Support the Decision Processes in Management Through the Automatic Generation of Simulation Models of Warehouses

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Abstract:

Purpose: *The most important goal of the paper is to demonstrate the possibility of developing and implementing the methodology of automatic generation of warehouse models of various types with the use of ABS – agent-based simulation.*

Methodology: *The highlights of the paper include management support through simple simulation modeling of storage and logistics systems using an agent-based approach, methodology of automatic generation of simulation models using Agent Based Simulation; Description of a new type of mobile, automatically controlled shelves. Simulation modeling is performed with the use of LogABS simulation software. The software engine/source code is written in the C ++ language.*

Findings: *The described mechanism can be extended with the ability to generate other types of storage systems to enable comparisons of their usability for specific input and output streams.*

Practical implications: *The paper describes the methodology, the use of which significantly reduces the time of decision-making in designing warehouse layouts. These decisions concern the organization of space and the choice of the storage technology. Using the described tools enables rapid verification of the given concept by automatically generating simulation models of warehouses, considering various storage technologies, including the drawer rack system.*

Originality/value: *The publication proves that automating the simulation modeling processes of warehouses brings many benefits, allowing simulation technologies to become a tool available to users with neither advanced programming skills nor previous experience in working with such programs.*

Keywords: *Management, simulation, warehouse.*

JEL Classification: *M2, C53.*

Paper Type: *Research article.*

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1. Introduction

Decision-making in the process of designing warehouse layout is time-absorbent and difficult. Its basis is the identification of the needs and possibilities of the enterprise, which are related to the specificity, quantity and rotation of the assortment held. One of the key decisions is choosing between the types of storage, warehouse layouts and infrastructure. The management team regularly selects from among several recommended solutions.

One of the decisions supporting tools is computer simulation. It is used, inter alia, to verify warehouse layout designs. Its disadvantage are the high level of operating difficulties and an extended amount of time needed to build and validate simulation models. For these reasons, a mechanism for automatic generation of various types of warehouses was developed. The mechanism does not require advanced simulation software skills as it is operated within a simple structured interface. One of the most interesting types of warehouses generated by the mechanism is the drawer rack system – innovative idea developed by Zrembud Cieszyn in Poland and currently on the patenting stage.

Above mentioned warehouse is a semi-automatic storage system using racks set on metal frames (called drawers). This storage system is based on single or double sections of row racks turned 90 degrees. Each double rack (drawer) can move perpendicular to the transport corridor. The structure of the rack (the number of storage levels and the number of storage places on single level) can be freely modified depending on the user requirements. The drawer rack system is a modified shelving system with single or double shelving sections that are rotated 90 degrees relative to the transport corridor. The rack movement is perpendicular to the transport corridor and is carried out by an automatic guided vehicle. The layout of the DRS warehouse is shown in Figure 1.

Figure 1. *The drawer rack system*

Source: *Own work.*

From the point of view of material flow, the main challenge is allocation of so-called SKU (stock keeping unit) in warehouse locations. Sliding out the double rack result in closing (partly or entirely) the corridor. It raises a need to prepare new allocation, replenishment and picking algorithms, as none of the existing WMS systems, any of the developed allocation or control methods does not take into account this type of dynamic structure solutions. Specificity of the dynamic structure lies in the fact that address units (locations) change their positions, which causes changes in the accessibility of communication routes- closing and opening of corridors, presented at Figure 2. It causes the necessity to develop a new solution in WMS technologies.

Figure 2. *The prototype of drawer rack system*

Source: *Kluska, 2021.*

The construction of a prototype of such a warehouse is expensive. It combines the development of a new rack structure and a construction of transfer trucks able to lift and move the multi-tone loads (consist of metal frame, racks with height of several meters, and containers with materials). Use of simulation allows testing the performance of such warehouse while verifying various allocation, replenishment and picking strategies. These strategies also depend on the size of warehouse.

Therefore, a research task is per-formed to automate the simulation modeling phase. It enables the user without advanced simulation skills to focus on solving the problems of allocation, replenishment and picking processes, without selecting the method and performing time-consuming process of simulation modeling. The paper presents concept of parametrization and automatic simulation modeling of warehouse with drawer racks system, defines the requirements for the methodology of designing/redesigning such warehouse, and defines the methodology it-self. It also presents the implementation of this methodology and shows the results in the form of an application.

The main goals of the paper are:
- Presentation of the new kind of automated drawer racks and its originality;
- Preparation of basis for defining the methodology of automatic modeling of warehouse using agent based simulation (ABS) as main approach;
- Presentation of initial implementation of defined methodology.

Main contribution is to indicate the possibility of implementing agent technologies for modeling drawer shelves – developing the basis for the methodology for rapid warehouse design. Mentioned methodology enables the automatic generation of warehouse layouts by non-specialized users allowing solving problems using the well-known concepts and terminology but without learning simulation methods and details related to the operation of specialized software. The highlights of the paper are:

- Support of the management through effortless simulation modeling of logistics using agent based approach;
- Methodology of modeling warehouse operations using ABS (Agent Based Simulation);
- Presentation of new type of semi-automated racks.

The paper is divided into six sections. Following an introduction, the second section presents the background of the research. In this section new type of racks - drawer rack system is presented in context of existing racks systems. The second section contains an analysis of the literature on innovation in warehousing and the use of agent-based simulation for warehouse modeling. Third section defines the problem. Proposed methodology to solve presented problem is described in section four. Implementation of defined methodology is presented in section five. The last section contains conclusions and outlines further research.

2. Literature Background

2.1 Innovations in Warehousing

Warehousing performs the important role in the supply chains and has a significant impact on production efficiency (De Koster *et al.,* 2007). Its function is critical in the supply chain (Aamer, 2018; Mostafa *et al.,* 2019; Ribino *et al.,* 2018). Warehouses are complex structures with many different processes and various equipment from different suppliers. All processes and equipment constitute an integrated system (Pawlewski *et al.,* 2018). Warehouses are strategic areas for receiving, handling, storing, and redistributing products (Ribino *et al.,* 2018). Warehouse operations plays an important role in providing the appropriate quality of services and mitigating the fluctuations of supply and demand (Sainathuni *et al.,* 2014).

Improving their performance is the key to avoid or eliminate unproductive bottlenecks in the system. It also includes striving to reduce costs (Aamer, 2017) and save space (Hao *et al.,* 2020). The efficiency of the warehouse is the focal point of competency among organizations to develop the company (Jermsittiparsert *et al.,* 2019).

Nowadays the companies can use many various solutions, involving organizational changes, sophisticated methods, advanced technologies, and tools. The access to such solutions is huge opportunity for improving efficiency and reducing costs, but it is also a great challenge of choosing the best solution from those available on the market, which will be possible to adapt and meet the requirement and restrictions.

It is also important to efficiently and effectively implement new solutions while mini-mizing costs (Stachowiak *et al.,* 2019). Due to the growing needs of companies, the mar-ket is developing new innovations, which are an important factor of the competitiveness (Ivanov *et al.,* 2020), regardless of the type, size, or environment of the company. Such innovations can be in the form of hardware equipment or new software solutions.

There are many studies about concept and implementation of new technical and organi-zational solutions for warehousing. The empirical study of Hao *et al.* (2020) is basis for companies to decide whether to implement Automated Warehouse Systems (AWS). It provides guidelines and measurements. Vasili *et al.* (2012) describe an automated storage system based on split-platforms, and evaluate its performance for various rack configu-rations. They also demonstrate the possibility in improving the system by modifying the number of entry and exit points.

Kulinska *et al.* (2019) describe the benefits of using IT solutions in terms of cost and time of cargo handling, which is the basis for determining system performance. The re-search concerned the following systems: Pick-Radar, Pick-by-Voice, Pick-by-Frame, Pick-by-Point, Pick-by-Light. The cost of these systems depends mainly on the number of users and the type of warehouse. Warehouse processes can also be improved by inte-grating several systems. Yang *et al.* (2012) describes the benefits arising from using dense mobile racks and pro-pose a mathematical model to optimize rack position move-ment and order cluster picking operations to minimize picking time. Rakyta *et al.* (2016) describes the innovations in logistics including autonomous and self-controlled material handling and storage robots, tools, and technologies, Laser guided Vehicles (LGV) and Automated Guided Vehicles (AGVs), Automated Storage & Retrieval Systems (ASRS), Sortation Conveyor Systems & Sortation Technology, MEMS and nano-tech sensors.

Kudelska and Niedbal (2020) prove the positive impact of organizational and techno-logical innovations on the staff workload and efficiency of processes at warehouse pick-ing stations. These innovations involve the use of robots, implementing unit-load system, and diversified distribution of the goods location. The authors used computer simulations to verify the effects of implementing various solutions.

Another interesting and increasingly popular concept is the Internet of Things (IoT). This is the idea that specific physical elements can collect, process and/or exchange data via the Internet. In logistics, it is a network that collects performance information on system components such as machines and electronic devices. Access to this information supports the management and increasing the efficiency of processes (Wortmann and Flüchter, 2015).

Affia and Aamer (2021) are developing a schedule for designing intelligent warehouse infrastructure using the Internet of Things. They also describe the critical points of the project, the implementation of project activities and the factors contributing to the idea of carrying out implementation works.
The study of Aamer *et al.* (2021) describes a theoretical framework used to enable the transfer and sharing of real-time data in a warehouse. The solution includes the use of

RFID technology and the Internet of Things concept. The extension of the existing WMS (warehouse management system) with the Inter-net of Things technology enables the full use of the potential of RFID technology. The use of Internet of Things allows to control all activities and goods in the warehouse. The benefits of implementing it in the warehouse translate into the entire supply chain (Buntak *et al.,* 2019).

Alias *et al.* (2017) also deals with the adaptation of warehouse management systems (WMS) owned by companies to the new requirements related to digitization. It also proposes the processes necessary to carry out such upgrades. Kim and Park (2016) describes the topic of organizational completeness, which can be increased by implementing modern WMS systems, updating existing systems, as well as implementing new advanced IT solutions and technologies such as sensors, robots, Big Data.

Rakyta *et al.* (2016) describes actions for successful implementation of smart logistics and smart maintenance in the companies. Paper describes the following technologies: Voice-Directed Warehousing, Voice Picking, Voice in the warehouse, and machine to machine (M2M) networking. Mourtzis *et al.* (2019) describes framework for designing highly adaptive and flexible warehouses, that support the integration of an Augmented Reality (AR) warehousing system.

2.2 Agent-Based Simulation of Warehouses

Simulation, due to the possibility of creating an abstract reflection of reality and freely manipulating it within space and time in an isolated simulation environment, is a tool that allows defining and understanding the dynamic complexity of systems (Cempel, 2005). The simulation can be used in various ways. For complex systems, simulation experiments allow evaluation of the system behavior before and after implemented changes, allowing alternative solutions to be assessed. Conducting experiments in a virtual environment eliminate the need for time-consuming, expensive, and often unmanageable concept of testing and improving the existing system. In many situations, computer simulation is the only tool that allows understanding the behavior of the system, the interaction between its variables and limitations of system performance (Ribino *et al.,* 2018).

Simulation software is a useful and valuable tool for building and researching multi-agent systems – current hot issue in the computer science and artificial intelligence. A multi-agent system is also a warehouse in which various autonomous systems and subsystems cooperate with people, robots, and equipment in order to carry out mate-rial transport and information flow. To achieve the assumed design goals, the simulation model of a logistics warehouse should offer a wide range of modifiability.

Kato and Kamoshida (2020) propose an approach for reducing modeling time of simulation model of the warehouse and its modifications. They describe an architecture of independent agents and information exchange in a multi-agent simulation (MAS) environment.

Liu *et al.* (2017) designed a multi-agent logistics simulation platform named MultiBots which can simulate the real warehouse logistics system and evaluate corresponding task allocation strategies.

For autonomous vehicles, Pannocchi *et al.* (2017) presents a simulation framework for multi-vehicle autonomous systems. Peñaranda, *et al.* (2017) proposes the use of SPADE MAS platform and multi-agent system to improve mobile robots' arrangement.

3. Problem Definition

The main goal is to build a 3D simulator for the automatic generation of drawer shelving systems including the transport means (Transfer Units and forklifts) and their routes in a way to enable the user creating its own algorithms for controlling a warehouse and checking the effectiveness of these algorithms through testing in simulation experiments. In order to achieve the goal, the task was structured. It consists of:

- A platform object with racks - a set of platforms forming the structure of the entire warehouse;
- Markers on the floor - a set of markers and their relations forming the structure of the transport network;
- Object Transfer Unit - a set of units forming the transport structure of platforms with racks - i.e. these objects have the ability to drive under the platform, lift it, transport it to another place and leave it at this place;
- Forklift (in the future semi-autonomous or autonomous) - set of forklifts forming the transport structure responsible for transporting logistic units from the collection area (entrance) to the shelves with racks and from the racks to the delivery area (exit);
- Management object - an object/mechanism with open structure, enabling the user preparing and implementing various management algorithms.

A standard location addressing system is adopted - the address consists of the following elements:

- Corridor number, e.g., 37;
- Left / right side of corridor: A - left side, B - right side;
- Shelf number in a row, e.g., 18;
- Level identifier (the number of level), e.g., c;
- Horizontal position identifier (the number of position), e.g., 2.

The example addresses 37A_18_c_2 indicates the storage position – location in the 37th corridor, row of racks on the left side of corridor, rack number 18th, level c (third shelf from the bottom), second position on the shelf (in depth).

The logic of forklift and Transfer Unit requires two-way communication. The forklift receiving the task (of picking or putting the SKU from / to a specific location) must synchronize its movement with the Transfer Unit responsible for sliding out of a shelf in

given corridor (from a defined side of the corridor) by the length of the slide determined by the horizontal position identifier. Synchronization should be carried out in order to avoid the forklift waiting for the platform and to evade collisions.

The number of Transfer Units is constant for a given warehouse structure and results from the number of rows of platforms with racks. The number of forklifts is variable and depends on the user's decision. SKU allocation problem is not considered in this paper. It should be solved independently (it does not affect the structure of the warehouse) and consider the structure of the SKU set as well as operations carried out in the warehouse (based on historical or forecast data).

4. Problem Solution

To solve the task defined in section 3, a hybrid methodology combining the parametric approach (prepared templates: platform with racks, object representing the Transfer Unit, object representing the forklift and object representing the management module) with a structure-based approach (the structure is a corridor-based system and platforms with racks, described by the addressing system) was developed. It is generated based on parameter settings provided by the user. This methodology also takes into account the agent approach, treating objects representing Transfer Units, forklifts and the management object as agents cooperating with each other.

The following steps in methodology have been defined:

1. Definition of a project (the goal, decision variables, performance measures);
2. Analysis of the rack structure - modification of object representing the platform;
3. The topographic data - definition of warehouse and storage area structure parameters;
4. Definition of restrictions for warehouse structure;
5. Development of mechanism for generation of platforms with racks and storage areas (locations) based on defined parameters;
6. Definition of restrictions related to the movement of vehicles;
7. Development of mechanism for automatic generation of transportation network;
8. Definition of restrictions for Transfer Units;
9. Development of mechanism for automatic generation of agents representing Transfer Units;
10. Definition of restrictions for forklifts;
11. Development of mechanism for automatic generation of agents representing forklifts;
12. Preparation of high level user friendly language for writing the logic of vehicles work;
13. Definition of information flow directions and communication rules for vehicles;
14. Definitions of the input data structure regarding the flow of materials at warehouse;
15. Development of a mechanism for automatic generating routes for vehicles;
16. Development of mechanism for presenting the results of simulation experiments at automatically generated charts;
17. Verification and validation of mechanisms.

The implementation of the first two stages constitutes for definition of the project and preparation of information and structures to build an automatic warehouse generation mechanism. The next three steps are the process of building this mechanism.

In accordance with the methodology, objects (templates) were developed in a simulation model. These objects create the library and are copied to the model in accordance with the defined parameters. The object representing the platform with racks consists of the so-called container, which has the dimension of the platform (with defined length and width, without thickness), on which the set of so-called locations is placed. Locations are SKU storage places, which are represented by a rectangle (its parameters are length and width, without thickness) along with the arriving point to this rectangle. The arriving point is a marker on the floor that identifies the point to which the forklift can move to pick up or put away the logistics unit.

Figure 3 shows the platform with assigned locations representing individual storage locations identified by the address described in section 3.

Figure 3. *The platform with set of locations representing storage places in racks*
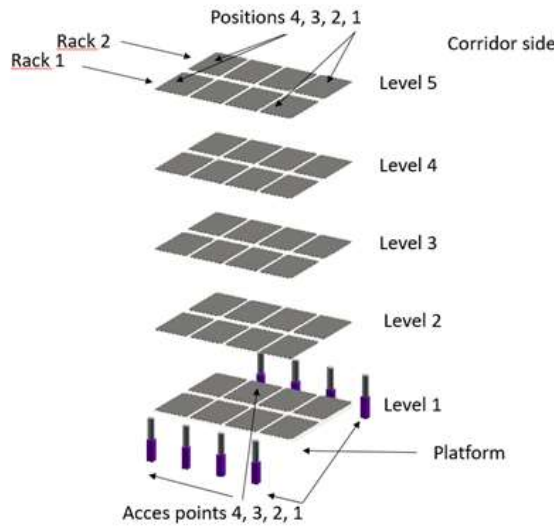
Source: Own study.

Table 1. *Parameters of warehouse structure*

Para-meter	Description	Unit of value	SRS	SRR
Xcr	X coordinate of the first rack in global coordinate system of simulation model	m	X	X
Ycr	Y coordinate of the first rack in global coordinate system of simulation model	m	X	X
Nrr	Number of rows of racks	pcs	X	X
Nrsr	Number of racks in a single row. In warehouse all rows have the same number of racks	pcs	X	X

CV	The way of corridors generation. Value 0 means an even corridor – corridor with shelving rows on both sides. In case of value 1 in the first corridor the racks will be generated only on its right side	no.	X	X
Cw	Corridor width. This parameter applies to all corridors in the warehouse	m	X	X
Psw	Width of a platform with a single rack	m	X	X
Pdw	Width of a platform with a double rack	m	X	
Plen	Length of platform – length of a rack	m	X	X
Dr	Distances between racks arranged side by side	m	X	X
Fnr	Number of forklifts in warehouse	pcs	X	X
Ph	Platform height. The distance from the locations on the first storage level to the floor	m	X	
Th	Total height of warehouse. The maximum height of loaded rack	m	X	X
BV	Variant of buffers arrangement - the number of variant of inbound and outbound buffers placement relative to storage area	no.	X	X
Snr	Number of sections - the number of racks sections to define in warehouse	pcs	X	X
SPnr	Number of storage places within a single storage level (defined for each section)	pcs	X	X
Lnr	The number of storage levels (defined for each section)	pcs	X	X

Source: *Own study.*

Each location is uniquely identified by the address, while its dimension results from the parameter settings, that are described later in this section. As the platform slides out, the location address in 3D space changes (described by the X, Y, and Z coordinates), but the logical address remains unchanged. Therefore, operating with a logical address simplifies Transfer Units and forklifts management.

The set of defined parameters of the warehouse structure is contained in Table 1. Next to the parameter name it is indicated what type of warehouse parameter applies: SRS - drawer rack system, SRR - row rack system.

Steps 6 and 7 include the construction of a mechanism for automatic generation of transport network consisting of various kinds of checkpoints (driveway points) – Table 2. These points guarantee traffic safety and enable its management.

Table 2. *Parameters of transportation network*

Para-meter	Description	Unit of value	SRS	SRR
Ccap	Maximum number of forklifts in single corridor	pcs	X	X
Dln	Distance between edges of locations and nodes (N_xx, and I_xx) – the safety distance for loading and unloading operations	m	X	X
CHnr	The numer of movement channels within a single corridor	pcs	X	X
Ds	Distance between edges of Transfer Unit and forklift during extension of platform – the safety distance for platforms manipulation	m	X	
Da	An additional distance for extention of platform – for easier manipulation of loads	m	X	

Source: *Own study.*

Checkpoints designates:

1. Forklifts paths between corridors;
2. Places of forklift entry and exit to/from the corridor;
3. Forklifts paths between rows of racks;
4. Transfer Unit paths under rows of shelves;
5. Points in the corridor to which Transfer Unit slide out the platforms with racks (to allow forklifts to access the storage places) and points that determine the path of the Transfer Unit to return to the row of racks when the platform is pulled back;
6. Places in front of the racks where forklifts stop in order to carry out loading and unloading operations;
7. Stopping place of forklifts while waiting for the Transfer Unit to stop moving;
8. Detour path around the extended Transfer Unit (with platform) for a forklift.

Necessary input and output parameters of storage areas (inbound and outbound buffers) are described at Table 3.

Steps 8-11 are steps using an agent approach. The object representing the Transfer Unit is an agent that has a dimension determined by the parameters and the ability to perform routes described in the tables assigned to a specific object. The tables represent cycles of moves. In these tables agent routes are stored in high-level scripted language, the example is shown in the Table 4. It contains the list of tasks of Transfer Unit cycle work. The task is formed by row, where "Address" defines position (point on floor) or platform, "Task" defines operation according to description in (Pawlewski, 2018), and "Parameter" defines time or number. Each Transfer Unit is characterized by set of visual and movement parameters, which are described at Table 5.

Table 3. *Parameters of storage places*

Parameter	Description	Unit of value
SRx	Width of a single storage place in X axis	m
SRy	Length of a single storage place in Y axis	m
Dspy	Distances between storage places on the Y axis	m
Dspx	Distances between storage places on the X axis	m
L1	Height of first level of storage	m
L2	Height of the second level of storage	m
L3	Height of the third level of storage	m
L4	Height of the fourth level of storage	m
L5	Height of the fifth level of storage	m

Source: *Own study.*

Table 4. *List of tasks of Transfer Unit*

Address	Task	Parameter	Description
–	ReadyForTask	–	Start of cycle – waiting for request from WMS
GG_001	Travel	–	Moving under the row of racks
/S1A_5	PickUp	–	Pick up the platform
GG_002	TravelLoaded	–	Ejection of the platform
–	ReadyForTask	–	Waiting for request from MFC

GG_001	TravelLoaded	–	Moving back of the row of racks
VS1A_5	Lowercontain	–	Lowering of the platform at its default position
–	Call	1	Return to the beginning of the cycle – to the first row of this table

Source: *Own study.*

**Table 5.** *Parameters of Transfer Unit*

Parameter	Description	Unit of value	Reference value
TUw	Width of Transfer Unit	m	2,60
TUlen	Length of Transfer Unit	m	3,60
SLmax	Maximum speed for movement without load	m/s	6
SLacc	Acceleration without load	m/s/s	3
SLdec	Deceleration without load	m/s/s	3
Smax	Maximum speed for movement with load	m/s	4
Sacc	Acceleration with load	m/s/s	2
Sdec	Deceleration with load	m/s/s	2
Pt	Time of picking up the platform	s	2
Rt	Time of release the platform	s	2

Source: *Own study.*

Two racks form the section that can be moved by transfer unit in directions presented at Figure 4. The rules of Transfer Unit are defined as:

- Start position racks 2&3 - section 2;
- R motion from section 2 till the section 9;
- B motion from position 1 (on the level/shelf) till the position 5.

Figure 4. *The drawer rack system*
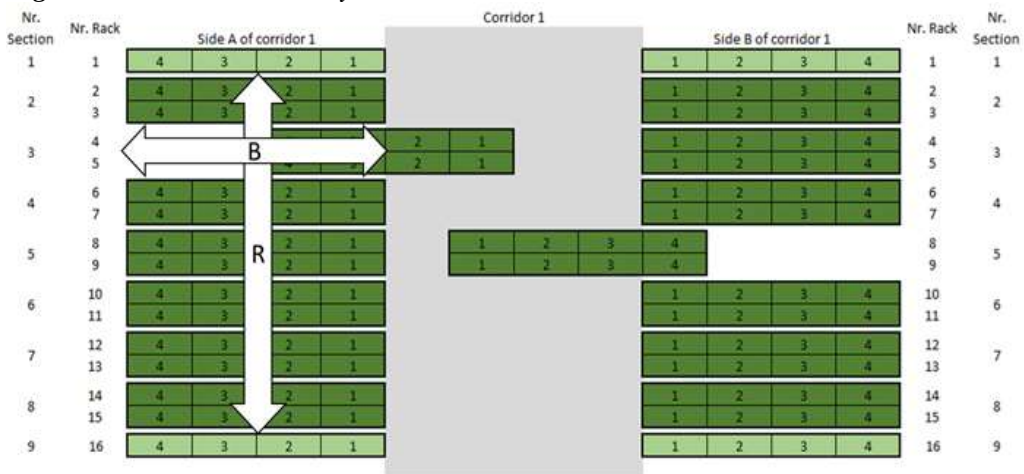
Source: *Own study.*

Next agents in the system are forklifts. They are cooperating with Transfer Units by sending and receiving signals. Agents that represent forklifts (one or more) works in two cycles:

- Receiving – from inbound buffer where materials are unloaded from trucks, to addressed rack;
- Delivering - from addressed rack to outbound buffer.

Transport orders with addresses are prepared by WMS. Forklift drives up to the slid out shelf always along the row from which the shelf has moved out. Tables 6 and 7 contains exemplary lists of tasks for receiving and delivery cycles.

Table 6. *Exemplary list of tasks for receiving operation of forklift*

Address	Task	Parameter	Description
–	ReadyForTask	–	Start of cycle – waiting for request from WMS
GG_015	Travel	–	Moving to receiving area (inbound buffer)
P_13	Load	1	Loading single pallet
GG_023	TravelLoaded	–	Moving to the entrance of corridor
N_07	TravelLoaded	–	Moving forward through the corridor to the rack
P_07	Unload	1	Unloading single pallet to the rack
GG_023	Travel	–1	Moving backwards to the entrance of corridor
–	Call	1	Return to the beginning of the cycle – to the first row of this table

Source: *Own study.*

Table 7. *Exemplary list of tasks for delivery operation of forklift*

Address	Task	Parameter	Description
–	ReadyForTask	–	Start of cycle – waiting for request from WMS
GG_023	Travel	–	Moving to the entrance of corridor
N_02	Travel	–	Moving forward through the corridor to the rack
P_02	Load	1	Loading single pallet
GG_023	TravelLoaded	–1	Moving backwards to the entrance/exit of corridor
GG_017	TravelLoaded	–	Moving to the delivering area (outbound buffer)
–	Unload	1	Unloading single pallet
–	Call	1	Return to the beginning of the cycle – to the first row of this table

Source: *Own study.*

Forklift parameters such as speed, acceleration and deceleration are stored in a data-base and depends on the model of forklift. During the phase of agents' generation researchers based on their earlier experiences (Pawlewski, 2015; 2018a; 2018b). Pawlewski (2018a) define the script language for describing the agent's behavior. To build the logic for designed simulation model the most important issues were:

- Levels of control and analysis;
- Using cyclic and agents approach.

The work cycles on following levels were identified:

- On the Transfer Unit and forklift level;
- On the control/management level – MFC/WMS (MFC – Material Flow Control system, WMS - Warehouse Management System).

Agent approach consists of describing and implementing the system operation logic in a distributed and autonomous way (as in reality). Central control and management (equivalent of MFC/WMS) is also treated as operation of the agent. To build the mechanism for automatic generation of simulation logistics model it is not necessary to focus on level of automation. The most important is to focus on level of rack's Transfer Units and forklifts, and define the rules for Transfer Units, forklifts and level of management. Steps 13-15 include definition of all necessary issues for generating routes for vehicles, considering the structure of input data, information flow directions and communication rules for vehicles.

Structure of input data describes the transport orders and defines:

- Type of task (receiving or picking operation);
- Address of storage location;
- Address of collection area (inbound buffer) or delivery area (outbound buffer);
- SKU.

The algorithm for Transfer Units and forklifts management is shown in Figure 5. It is divided into six modules.

The first module activates the algorithm, loads, and process the input data, as well as monitors the availability of forklifts and Transfer Units. The second module manages transport orders. At this stage algorithm selects and assigns orders to available vehicles. Then the third module analyzes assigned task, specifying:
- The inbound and outbound buffers' location in relation to storage area in the warehouse (in order to define how routes should be generated);
- The type of racking platform to operate with - a single or double racking platform (in order to define whether or not activate Transfer Unit);
- Which side of the double rack the address defines (what number of routes is needed);
- To what extent the double rack has to slide out (what access path to set for vehicles; when vehicles will exchange signals initiating their movement);
- As well as the type of order - receiving or picking operation.

The fourth module generates routes for forklifts and Transfer Units and activates forklifts. In the fifth module algorithm observes the state of vehicles, records the fulfillment of transport order, and sets vehicles as available. It enables reactivation of the second module and continuation of the orders implementation. As vehicles fulfill all orders from the list the sixth module is activated. It generates routes that allow vehicles return to parking lots.

**Figure 5.** *The logic for management of Transfer Units and forklifts work*
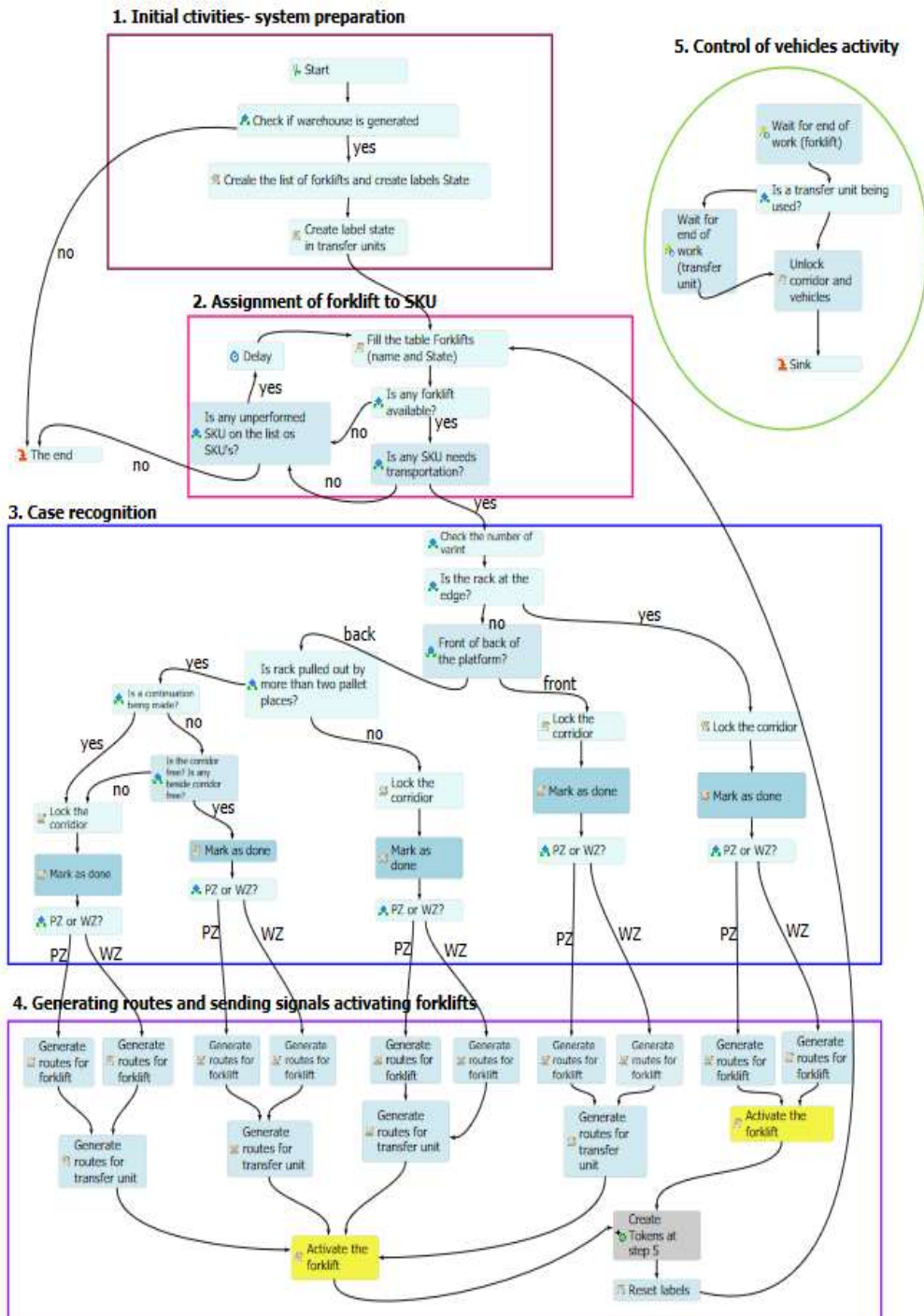
Source: *Kluska and Hoffa, 2020.*

The mechanism utilizing high-level script language enables generating routes and saving the instructions (corresponding to activities carried out in the real world) to the database along with execution times. The databases have the form of tables that can be displayed to read out the duration of individual instructions. Such data collecting standardizes the way of observing and recording changes in the state of objects, and thus enables the automatic generation of time charts as the results of simulation experiments.

Similarly, data is recorded regarding the distance travelled by the units each time they follow "Travel" or "TravelLoaded" instructions. This data enables the automatic generation of a chart displaying total distance travelled by all forklifts and Transfer Units during the simulation experiment. Figure 6 shows the developed mechanism for generating charts.

Figure 6. *Scheme of processing implemented routes into automatically generated time charts*
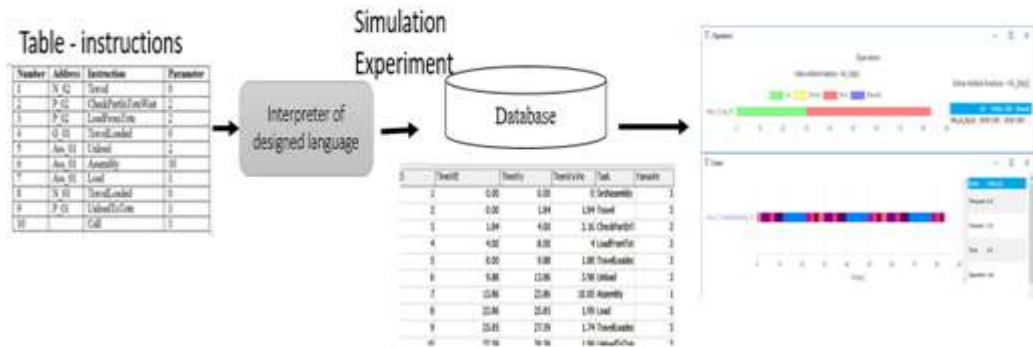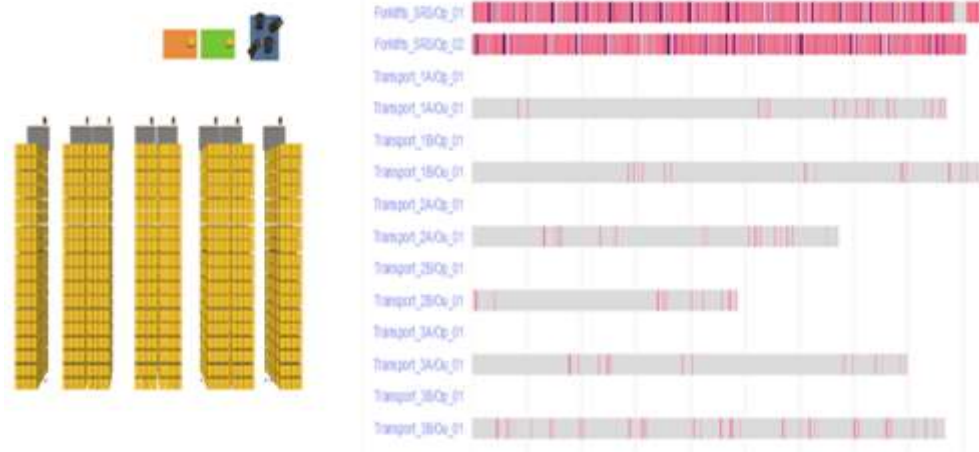

Source: *Own study.*

5. Implementation

Based on the developed methodology, a simulation application was designed and built. The core of this application is the FlexSim GP graphics engine offering 3D modelling using the DES approach. FlexSim GP is used in this case as a simulation operating system. Based on this engine, a layer has been built that implements operations defined in the form of a high-level scripting language (Pawlewski, 2018a). At this layer, the mechanisms of the high-level language interpreter and a database have been defined. The database stores set of operations performed altogether with their durations (shown in Figure 6).

Based on these structures, a set of tables defining warehouse parameters, a mechanism for generating warehouse structure, a mechanism for generating routes for forklifts and Transfer Units, a mechanism for assigning tasks and synchronizing operation of Transfer Units and forklifts, as well as a mechanism for automatic processing of vehicles' routes into time charts were developed. These charts show graphically the progress of high-level instructions during the experiment.

The developed application is dedicated to the user without advanced simulation skills. Therefore, an interface has been designed in order to allow building a simulation model by filling in the template tables with values of defined parameters. Figure 7 shows a model of a row shelving system with a generated graph of operations performed by units during a simulation experiment. More about implication of methodology and initial results of simulation experiments is described by Kluska and Hoffa (Kluska and Hoffa, 2020; Kluska, 2021).

Figure 7. *The time charts generated automatically based on performer vehicles routes*

Source: *Own study.*

6. Conclusions

The methodology for automatic warehouse generation presented in this paper has been implemented in the form of a simulation application. It enables generation of drawer rack systems. The developed method effectively shortens the modelling time of the warehouse, and its use requires only filling the tables with the values of defined parameters.

The entire warehouse altogether with transport infrastructure is automatically generated. A separate module manages transport orders and operation of both types of vehicles. This mechanism is based on algorithms and allows building, improving, and testing subsequent concepts of warehouse control.

Using the designed mechanisms, the application is expanded with the possibility of generating row rack warehouses and can be additionally expanded with other types of storage systems. This enables simultaneous generation of many types of warehouses and their performance comparison for the same input and output streams. The use of methodology to compare different types of storage is useful support in decision which type of storage will be better for enterprise.

The producer of drawer racking systems plans to use the application to test ware-house management algorithms. These activities will provide the basis for constructing the WMS (Warehouse Management System) system and will set the direction for further re-search.

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