inter alia, more and more common use of modelling and computer simulation methods. IT tools intended for these purposes are then used. The methods of computer modelling and simulation are used when achieving a solution by analytical methods is too complicated, and when conducting an experiment directly on a real system is too laborious, expensive or impossible to carry out. Building models that represent an existing physical system or a planned system is now common practice in many industries. Models are used to improve or verify system solutions for future or current production lines. In the early stages of a project, before the inception of the physical system, the best approach to predicting future performance is to build models. Testing the proposed changes to the models before their physical implementation increases the certainty and reliability of the proposed solution and reduces the likelihood of implementation of costly errors. Models should be built for a specific purpose, usually to answer one or more specific questions. Each other question requires a different level of model detail and has different input requirements. A detailed or difficult question can trigger the development of several subsystems that will require additional input data. Adding details often means that the computational time will be longer when running the model, but also that the simulation project will take longer to collect data and validate the model, which is a cost for each model update.

The use of computer simulation is in line with the assumptions of Industry 4.0. The use of this technology can provide the company with a significant competitive advantage in the development, implementation and execution of its plans and strategies. Testing virtual models before real-world application helps to: determine performance, identify bottlenecks, study interactions between different system components, experiment and evaluate alternative scenarios.
Discrete event simulation (DES) is widely used for simulation studies. The DES method is used to present real processes by determining the moment of events affecting the process. An event is the occurrence of a system state change at a certain point in time that may cause a change in the characteristics of an object or start or stop activities in a process. In the case of discrete event simulation model state changes only at discrete moments called timing events. DES method is applicable in situations where we are dealing with known processes, for which situations of uncertainty can be defined using statistical distributions [9].

DES can be used to estimate the amount of warehouse space required in a factory based on expected material flows to compare different operational scenarios against performance indicators such as throughput or machine utilization [10]. In addition, DES can be used to plan material handling systems in factories in particular to determine the required number of AGVs or to compare different shipping rules for AGVs. The ability to simulate discrete material flow events also exists in many factory planning applications. For example, it is used to analyze and evaluate alternative schedules for production systems to find the best solution.

In the available software for simulating discrete events in most cases models are created from ready-made objects for which input parameters, connections with other objects and the accurateness of the process are defined. Simulation tests are carried out on the created simulation model. The study of the process with the use of simulation models enables the analysis of the characteristics of the process taking place during the simulation experiment and enables the determination of the influence of input parameters on the behaviour of the modelled process. During the simulation of the process, more experiments can be carried out using different values of the input parameters. The obtained results, which are most often presented in the form of reports and charts, are subjected to further analysis and allow for the selection of the optimal solution. The developed simulation model may also be subjected to continuous modifications and further simulation experiments may be carried out for the resulting new versions of the model. The use of computer tools for modelling and simulation significantly reduces the time of analyzing the modelled process, and thus allows for quick decision making. Simulation modelling tools vary in terms of options and capabilities, and therefore prices. When selecting the software one should be guided by the purpose of the simulation and the type of process being analyzed.

In the case of logistics processes the most popular tools are: Enterprise Dynamics, Flexsim, Dosimis, Arena, Visual Simulation [11–15].

Enterprise Dynamics is a program designed to create models for simulating processes including in the area of logistics such as: storage and distribution processes, production processes or transport processes. The construction of a simulation model with the use of this tool consists in selecting and arranging objects in the working space of the program, defining connections between objects and introducing input parameters for individual objects. Input parameters defined for individual objects can be described by the values of a constant, probability distribution or an expression written in the 4DScript programming language. This language available in the Enterprise Dynamics package also allows you to create your own user interface and implement your own objects and create your own functions [16]. In addition to building simulation models, Enterprise Dynamics also enables simulation tests of the developed models. The results obtained from the conducted experiments can be presented in the form of reports and charts.

3. Experimental research

In this section, the unloading point model is considered. It analyzes the processes taking place between the unloading part and the warehouse part where the goods are stored. At the unloading point, there are two transport processes that occur periodically (Figure 1). These are the transport of goods from the truck to the temporary storage place, and then return to the place of collection from the truck, (TP1) and transport of the goods from the temporary storage place in the unloading area to the storage area, and then return to the unloading area (TP2).
In the analyzed system, it was assumed that transport is carried out with the use of AGV. The analyzed process is the transport of goods from the temporary storage place in the unloading area to the storage area and then return to the unloading area. It is assumed that the goods are stored in a warehouse on the floor without any stacking.

It was assumed that the deliveries reach the unloading point on average every 15 minutes. Each truck holds 30 pallets. Pallets are unloaded individually to the unloading area and then transported by AGVs to the main warehouse. The time of unloading one truck was set at 8 minutes on average. The load of one truck can be handled by several AGVs. The system must be able to transport 40 loads per hour.

Manipulation of materials is very important from the point of view of the functioning of any warehouse. The reloading device used in the analyzed system is the AGVs. During operation, the AGV carries out many operations, which can be divided into four main stages, such as: driving the transport vehicle without a load, picking up the load, driving the transport vehicle with a load, depositing the load, and handling.

Figure 2 shows the situational plan of the analyzed unloading point along with the marked transport distances (with dimensions).

The following assumptions were adopted for the analysis: the AGVs moves at a speed of $v = 1 \text{ m/s}$. It was assumed that the AGV is moving at a constant speed. The analyzed example does not take into account random situations and the need to charge AGV batteries.

On the basis of the adopted assumptions, first of all, the average distance to be traveled by an AGV with a load ($D_1$) and the average distance for an AGV without a load ($D_2$) should be determined. Next, the required number of AGVs necessary to complete the assumed task will be defined [17].

The time parameters for a typical AGV journey are:

- loading operation in the unloading area and unloading operation in the warehouse. It was assumed that the operations of picking up $t_p$ and depositing the load take 45 seconds each respectively, times are marked accordingly: $t_0$, $t_p$;
- average journey time of an AGV with a load from the unloading area to the warehouse: $\frac{D_1}{v}$;
average journey time of an AGV vehicle without a load from the warehouse the unloading area:

\[ \frac{D_2}{v} \]

Some simplifications were adopted in the analyzed system: in the calculations of the travelled distances, the effects of slightly shorter distances around curves in turns were ignored. P1 and P2 are the average points for depositing the load (Figure 2).

The average distances travelled by the AGV with and without load sequentially are \( D_1 = 54.5m \) and \( D_2 = 84.5m \).

Ignoring any effects of traffic jams, the total round trip time \( T \) was calculated on the basis of equation (1):

\[
T = \frac{D_1}{v} + t_p + t_o + \frac{D_2}{v}
\]

The total travel time was 229 seconds.

As the performance of an automated AGV system may be affected by losses, it is therefore necessary to define the AGV traffic factor \( f \).

Sources of inefficiency in AGVs that are accounted for by the traffic factor include blocking waiting vehicles at intersections, poor planning, inefficient vehicle routing, and poor guidance path layout. If there is only one vehicle in the system, there will be no blocking and the traffic factor will be very close to 1. For multi-vehicle systems, there will be multiple blocking and congestion and the traffic factor will be a lower value. Other factors that affect the traffic factor are planning, routing, and the layout of the AGVs. The typical value of the traffic coefficient is in the range 0.85–1. In the analyzed system its value was assumed as 0.9.

The next step necessary to calculate the required number of AGVs is the calculation of the number of round-trip trips per hour per vehicle. This parameter was calculated on the basis of the dependence (2) and amounted to 14.14 round trips (vehicle h).

\[
R = \frac{60f}{T} \text{ round trips (vehicle h)}
\]

The required number of AGV \( N \) vehicles was calculated on the basis of the dependence (3):

\[
N = \frac{L}{R}
\]

where:

- \( L \) - the amount of goods transported to the storage area within 1 hour.

The required number of AGVs is 3 AGVs.

Having calculated the required number of AGVs in the analyzed system, in the next stage a simulation model of the analyzed system was developed. The model was developed in the Enterprise Dynamics software. The third figure shows the appearance of the developed model in a 2D view (Figure 3). All elements that create the unloading point have been mapped in the model. Transport roads on which AGVs travel have also been designed. All the assumed distances to be traveled by AGV vehicles in the analyzed system were taken into account. Input parameters are defined for each of the model elements. Since in real working conditions there are always deviations from the adopted tact of work therefore in the simulation process deviations from the constant tact were assumed using for this purpose the probability distributions implemented in ED software.
For the developed model of the unloading point, simulation tests were carried out. Three scenarios were analyzed. The first, according to the obtained calculation results, used three AGVs for transport operations between the unloading area and the storage area. In scenario 2, two AGVs were used. However, in scenario 3, four AGVs were used. For all three scenarios, experiments were carried out, each of which included 100 simulation observations. As part of the conducted experiments, the average time of transporting 400 loading units from the unloading area to the storage area, the average waiting time of loading units in the unloading area, and the average use of the transport system used were determined for individual scenarios. The obtained results are summarized in Figures 4–7.

The graph presented in Figure 4 shows the states of vehicle groups in individual scenarios. These are the idle of the vehicle, driving with a load, driving an empty AGV, loading and unloading. The highest utilization rate was found in the two-vehicle system at 99%. When the number of vehicles was increased to three, the utilization rate was 97%, while with four AGVs, the utilization rate of the transport system was 93%. The transport system took the most time to return empty vehicles to the unloading area for more loads, it was caused by the need to cover a longer route by AGV in relation to the route they covered with the load. Another time-consuming operation was loading and unloading.
Figure 5. Transport time for 400 loads from the unloading area to the storage area

The graph in Figure 5 shows the transport time of 400 loads from the unloading area to the storage area. With the transport system with 2 AGVs, the average time was 13 hours. The system with 3 AGVs completed this task in the average time of 8h and 47min, while the system with 4 AGVs needed an average of 6h and 52 minutes to complete this task.

Figure 6. Occupation of the unloading zone

The chart presented in Figure 6 shows the occupancy of the unloading zone during the implementation of the transport task by the analyzed transport systems. The graph shows the average, maximum and minimum values obtained from the experiments carried out for each scenario each of which consisted of 100 independent simulations. As can be seen, the occupancy of the unloading zone decreases along with the increase in the number of AGVs included in the transport system.
Figure 7. Distance traveled by AGVs

Figure 7 shows the average distance traveled by an AGV in each of the analyzed scenarios. In the system with 2 AGVs, the vehicle covered an average of 27,800 m, in the system with 3 AGVs it was on average 18,626 m, while in the system with 4 AGVs it was 13,900 m.

4. Conclusions

When using tools supporting the modelling and simulation process, it is important to pay attention to the fact that the potential benefits resulting from their use are greater than the costs incurred for their implementation. The simulation gives the best results when it is carried out in a timely manner, that is at the beginning of the project development. It enables the adoption of appropriate parameters of the designed system already in the initial phase where the costs of implementing the proposed changes are much lower.

The aim of the analyzed task was to determine the optimal number of AGVs. The optimal number of AGVs is one that allows the system to achieve the desired throughput on time. Besides, it must be affordable from an economic point of view.

In the analyzed case, assuming that the transport system should transport 40 units per hour, the best results were achieved with 3 and 4 AGVs. The duration of the task with two AGVs was almost twice as long as with 4 AGVs. The system with two AGVs did not meet the assumed time criterion. Two AGVs also require the allocation of a large space for the unloading area. The selection of the appropriate number of AGVs should be preceded by a detailed economic analysis.

The effect of detailed simulation analyzes should be the improvement of the quality of the characteristics. Conclusions from such analyzes are a valuable element of decision support in the design of logistics processes. In further research, it is planned to use simulation modelling to determine optimal transport routes in warehouses.

5. References

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