HIERARCHICAL APPROACH TO DEVELOPING A LOGISTIC DISCRETE EVENT SIMULATION MODEL USING AUTOMATED GUIDED VEHICLES

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ABSTRACT
The paper deals with the hierarchical approach used in developing a logistic discrete event simulation model using AGV (Automated Guided Vehicles) in a real industrial company. The hierarchical approach (using the principles of object oriented programming and inheritance) was used to develop the simulation model. We used template class programming and we also used the principle of inheritance in the simulation model. We used the structured Excel file to set up the input simulation model input parameters and objects in the simulation model. We used a genetic algorithm to find suitable settings for the simulation model. The simulation model was built in Plant Simulation v. 11.

Keywords: Discrete Events Simulation, Automated Guided Vehicles, Hierarchical Approach to Developing a Logistic Discrete Event Simulation Model, Simulation Optimization

1. INTRODUCTION

Many industrial companies are addressing the issue of internal logistic optimization. One of the possible modern approaches to this topic is the automatic logistic system using AGVS (Automated Guided Vehicles Systems) (Berman, Schechtmana, and Edana 2009). This system ensures the supply of material between production lines and warehouses. This system can fully replace the human factor associated with transportation and thus eliminate some of the risks. However, changing the mode of transport also brings unpredictable behaviour of this transport. This behaviour can be detected by discrete event simulation.

This paper is focused on description of the program of the implementation of the solved simulation project. This project deals with the newly proposed transport using automated guided vehicles (AGV) (Kesen and Baykoç 2007) in a company producing products in the field of ventilation and climate control. The discrete event simulation model was created in Plant Simulation v. 11 (Siemens).

2. SIMULATION PROJECT CHARACTERISTICS

The goal of the project was to verify the proposed method of supplying the production lines using AGV with different numbers of trailers and determining the minimum number of required AGV capable of ensuring the supplying of the production lines. A secondary goal of the project was to verify the behaviour of the proposed transport system. The project was divided into two stages which are mutually linked. Stages included the following main points:

- The first stage was focused on the verification of the transport by AGV to three production lines. This stage was focused on:
  - Mutual familiarization between the sponsor and the project implementer
  - Clarification of the simulation project options to the submitter
  - Defining the suitable input and output parameters and the model statistics
  - Testing AGV transportation for the selected production lines
  - Verification of the proposed solutions to the simulation model
  - Verification of the proposed transportation in the model for the subsequent stage of the project
  - Evaluation of the results obtained from the simulation experiments, report, presentation
- The second stage verified transportation using AGV supplying remaining production lines in the company. This stage was based on the first stage and it is was focused primarily on:
  - Defining the remaining suitable input parameters and complementing the output statistics of the simulation model
  - Checking the behaviour of the planned whole internal transport using AGV supplying the rest of the production lines in the company

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o Finding the suitable number of AGV according to specified customer requirements
o The evaluation of the results obtained from the experiments, the final report and the presentation of results.

2.1. Description of Simulated System

Large parts are supplied by the trailers and it is not possible to load a big number of these parts to satisfy the needs of the production line for a longer time. Hence more trailers must be used for the transport at once. It is also not possible to control the supply in a way that if the supply falls below a certain level there would be generated a requirement for transport from the warehouse (except for a limited number of some parts). This is caused by the transport time which is longer than the time of consumption of the parts transported to the production line.

The whole system of supplying the production lines is based on a simple principle: the tractor with the trailers continually transports the parts and after the unloading of transported parts goes to the warehouse or to pre-production for new parts which transports them immediately to the production lines. Limited capacity of the buffer (parts storage) at the production line represents a regulation in this case. Each tractor has a defined path using different loading and unloading stations which must be passed. The various types of parts are loaded and unloaded at different stations in the company. The parts can be loaded on the trailer at the loading stations in the warehouse or at the various production departments in the company. Each production line has defined several unloading stations for various parts. Schematic layout of the loading and unloading stations is shown in figure 1

Based on the outputs from the simulation model:
- AGV paths have been changed
- Logical errors in the proposed system were deleted
- The minimum number of required AGV was identified
- There were also identified serious potential risks which could paralyze the AGV transport and thus the production itself

2.2. Basic simulation model behaviour

The simulation model was designed in a way that can be managed by the data entered in MS Excel. These data mainly concern: the time characteristics of loading and unloading trailers attached to the AGV (tractor); cycle times of production lines; the number of trailers trailed by the tractor including specification of various types of parts and determining whether the transported part is critical; the maximum size of inventory of parts at the production line; the number of trailers and the transport paths for AGV.
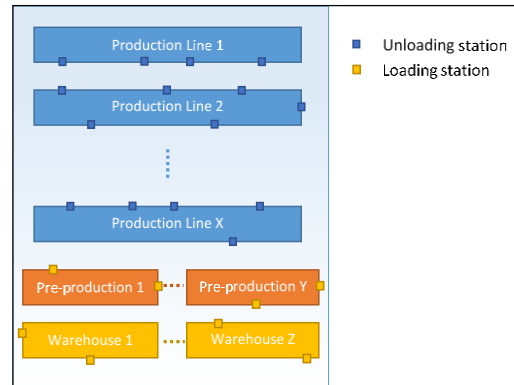

Figure 1: Simple Layout of Loading/Unloading Stations for AGV in the Simulation Model

Production lines are modelled in a simple way using only the cycle time. There are no transport constraints in the simulation model (e.g. transport using the forklifts): the blocking of AGV by the employs entering into the AGV path; discharging the battery in AGV; failure. Modelled constraints are: blocking of AGV arrival at the unloading station because of station occupation by another AGV; blocking one-way transport path because of unsatisfied AGV waiting for the unloading or loading of parts; blocking junction by another AGV; etc.

2.3. Transport behaviour

Transport is characterized by the following points:
- AGV takes the same transport path
- AGV transport paths are defined as one-way paths
- Each AGV is responsible for supplying only one production line
- When the AGV unloads all the parts, it runs immediately to load new parts for the production line
- AGV transports the parts on a defined maximum number of connected trailers
- Each trailer transports the same type of part
- AGV cannot overtake another AGV standing in the transport path
- It is possible to load / connect only one trailer to tractor at IN station in one time
- The trailer contains the information about at which IN station it will be loaded or at which OUT station it will be unloaded
- The trailer is unloaded or disconnected at OUT station. If the trailer is disconnected the tractor must connect another empty trailer at the same OUT station
- One or two employees provide unloading / switching at the production line

2.4. Production lines behaviour

The exact behaviour of production lines is not modelled in the discrete event simulation model. Production is defined by the cycle time of production line and the bill of material. The behaviour of each production line is defined as follows:

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- The production line is defined by the cycle time of production (the time between the completion of two consecutive products)
- There are several unloading / loading stations for each production line
- Key parts are stored in a buffer (parts storage) placed at the production line by the unloading of these parts. This occurs only if there is free capacity of this buffer. When the buffer is full the unloading trailer stops.
- Only one key part of each type is taken from OUT station per one cycle time of production line
- The line stops if any key part is missing

2.5. Unloading / switching trailers at production lines

Unloading and switching trailers at the production line is provided by the operator (worker). Each production line has own operator. The operator can move between OUT stations faster than the AGV. The operator is able to unload / switch a single trailer of one AGV at one time. The operator moves between unloading / switching stations. Unloading / switching trailers are modelled as follows:

1. AGV arrives at the production line and stops at first station of unloading / switching.
2. Checking the trailers to be unloaded at the OUT station.
3. If the buffer has a free capacity the trailers set to OUT station are gradually unloaded / switched. If there is no free buffer capacity the parts cannot be unloaded and the AGV waits.
4. Once it is possible to unload parts, AGV waits for the operator until he comes to the OUT station at the production line. When the worker comes to the station the time of unloading (switching) of the entire AGV starts. Loading (switching) time of the entire AGV is defined for each IN / OUT station. Time of unloading / switching AGV is defined by triangular distribution (minimum, medium, maximum).
5. If all trailers are unloaded / switched at the OUT station, AGV moves to the next OUT station at the production line.
6. Next step is to check whether the next OUT station is served by the same operator. If so, the operator moves together with the AGV to the next position OUT station for AGV. If the same operator does not service another OUT station, operator remains at the current position or he goes to his starting point (defined separately for each location)
7. If the operator comes to the OUT station before the AGV, the operator waits until the AGV arrives (operator cannot begin to operate another AGV). In some OUT stations there is defined the maximum time limit for how long the operator can wait for AGV. The operator

can start operating another AGV if AGV does not arrive in the time limit. Proceed to step 3
8. If AGV leaves the last OUT station on the production line, AGV goes to its IN station (loading)
9. After unloading the last trailer of the AGV at last OUT station on the production line it is recorded how long AGV spent on the production line.

2.6. Simulation model structure

Principles of object-oriented programming were used by creating a simulation model in Plant Simulation software. We mainly used the following principles:

- Creating custom classes
- Using inheritance

The following classes were created for creating a simulation model:

- Production line template
- Station for loading the trailers template
- Station for unloading the trailers template
- Template of station where each AGV with attached trailers is created

2.6.1. Production line template

Production line template representing individual production lines is shown in the next figure 2. The "Production Line" part (orange-tinged part) represents the actual line where up to five inputs exist for up to five different representatives of the critical parts needed to build a product coming from associated unloading stations. "SP" object in this part represents the cycle time of production line. The tables containing data to set the production line are in "Settings of Production Line" section (yellow background). The table named "OutStationList" contains information about which unloading stations the critical parts for the production line come from. Section "Statistics" (green background) contains program code and tables with different statistics about:

- Time required for transport of parts from the loading station to the unloading station at the production line
- Statistics about the unloading part at individual unloading stations
- Statistics about the time needed to unload the entire AGV (all trailers) at the production line
- Statistics about the traffic light located on the production line
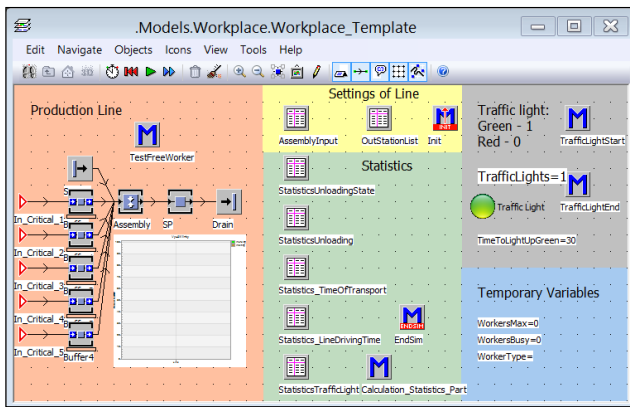
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Figure 2: Production Line Template

The section "Temporary Variables" (blue background) contains temporary variables used for the proper operation of each method performed at the production line during the simulation.

The part "Traffic light" (grey background) was used only in the first stage of the project. It was assumed that only one AGV can arrive at the production line and others must wait before the production line. The part controls the switching of the traffic light.

2.6.2. Station for loading the trailers template
Another class template is a class representing a loading station for trailers connected to the AGV. The "Settings" section (yellow colour) contains information about the setting of the specific station for loading. This section also contains a table defining parts to be loaded at loading station. The middle yellow part is reserved for the setting of time requirements for the distribution function. This distribution function is used to simulate the loading of a trailer. The bottom yellow part defines whether the operator is needed for the loading. This operator helps to unload trailers on some production lines.

"Loading On the Trailer" part (orange background) provides simulation of loading the trailer. It looks like the simulation process of loading the trailer is quite simple but the opposite is true. We used the code implemented by the programming language SimTalk located in the "Loading" method to model the loading behaviour.
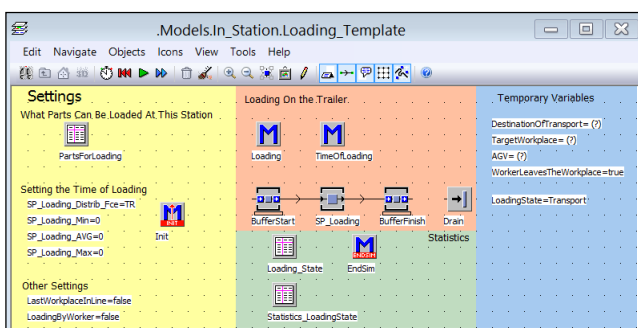

Figure 3: Station for Loading the Trailers Template

The green background section ("Statistics" part) contains tables with the statistics of loading station states stored during the simulation. The section "Temporary Variables" (blue background) contains temporary variables used for the proper operation of each method performed at the loading station during the simulation.

2.6.3. Station for unloading the trailers template
From the logic point of view this class template is the complex model class. This class provides the correct behaviour of the simulation model when the trailers are unloaded. This class must ensure that the trailer can be unloaded when the operator comes to the station. The operator checks the trailer if the part must be unloaded. If so the operator unloads these parts at the unloading station. The operator must check the free place to unload the critical parts before unloading the parts. If there is no free capacity the operator must wait.

If the operator unloads all the trailers this class will ensure that the operator moves together with the AGV to the next unloading station on the production line (only if the operator must unload the parts at the next station). Individual critical parts are merged into a representative critical part of the unloading station and this representative part continues on its production line. This logic is implemented in the "Modelling the Time of Unloading" (orange) section. Almost all the unloading behaviour provides a method called **Unloading**.
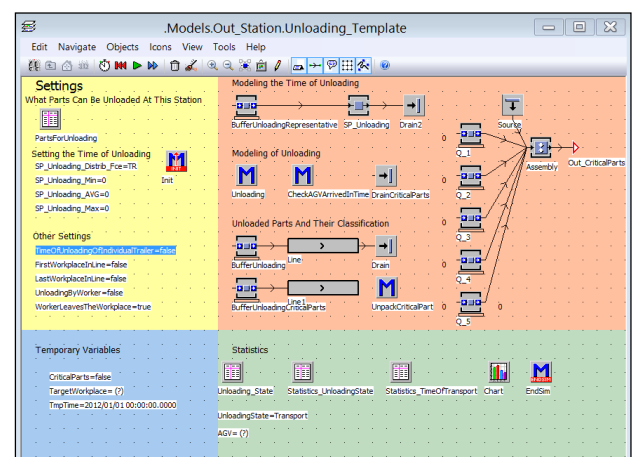

Figure 4: Station for Unloading the Trailers Template

We can find the information about a specific unloading station in the "Settings" section (yellow background). The upper yellow part contains a table that defines the selected unloaded parts at the unloading station. The middle (yellow) part named "Setting the Time of Unloading" is reserved for the detection of time requirements for the distribution function used for unloading a trailer / tractor. At the bottom of the yellow portion is defined:

- Whether the unloading requires operator
- Whether it is the first or last place of unloading on the production line
- Whether the operator leaves the station after finishing unloading or if the operator goes to the starting point provided that the operator does have to unload the same AGV at the following station

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The "Statistics" section (green background) contains tables containing the statistics of the status of unloading station states stored during the simulation experiment. The "Temporary Variables" section (blue background) contains temporary variables used for the correct operations of the specific methods ensuring the unloading of the parts at the unloading station during the simulation.

2.6.4. Template of station where each AGV with attached trailers is created

The last class template to be created is a class that subsequently ensures the creation of the AGV consisting of a tractor providing supplying the specific production line. The trailers are connected to the tractor. Each trailer conveys predetermined transported parts.
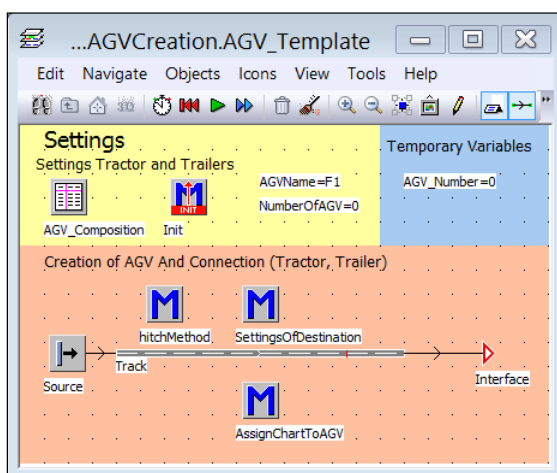

Figure 5: Template of Station Where Each AGV with Attached Trailers Is Created

The "Settings" (yellow) part is again used to define the properties of the AGV (tractor and all the trailers). The "Temporary Variables" (blue) contains temporary variables. The "Creation of AGV and Connection" (orange) part is responsible for the creation of tractors and trailers. Trailers are connected to the tractor and the target station of the AGV is set. The chart showing the statistics is generated for each AGV.

2.7. Setting the simulation model behaviour using input parameters

The project goal was to verify the behaviour of the planned method of supplying lines using the AGV. There are tens of loading and unloading stations. More parts for various trailers were always loaded / unloaded at each loading / unloading station and also the number of different AGV transporting different parts was in the tens. It was needed to set many parameters in the simulation model. Hence almost all parameters setting the simulation model behaviour are stored in a structured Excel file. These settings are:

- The time characteristics of loading and unloading trailers
- Cycle times of production lines

- The number of trailers trailed by the tractor transporting parts
- AGV settings:
- The dimensions of connected trailers
- The transported parts on the trailer including:
- The number of loaded parts
- Identification of critical / non critical part
- Maximum buffer size (capacity) on the production line for the critical part
- The specification of the overall AGV path around the production hall defined by the names of the loading and unloading stations

Downloading a new set of input data stored in the Excel file into a simulation model is performed using the **"Load Data from Excel"** button located in the simulation model - see figure 6. All data are loaded into the tables in the simulation model. After that the adaptation of the model (various objects in the model) automatically starts. This adaptation is performed according to previously described simulation model class templates. In other words, it is all about reconfiguration of the yellow parts and possibly some objects in the orange part of the object.
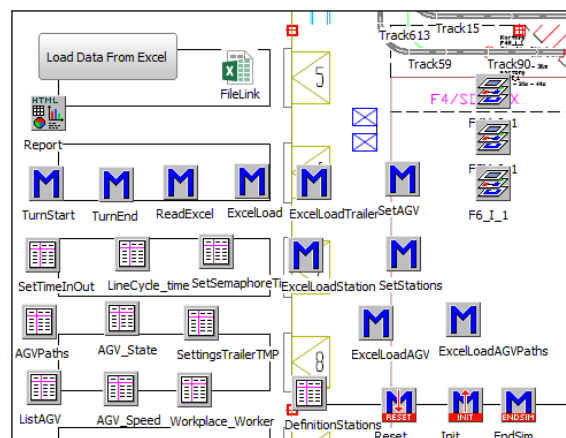

Figure 6: A Part of the Simulation Model Providing Loading of the Input Data into the Simulation Model - Reconfiguration

Operations performed after loading the Excel file into simulation model are following:

- Loading data into hierarchically structured tables of AGV for each AGV type (figure 7):
  - The trailers arrangement – which trailers transport, what and how much can trailers transport, whether it is a critical part for assembly, the size of the buffer containing the parts on the assembly line
  - The default path - which loading and unloading stations AGV must take
  - Retrieving the number of AGV types
- Loading data into structured tables describing the definition of loading and unloading stations:
  - Association of stations with the production line

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- o Defining the number of loaded / unloaded types of parts
- o The list of loaded / unloaded types of parts
- o Unloading all parts of the specific type or unloading only part of them
- Reading process times:
  - o The time of loading / unloading
  - o Cycle times of the production lines
- The reconfigurations of loading and unloading stations – objects are generated according to class template of loading and unloading stations. Objects are located in the production floor. The following steps are:
  - o Filling the list of loaded / unloaded parts (yellow area)
  - o To set the chart displaying statistics of critical parts in buffers on the production line
  - o To set the buffers for critical parts
  - o Which operator operates the unloading / loading trailers
- The setting of the production line:
  - o The setting of assembly – from which stations are the critical parts transported
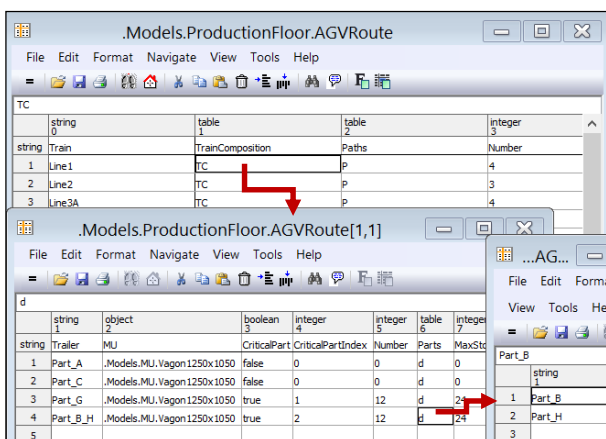

Figure 7: Sample of Structured Tables Defining the AGV

Other modifications of the model are automatically executed when the model is run. These modifications are:

- Objects created according to class template providing generating of AGV:
  - o The number of AGV type
  - o Assignment of specified trailers to the tractor
  - o The setting of which trailers will transport which parts
  - o Creating AGV statistic charts
- Objects created according to class template providing loading:
  - o The setting of the loading time
- Objects created according to class template providing unloading:
  - o The setting of the unloading time

- o The setting of all critical parts assembly into one representative of critical parts from one position
- Objects created according to class template representing the production line:
  - o Setting the cycle times of production lines

We can test different variations of setting the simulation model by this procedure. The risk of errors caused by incorrect setting of any parameter in any object is also reduced. This procedure also eliminates the risk of forgetting to set some parameter in the simulation experiment. Some values can be also changed directly in the model using tables. The model is reconfigured correctly by the simulation run.

2.8. Optimization of the number of AGV
The optimization tool (the module of the Plant Simulation software) was used to find the number of each AGV type. This optimization tool uses a genetic algorithm (Homayouni, Tang, and Motlagh 2014). The optimization algorithm changes the values in the tables used to retrieve values from Excel. Thus the whole setup has been simplified.

Used objective function reflects the average use of AGV (tractor with trailers). The objective function also reflects overall average utilization of production lines. Average use of production lines is superior to the average use of trains using the coefficients in the objective function. The objective function was maximized.

The objective functions definitions:

$$F_1(\mathbf{X}) = \sum_{i=1}^{n} VL_i \qquad (1)$$

where VL_i denotes the utilization of the i-th production line; n denotes the number of production lines.

$$F_2(\mathbf{X}) = \frac{\sum_{i=1}^{m}(10 - VTP_i)}{1000} \qquad (2)$$

where VTP_i denotes the number of AGV of the same type; m denotes the number of AGV of different types

$$F(\mathbf{X}) = F_1(\mathbf{X}) + F_2(\mathbf{X}) \qquad (3)$$

where $F(\mathbf{X})$ denotes the resulting objective function

3. CONCLUSION
The described method of creating a discrete event simulation model was chosen because the simulation model is complicated and the logic of the simulation model is not simple. In addition, during the implementation of the project, there were many changes made to the logic model. Many changes to the logic of the model were made by the implementation of the project. This is because the hierarchical approach using object inheritance was used to create the model. It was easy to change the behaviour of the model class using this approach. Programming changes of the class template implemented in the simulation model also automatically affect a change of behaviour in all

inherited objects of the class. Objects are logically interrelated. Many settings are defined using the built-in tables. The simulation model was automatically adjusted by the run of the model or by retrieving data from an Excel file. We drastically reduced the number of errors in the model and increased the flexibility of the model needed to find the optimal solution of the implemented simulation project by using this approach. The following figure 8 illustrates a situation where a collapse of the whole transport system occurred (because of blocking the AGV by a different AGV). This is an example of a situation which led to a change in the model.
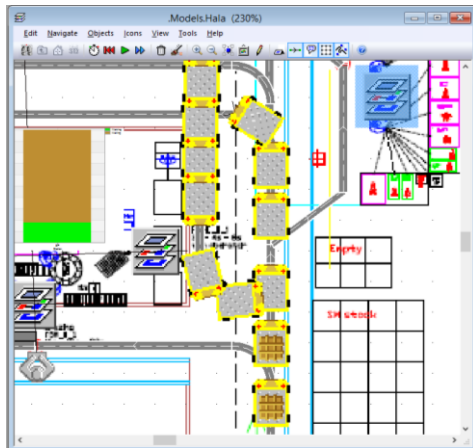

Figure 8: Sample of AGV Collapse in the Simulation Model

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REFERENCES

Berman, S., Schechtmana, E. and Edana, Y. E., 2009. Evaluation of automatic guided vehicle systems. *Robotics and Computer-Integrated Manufacturing*, 25 (3), 522–528.

Homayouni, S. M., Tang, S. H. and Motlagh, O., 2014. A genetic algorithm for optimization of integrated scheduling of cranes, vehicles, and storage platforms at automated container terminals. *Journal of Computational and Applied Mathematics*, In Press.

Kesen, S. E. and Baykoç, Ö. F., 2007. Simulation of automated guided vehicle (AGV) systems based on just-in-time (JIT) philosophy in a job-shop environment. *Simulation Modelling Practice and Theory*, 15 (3), 272–284.

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