AUTOMATED GUIDED VEHICLES (AGV) IN PRODUCTION ENTERPRISES

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Abstract

This paper presents the problems of work scheduling for automated forklift AGVs (Automated Guided Vehicles) aimed at balanced and efficient distribution of the material transported. The analysis of the distribution problem is much easier when treated as a specific case of a general problem of material transfer. The innovative solutions for internal transport proposed in this study are helpful in evaluation of the efficiency in the enterprises through monitoring of performance parameters and evenness of material distribution. The study discusses the problem of supplying construction materials in the aspect of transport from receipt points to storage areas in the warehouse.

Keywords: enterprises, automation, transport, optimization

INTRODUCTION

Enterprises today are striving for improvement in their production capacity and ensuring a more regular material flow. This attracts a great interest in automated systems used in both production and transport. Consequently, automated guided vehicles are increasingly used in modern enterprises for transfer of material goods throughout production lines. This stimulates productivity through facilitation of internal transport systems. However, in times when equipment for AGV systems is being developed and evolving, the software for control and monitoring of groups of vehicles used for the enterprise's internal handling remains far from the expectations in many ways [1].

The main cause of this limitation is the complexity of the problems of using and programming of many AGVs. On the one hand, the need arises for optimization of transport routes between particular points of loading and unloading [2]. On the other hand, the problems of assigning transfer to particular vehicles at particular times in order to avoid possible conflicts and stoppages at the same routes should also be analysed [3]. These two concerns, i.e. optimization of routes and work scheduling, which are independent of each other, cause that the problem of multi-AGV programming is a particularly difficult problem to solve.

The following objectives can be formulated for the analysis of AGV system of material distribution [4]:

- evaluate minimum number of vehicles necessary for meeting transportation requirements;
- propose and assess varied principles of distribution of the tasks assigned to a particular AGV. The parameters will be introduced to allow for comparison of the efficiency for different rules of assignment in terms of material throughput and constant distribution to all UPs;
- the proposal for division of the working area into smaller operational zones (one zone per one AGV) in order to reduce the overload in routes and prevent from the consequences of sharing routes;
- making a discrete simulation based on the case of the evaluation of the effect of changes in each of the above parameters.

Further in the study the author discusses the environment where mobile robots will operate and analyses the number of the vehicles necessary for proper functioning of the system. Furthermore, the author presents the principles of distribution and introduces the parameters that characterize their effectiveness.

SPECIFICATION OF THE TRANSPORT PROBLEM

In the system adopted in the study, which is based on AGV technology, materials are supplied to the loading point in the form of palletized units which have to be distributed to particular locations in the storage area. Variety of the materials delivered and the variety of demand make it necessary for warehouses to be equipped in flow racks. This allows for the definition of precise location of UPs and division of individual racks into groups of goods, depending on the frequency of flow and time of storage. The units that necessitate more time of storage are located further from LP, whereas those that are characterized by shorter times and high transfer frequencies are located closer. Each transporting unit is assigned to a particular point of unloading but it might be also be required at several other points in order to move goods to another part of the warehouse. The proposed transport process is a complete automated distribution of transport units in the form of pallets (EUR 800x1200) from the loading point (LP) to many unloading points (UP) in the receipt zone of the finished goods warehouse using a single or multiple AGV mobile robots. The materials are supplied to the receipt zone by means of the roll conveyors which carry transport units
loaded by means of forktrucks. All other operations, such as reception of goods from loading point by an AGV, transport to a particular unloading point and unloading from the AGV into racks, must be performed independently [5].

**Object layout**

There is one loading point in the receipt zone and 36 target unloading points (k = 36) with the locations presented in the Figure 1. The unloading points are located in three horizontal rows (A, B, C) and twelve columns, which allow for definition of the coordinates of each UP in order identifying them in the future. As mentioned above, the goods are loaded by means of forktrucks into the roll conveyors (LP) and then, by means of AGVs, the pallets with material can be delivered to unloading points with the specified coordinates.

![Fig. 1 Layout of unloading points with division into zones.](image)

**Table 1. Throughput in storage zones and distances from UPs to the loading point.**

<table>
<thead>
<tr>
<th>Storage capacity (pallet units)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - 25 pallet units/h</td>
<td>14.4</td>
<td>15.6</td>
<td>16.8</td>
<td>18</td>
<td>19.2</td>
<td>20.4</td>
<td>21.6</td>
<td>22.8</td>
<td>24</td>
<td>25.2</td>
<td>26.4</td>
<td>27.6</td>
</tr>
<tr>
<td>II - 25-15 pallet units/h</td>
<td>13.2</td>
<td>14.4</td>
<td>15.6</td>
<td>16.8</td>
<td>18</td>
<td>19.2</td>
<td>20.4</td>
<td>21.6</td>
<td>22.8</td>
<td>24</td>
<td>25.2</td>
<td>26.4</td>
</tr>
<tr>
<td>III - &lt;15 pallet units/h</td>
<td>12</td>
<td>13.2</td>
<td>14.4</td>
<td>15.6</td>
<td>16.8</td>
<td>18</td>
<td>19.2</td>
<td>20.4</td>
<td>21.6</td>
<td>22.8</td>
<td>24</td>
<td>25.2</td>
</tr>
</tbody>
</table>

The number of nodes and segments of the routes located on the floor should be specified based on the previously assumed number of LP and UP. The nodes are basic determinants which can be used to define transport routes. Layout of the routes on which the AGVs are supposed to move is presented in Fig. 2. There are two types of shapes of the sections of routes defined for these vehicles: straight lines and corners.

![Fig. 2. Transport routes for AGV system.](image)

**PROBLEM OF DISTRIBUTION AND THE STRATEGY OF SOLUTION**

Standard actions that are aimed at optimum planning and control over a distribution problem are in the case of AGV system discussed in the study defined as follows [7]:

- definition of the locations of the nodes and route sections on the working area with consideration of locations of LP and UP points and capabilities of the trucks,
- evaluation of the number of vehicles necessary for meeting the specific material requirements in individual UPs,
- definition of the parameters necessary for evaluation and comparison of the capacity of the system with varied principles of distribution,
- specification of the principles of distribution for AGV. These describe the procedure for making the decision on which points of UP should be supplied based on the information about the inventory status in LP,
- marking up the optimum routes for the trucks so that they have the highest possible performance,
- determination of the protocols for using common routes by multiple vehicles. It is necessary for AGVs to operate according to particular protocols in order to avoid collisions and stoppages.
The next part of the study presents the analysis of the most important tasks of distribution.

**Determination of the necessary number of AGVs**

It can be assumed that a single truck is capable of transporting $p$ units at a particular time. If total time of moving to $i$ UP point and return to LP is adopted as $t_i$, a single vehicle will be capable of supplying material to $i$ UP point with the rate expressed as a number of transport units per time $(p/t_i)$. Furthermore, if UP point expresses the demand for $i$ transport units at a particular time, the coefficient that represents the demand for AGV for $i$ UP point can be given by:

$$z_i = \frac{x_i}{p} \cdot t_i$$  \hspace{1cm} (1)

The load of the $i$ UP point can be expressed as:

$$l_i = x_i \cdot t_i$$ \hspace{1cm} (2)

This formulation also describes work intensity of the transport vehicle it must perform in order to meet the material demand of UP point. The coefficient of demand for AGVs ($z_i$) for $i$ UP changes its form and can be presented as the coefficient of load divided per AGV’s load capacity:

$$z_i = \frac{x_i \cdot t_i}{p} = \frac{l_i}{p}$$ \hspace{1cm} (3)

This causes that the coefficient of demand for AGVs can be reduced through limitation of the load $l_i$ or increasing transporting capability of $p$ truck. Reduction in the value of $l_i$ coefficient is connected with a reduction in the demand for load units $x_i$ in UP point or shortening AGV’s time to reach this UP, which necessitates an increased trucks’ speeds.

With regard to the considered system, the total of all the coefficients of demand for AGVs in all UP points can be expressed as a coefficient of total demand:

$$Z_c = \sum_i z_i$$ \hspace{1cm} (4)

If $Z_c<1$, one vehicle is able to fully meet the demand for transporting materials. However, if $Z_c>1$, this points to increased transport requirements that exceed the capability of a single vehicle, whereas the value that expresses the number of necessary vehicles should be adopted as a whole number greater than the obtained value. For instance, if $3<Z_c<4$, this suggests that at least four AGVs will be necessary for meeting the total transport demand.

The above simplified analysis of the number of AGVs was possible since the discussed case of material distribution is a specific case of a general problem of material transfer within the enterprise. Moreover, this analysis can be useful only if one AGV supplies goods to one UP point and no conflicts are observed when sharing the routes with other AGVs, which allows for merely initial calculation of the number of vehicles required [8].

**Specification of the conditions of distribution**

**Storage time** in a UP point is represented by the time when the materials is stored until it is moved, assuming the lack of supplies in the meantime. If current level of $i$ UP is $r_i$, their storage time can be expressed as:

$$t_s = \frac{r_i}{x_i}$$ \hspace{1cm} (5)

The value of $t_i$ coefficient can be either positive or negative. Negative storage time refers to the time that elapsed after the inventory level reached zero.

**Priority** which can be assigned to UP points depends on the negative storage time. A value for the storage time ($t_s$) was specified, below which UPs become authorized to receive materials. In this case, a decision is made on which of UPs can be supplied goods by the AGV in next transport cycle.

**Single Transfer** (TJ) to UP point is the distance which must be covered by AGV in order for it to complete the transport cycle $LP \rightarrow UP \rightarrow LP$. In the context of the principles of the multiple transfer (TW), the transport cycle changes its form into a more complex one: $LP \rightarrow UP1 \rightarrow UP4 \rightarrow UP3 \rightarrow LP$, where the order of supplying goods to UP results from the meeting the principles of distribution.

The considered case of internal distribution of building materials is specific in consideration of the form of transport units. The specificity of materials forces manufacturers and distributors to have palletized units in order to allow for their transport, loading and unloading inside the enterprise and at the customer’s place. Considering the form of the load and transporting capabilities of AGVs, it is obvious that they are able to transport a single cargo during a single transport cycle. This allows for exclusion of the multiple transfer from the cases of multiple transport, which is impossible to be realized during distribution of the materials in non-palletized units.

**Single transfer** can be defined as engaging a single AGV at the maximum using its load capacity in order to supply goods to the UP with the highest priority. The conditions of distribution such as time, priority and type of transfer have substantial effect on the decisions of assigning AGVs to UPs during a transport cycle and they also considerably affect the performance and sustainable level of material distribution [9].

**SPECIFICATION OF THE PARAMETERS FOR EVALUATION OF PERFORMANCE**

Evaluation and comparison of system performance with varied rules of material
distribution is possible through specification of concrete parameters.

**UP saturation** means the level of satisfying the demand for the material and can be expressed as a fraction of time when a UP maintains a positive storage time $t_s$. If, after the simulation time $t$, a zero status can be observed for $t_0$ time in $i$ UP point, the positive time of inventory level can be expressed as:

$$t_s = t - t_0$$

(6)

whereas its saturation is given by:

$$n_i = \frac{t - t_0}{t}$$

(7)

assuming that the saturation of all UPs can be defined as mean saturation $N_{\text{sa}}$.

**Mean saturation deviation** is given by:

$$N_{\text{dev}} = \sum_{i=1}^{k} \frac{|n_i - N_{\text{sa}}|}{k}$$

(8)

where $k$ denotes the number of all unloading points (UPs). This allows for determination of the evenness of material distribution while meeting the rules of distribution. Low value of mean saturation deviation provides information about the evenness of material distribution.

**AGV’s utilization level** can be expressed as a fraction of time during simulation when the vehicle was busy with meeting the demand for transfer. If this parameter equals one, this means that the truck is fully loaded and that it cannot meet all the transport assignments. The AGV's stoppage means a time fraction when the vehicles are available for the services but no transfer order occur. It is obvious that both the numerical value of utilization and stoppages of an AGV are approaching a unit, which is different from the case when the vehicle is forced to be queued. AGV's queuing time is expressed as a fraction time when a vehicle waits at the parking place until the route is available for transfer. The lower value of the queuing time means the higher the efficiency of utilization of AGVs. Unfortunately, AGVs' queuing is the "necessary evil" and a side effect of meeting protocols used in order to avoid stoppages in multi AGV solutions.

**Operating time** is the time from starting the simulation until the moment when one of the UPs reaches the zero state, with the simulation starting with a particular random inventory levels for each UP. This situation occurs if the AGV system is unable to meet the material needs of the UP. With the same or identical initial conditions, operating time represents an indicator of the response of operating rules of distribution with respect to material demands in UP.

**Throughput** is a parameter defined as a rate at which goods are transported by AGVs. Transfer of materials can be expressed by means of:

$$M = \sum_{i} m_i \cdot c_i$$

(10)

where: $m_i$ is the number of load units provided by AGVs to $i$ UP, whereas $c_i$ is the number of single transfers to the same UP. Since the specific nature of the vehicles and load units allow for moving a single load during a single transfer, the following expression will hold true:

$$M_i = c_i$$

(11)

therefore, the expression that describes the material transfer will be given by:

$$M = \sum_{i} m_i$$

(12)

If $M$ is performed during time $t$, the throughput can be defined as $M/t$. Assuming that the requested throughput is expressed as $M/t$, the normalized throughput might be at least 1 and calculated as $M/(X \cdot t)$. Since **saturation of UP** and **throughput** affect transport capacity of the AGV system to similar degree, the differences between each other can be easily noticed. The throughput allows for identification of the variety of the needs in closer and further nodes (the further the node the higher workload and time), whereas saturation of UP receives the information from each UP. If the increase in mean saturation was requested, it can be met by increasing the frequency of deliveries to the nearest UPs, which necessitates less time. However it is throughput that represents the true indicator that shows how many material units can be supplied by the AGV system [4].

**MODELLING AND SIMULATION**

Simulation of the assumed case is required for observation of the dynamic behaviour of the system of material distribution. It will be possible through analysis of the situation with the above parameters, with respect to single- and multi-AGV systems and with different rules of distribution. The typical example of the system of discrete events is automated material transfer system (AMTS), where demands for AGV services, replenishment of inventory levels at individual UPs, start and end points of AGVs’ transport cycles or delivery of material to UPs are time-discrete events. In order to apply the Discrete Event Simulation Method for AMTS the following additional assumption are specified [10, 11]:

$$X = \sum_{i} x_i$$

(13)
• since AGV is adapted for moving a single transport unit (1 AGV = 1 pallet unit), it can perform exclusively single transfer to i UP point;
• each UP point, after receiving the load, transfers the load by means of rolls to the most remote storage location;
• AGV robots move at a mean speed of 0.5 m/s during a single ride with consideration of higher speeds on straight lines (ca. 1 m/s) and lower speeds at corners, whereas the assumed AGV positioning time with respect to LP or UP in order to receive or unload the goods is 20 seconds;
• during stoppages, AGVs can wait exclusively in the special parking places;
• type of the goods sent to UP and its inventory states are adjusted and known;
• all the AGVs are able to travel with the same speed in two directions and all route sections have two-directional;
• the requested cargo is always available in LP.

The process of simulation is considered as moving through consecutive points of events in the systems, which is based on the method of ‘event step size’, which considers the time increment until the next event and updates the statuses in the system. Event order can be defined by the system in the form of a table with each entry representing the information about the type of event and the time it occurred. The process of simulation is rather difficult to be carried out and requires knowledge of programming in C++ language. Development of a simulation program will allow for analyses of the parameters such as UP and throughput for any number of transport cycles.

CONCLUSIONS

Solving the problem of planning of an automated transport system presented in the paper is aimed at improvement of the performance and balancing material distribution inside the object considered. The presented investigations of transport automation, with particular focus on application of mobile AGV robots, allow for referencing them to any internal transport systems in enterprises. Specification of the conditions of distribution and individual parameters provide opportunities for development of both individual AGV systems and complex transport networks. The aim of the author was to make readers familiar with the concepts of automation and innovative solutions of internal transport in enterprises dealing with supplying construction materials. Characterization of the parameters used for evaluation of the system efficiency allowed for indicating the most essential factors that determine its performance. Efficiency in any transport or manufacturing system is subject to certain temporal criteria. It is one of the most essential factors that determine the success or failure of the enterprise that functions in local and world markets. Application of automated transport systems allows for scheduling tasks and systematization of the processes while minimizing times and ensuring full control over the material flow throughout the enterprise. Solution to this problem might provide an essential facilitation to the processes of warehousing and distribution in the enterprises that manufacture and supply construction materials.

REFERENCES