

SELECTED ASPECTS OF SIMULATION MODELLING OF INTERNAL TRANSPORT PROCESSES PERFORMED AT LOGISTICS FACILITIES

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Abstract: *The transport is an important part of logistic systems. Improper management of transport operations may contribute to the low level of the usage of vehicles and to high transport costs, as well as to the formation of unnecessary high inventory at each location of storage, as well as prolonged time of order realization and not full use of company capacity. It is therefore important the appropriate dimensioning, planning of the transport system and performed transport operations so as to allow the supply of certain goods at the right time and the amount to the appropriate points of the system. The article presents the methods of transport operations modelling, taking into account different criteria based on discrete event simulation. In the article the case study of modelling transport operations in the small cross-docking centre is also presented.*

Key words: *transport, logistics system, transport operation, simulation, optimization*

1. Introduction

Inside facilities such as warehouses, distribution centres, manufacturing plants and container and freight handling/reloading terminals an important is the role of systems and processes of freight transport. They are an integration element for other subsystems, and the efficient handling of load stream largely depends on the efficiency of realized transport operations. They belong to the main components of all processes and logistics systems and they require a number of activities to be proceeded, such as planning, controlling, managing both within its internal and internal area. Technology and the method of organization of the internal transport processes in the company is one of the key factors affecting the level of flexibility of the other processes for which, the materials flow is important. Transportation as a system is a kind of connection between areas, for example production and storage or consumption zones and it consolidates separated subsystems and ensures the exchange of goods between these subsystems. Therefore, an important challenge for each unit becomes the continuous improvement of the functioning internal transport system, often on the basis of an automated solution. The activities of the transport system should be coordinated with other activities and company processes, such as manufacturing, warehousing, storage or realization of orders. The main criterion used in the design and

rebuild of the internal transport systems is to maximize the efficiency of use of the basic processes. When defining tasks for these systems there is a necessity to take into account many parameters and relations between them. Important is the decision-makers awareness that the modification of one parameter may have a positive or negative effect on the operation of the system. It not infrequent, that making decisions need to take into account many factors, and the problem can be formulated as a multi-criteria optimization task.

In modern logistic and production systems, the automated transport systems are often used. Transport tasks in such systems can be realized with the use of e.g. AGV type unmanned vehicles. Such solutions are widely used in many fields: e.g. storage systems, flexible production systems and transport of containers in container terminals. In many modern systems, in which we have to deal with the materials flow, the solutions based on the AGV type transporters are selected due to the belief that this will increase the efficiency and flexibility of the system, and operating costs will be decreased. An important aspect of the design of such systems is the selection of a control method for vehicles and / or transport orders. This action usually must be preceded by a thorough analysis of system behaviour, in particular with regard to its dynamics. In general, this is a big challenge for designers, because the scale and complexity of

above discussed system is still increasing, and the study of transport systems effect on other elements and components of systems in terms of their dynamics is virtually impossible with the use of analytical methods.

The main aim of this article is the analysis of selected aspects of modelling the internal transport systems using methods of stochastic discrete event simulation. Structure of the article is as follows. The second chapter presents a review of current literature, including the problems of modelling and optimization of transport operations carried out in different logistic facilities according to various criteria. The next chapter discusses the basic components of the models of transport systems and basic decision problems. The content of the fourth chapter contains the elements of simulation models of processes and operations, and the method of the model constructing and logics of the realized processes. The next part of the paper presents an example illustrating an analysis of transport operations in the cross-docking centre with simulation methods and the evaluation of the three variants of objects flow control within the examined system. The final section of the article presents the most important conclusions and summary.

2. Issues on modelling and optimization of transport operations – the review of current literature

A wide class of problems (for the solution of which, the logistic decisions are made) contains systems of internal transport of companies and materials flow and processes related to the freights handling. Decisions in this area relate to the flow of materials within the production plant or logistic facility. Basic decisions relate to the selection of the load units parameters and equipment used for materials handling (conveyors, roller belts, hand pallet trucks, forklifts, systems of dual track suspended conveyors of Power & Free type, unmanned carriages of different types). The problems associated with internal transportation issues and concerning dimensioning and design of transport layouts and systems is raised by many authors, including [3, 4, 13, 16, 17, 19, 22, 24, 27]. Designing of internal transport involves the selection of transport means, taking into account the technological requirements, combining them in

a transport network and the determination of transport routes in the available space. In turn, the dimensioning of such a system is the determination of the length of transport routes, their capacity and determination of the necessary number of transport vehicles. Issues related to the organization of the system relate to the construction and configuration of control concept, while scheduling is aimed to determine the optimal plan for transport orders realization in the particular system. Very often the travel of a vehicle from start to destination point has a stochastic nature, because the transfer time depends on unpredictable factors such as traffic density, weather conditions, etc. In contrast, the transport of a workpiece on a conveyor belt at a constant speed in a production plant, is a deterministic type.

The determination of the number of AGV automatic vehicles (*automated guided vehicles*) in an open container warehouse is the subject of the work of Vis and others [32]. The authors propose a network model and algorithm of minimum flow in order to determine the optimum number of vehicles, which provides the support of the load, assumed in the storage system. The work of Ambroziak and Jacyna [1, 2] presents the issue of the determination of the parameters characterizing the dynamics of the transport process. The authors applied the theory of mass service models for the support of multiaspect analyses of transport processes. The work of Devikar and others [11] presents a methodology for modelling and analysis of complex suspended transport system of a Power & Free type, performing the transport operations in a flexible production system. Simulation studies were performed to identify bottlenecks and to determine and improve the efficiency of the transport system. Analyses were performed assuming a peak load with transport tasks.

Another group of issues relating to the internal transportation is a problem associated with scheduling of transportation tasks. In paper of [15] Gharehgozli and others, authors use the exact methods for scheduling the transport operations carried out by the crane in the marine container terminal. The objective of the optimization is to minimize the total travel time of the crane during the realization of all transport orders. Another issue related to the internal transport is the vehicles routing. It refers to the designation of routes and

path that must be travelled by vehicles in order to carry out the transport tasks within the coverage area. As noted by Carlo and others [5, 6], in the literature, the most of the problems have static nature. The same authors point out that in the actual systems of internal transport operations planning, the importance is gained by disposing systems that allow for the dynamic analysis of current orders of transport processes and appropriate control of assigning vehicles to order, or vice versa – orders to vehicles.

A wide class of objects, in which issues of planning, scheduling and controlling operations and transport tasks are important elements of the decisions made are reloading terminals and cross-docking centres [4]. Paper of [25] Legato and others presents the model of work and scheduling of the operations carried out by the crane in the marine container terminal. The authors formulated the assumptions for the optimization model using mixed integer programming (MIP), and then, they used the notation of time Petri nets to build a simulation model.

In the cross-docking objects, the internal transport can be carried out manually (e.g. using pallet vehicles), or using the automated system, for example the networks of conveyors or AGV transporters. The choice of transport method generally depends on the type of freights handled at the terminal. And as for handling loads on pallets, usually forklifts are used. In turn, solutions that use conveyors are often used by operators performing courier, express and parcel shipments (CEP). Practiced is also a combination of these two methods of transport realization [4]. In the objects of this type, the internal transport is the basis for the effective realization of tasks and handling the operation of incoming and outgoing load. Vahdani and Zandieh in the paper [31] proposed five metaheuristics to solve the problem of scheduling transport tasks and minimization of transport operations time in the reloading centre: genetic algorithm (GA – *genetic algorithm*), searching in accordance with the list of forbidden moves (TS – *taboo search*), simulated annealing (SA – *simulated annealing*), electromagnetic algorithm (EMA – *electromagnetism-like algorithm*) and a searching in the variable neighbourhood (VNS – *variable neighbourhood search*).

The above discussed issues generally relate to large, complex internal automated transport systems. In many logistic facilities, the fundamental element of logistic transport are different types of trucks operated by the operators. In paper [28] Takakuwa and others presented problems of constructing simulation models for transport operations in non-automated distribution centre. In the conclusions part, the authors drew an attention to the much greater difficulty in building simulation models for such systems in comparison to automated handling solutions (eg. AS/RS systems, conveyors, AGVs, etc.) due to their complexity. A similar opinion is also shared by Clausen and others in work [9]. In their paper, they studied the application of simulating a manually operated distribution warehouse characterized by complex and dynamic processes. According to the authors, simulation and models are needed to meet the challenges of the transportation and logistics problems of today and the future.

Summarizing this part of the article one can say that during analysis of the literature, it is possible to find that many of the proposed solutions concern the specific issues and they often take into account one of the criteria of formulated tasks optimization.

3. Modelling systems and processes of the internal transport

In complex systems of internal transport, it is possible to distinguish the following as the basic elements of the structure:

- places where loads are taken to the transportation mean,
- points of reloading, unloading,
- one or more transport means,
- transport routes,
- places where load or transport means handling is carried out (e.g. places of charging the battery, the required loads processing, etc.).

A very important element is also the transportation management system which allows to control vehicles and the allocation of transportation orders. The purpose of such a system is to decide when, where and how vehicles should be allocated to tasks, including decisions regarding the routes on which the vehicles will be moved. If all tasks are known before the commencement of the planning period, the problem of planning is static and can be solved without the knowledge of future states of the

system. However, in practice, the accurate information about the locations of works (tasks) of the vehicle are not usually known at the plan design stage. Thus, the development of the transport tasks schedule in such a mode is virtually impossible. In such case, it is often necessary to apply an approach known in the literature as dynamic scheduling, which consists in the allocation of transport tasks to the resources (transport means) using different rules of tasks prioritization and vehicles allocation.

During the construction of the transport system model, its network nature is often taken into account. Transport networks are usually described using directed graphs [3, 19, 22]. Directed graph G can be represented as two:

$$G(V, E) \quad (1)$$

including the not empty set of V nodes, $V = \{v_1, v_2, \dots, v_n\}$ and the set of ordered pairs of vertices called as arcs $E = \{e_1, e_2, \dots, e_m\}$, which is the subset of $V, E \subseteq V \times V$ set. The first and the second element of the ordered pair (v_i, v_j) is called respectively as the start and the end of the arc. An example of the graph which may represent the transport network is shown in the figure 1. The presented graph is not a complete one – there are no arcs between node 1 and 5, and between node 2 and 4. Node 1 and 5 are designated as the source and sink, and they indicate respectively the load taking location (source) and the target transport location (sink).

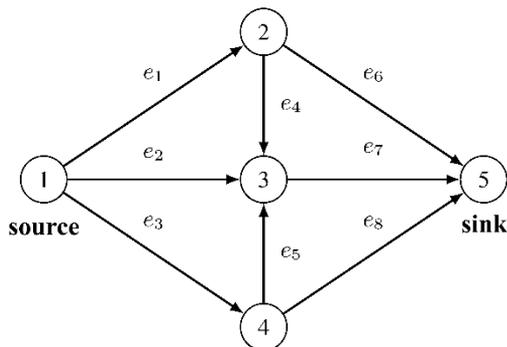


Fig. 1. Graph of the sample transport network

The flow of materials in such a network is often formally represented as the adjacency matrix $A(G)$. The elements of the matrix $A(G)$ are defined as:

$$a_{ij} = \begin{cases} 1, & \text{if the arc } \langle i, j \rangle \text{ exists} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

The distance matrix $D(G)$ corresponds with adjacency matrix of $A(G)$. Elements of distance matrix are defined as:

$$d_{ij} = \begin{cases} d(i, j), & \text{if the path from } i \text{ to } j \text{ exists} \\ \infty, & \text{otherwise} \end{cases} \quad (3)$$

An expression of $d(i, j)$ means the distance determined for the transport task from i to j point. For $i=j$ the distance of $d(i, j) = 0$, when between the vertices there is no arc, the distance is determined with symbol of ∞ (infinity).

One of the main problems for structure of transport network, defined by dependencies of (1–3) is to determine the minimum path between two nodes in the network. Such nodes are referred to as source and sink, which means the place of taking load for transport (source) and destination of transport (sink).

In logistic systems, the problem of determining the shortest path often occurs in practical applications directly and as a partial task of more complex issues. There are three main variants of the problem:

- 1) the determination of the shortest path between two given vertices;
- 2) recognition of the shortest paths from a particular vertex called the source to all other vertices of the graph and
- 3) the determination of the shortest paths between two any vertices of the graph.

To determine the shortest route, the widely described in literature algorithms are used, among others Dijkstra, Bellman-Ford, heuristic search of A^* , Floyd-Warshall and others [7, 8, 12].

An effective analysis and planning of internal transport systems operation requires the application of appropriate solutions and tools. Depending on the scale of the problem, as well as the complexity of the tested systems and processes, the researchers dealing with the above issues have different classes of methods for their disposal: analytical methods, identification and optimization methods based on operational research algorithms and methods of discrete event simulation (DES), that enable the analysis of the dynamic behaviour of the system

and the detailed study of the time parameters associated with the different states of the system entities. In case of applying a discrete event simulation methods it is possible to carry out thorough researches and experiments on the models taking into account the detailed elementary operations and information on transport processes.

4. Simulation models of selected transport operations

4.1. Simulation method and environment – the discrete event simulation

Methods of discrete event simulation are used in modern simulation packages to which the DOSIMIS-3 packet belongs [21, 22]. It is a graphical, interactive package used for modelling, among others, the internal transport systems. By using standard modules as sources, sinks, processing stations, vehicles, buffers, or conveyors the user in a relatively simple manner can represent transport system elements. Available modules (representing the emergency conditions and down times) allow for the analysis of blockages, interferences or disruptions in the materials flow, analysis of their causes and locations. Also the processes of loading and unloading the load to and from transport vehicles, as well as the processes of reloading and repackaging may subject to modelling in the DOSIMIS-3 environment.

4.2. Identification of transport processes and operations in models of discrete event simulation

The input data used in the models of internal transport operations and processes include the distance between the vertices of the network, data on transported goods (number and place of source and sink, time data), the vehicle data (type, capacity, speed, etc.) and additional data (e.g. rules of parking of available vehicles or the principles of energy management repair policy principles).

In the simulation model built in the used simulator, the equivalent of graph representation is the representation of the transport network with the use of predefined elements that reproduce the functionality and logics of the actual internal transport infrastructure elements. The relationship of the mathematical model elements in the form of a graph and the simulation model built in an

integrated modelling environment is shown in Figure 2.

Another important component of transport processes models is an element called crossing (complex node) used for the presentation of the nodes involved both in merging and distribution of transported loads streams. Such elements may represent with such components the real processes like crossings in transport systems, receiving and distribution nodes. Element takes n input streams with a fixed strategy of input priority selection (e.g. FIFO, maximum occupancy of the predecessor, priority of input, etc.). The input stream may be divided into m output streams and the balance of the input and output streams flow will have the following form:

$$\sum_{i=1}^n \lambda w e_i = \sum_{j=1}^m \lambda w y_j, \quad n, m \in \mathbb{N} \quad (4)$$

The parameters of n and m determine the number of inputs and outputs of crossing type elements. Capacity of C_E element equals one, which means that within a certain time, there can be only one object in the node (e.g. vehicle or carriage). An important parameter of type crossing type module is also the length matrix between the specific inputs and outputs, described with the formula of (3).

The algorithm of objects pass through the complex node element has the following course. At the first moment, the decision on the selection of inputs, from which the object is passed is made. After receiving the object on the basis of the agreed distribution strategy, the number of output to which it will be directed is being determined. If it is possible to transfer the object to the selected output, the transport of the object occurs. Transport operation time $T_{t_{ij}}$ depends on the defined transport velocity v_t and distance of s_{ij} between the i -input (IN_i), and j -output (OUT_j):

$$T_{t_{ij}} = \frac{s_{ij}}{v_t} \quad (4)$$

In practice, it may also be necessary to take into account the vertical transport T_{t_v} – there are many solutions where the input and output points are located at different levels and in addition to the horizontal transport, also the vertical one is required, e.g. using the elevator (fig. 3).

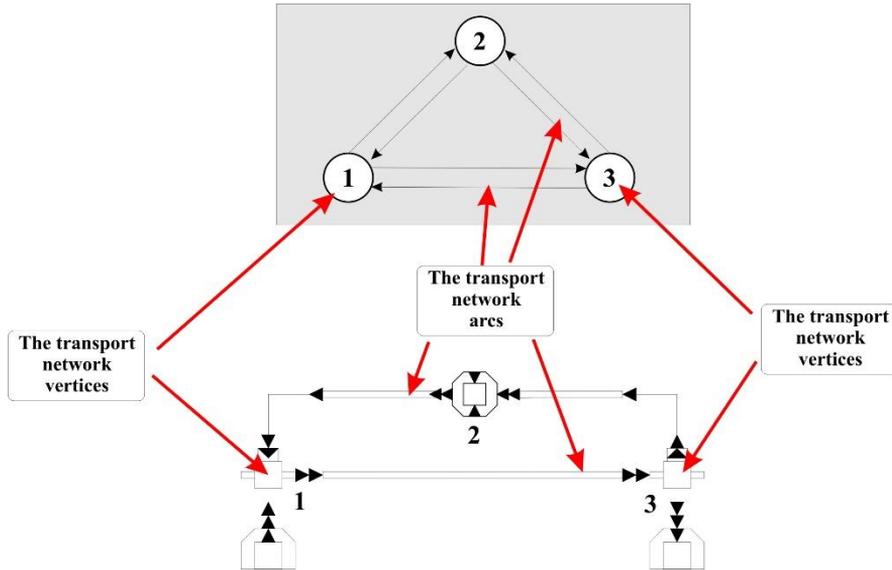


Fig. 2. Illustration of relations of components in transport system models: graph model and simulation model built in the simulator environment

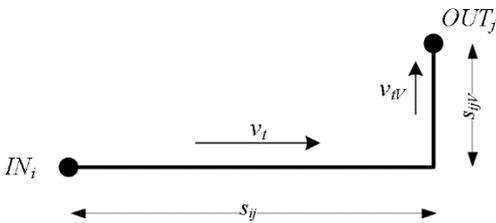


Fig. 3. Horizontal and vertical transport between input IN_i and output OUT_j in crossing module

In such case it is required to take into account the additional track of s_{ijV} , which must be passed during the vertical transportation at the usually different velocity of v_{tV} . In such case, the transport time of the mobile unit from input i to the output j will equal:

$$T_{t_{ij}} = \frac{s_{ij}}{v_t} + \frac{s_{ijV}}{v_{tV}} + T_{pos} \quad (4)$$

where T_{pos} is the time of vertical transport device positioning and this component has often significant effect on the entire transportation time.

In order to distinguish the different types of vehicles in the model it is required to assign a type to the appropriate objects – it consists in assigning an integer number to the specified type of vehicles. The load transported by vehicles is the object taken from the loading station and the transport order is described with two parameters:

- the first specifies the location (address of loading station), from which the load is to be taken - in the simulation model also named as the primary destination;
- the second indicates the location (address of unloading station) to which the load is to be delivered – also defined as a secondary destination.

In case there is a one-time need to transport more than one load using the carriage, it is possible to specify a rule for laying the cargos which is based on the following principles:

- **FIFO** (*First In First Out*) – the sequence of loading is the same as the load arrival to the station. The load which is going to arrive to the loading station as the first is loaded onto the vehicle as the first.

- **LIFO** (*Last In First Out*) – loading is done in the reverse order than the arrival of load – at the first the last load is going to be loaded.
- **shortest path** – an order of loading is carried out according to a distance from the destination point. Thus, the firstly loaded item is the load for which the target is closest from the loading station.

Unloading takes place in *unloading station* which is pre-defined for a given load. This operation takes place at a time specified by the one who builds the model (determined or random). After completion of unloading, it is required to make a decision on how to dispose the empty vehicle. In such situation, the vehicle can remain at the unloading location, transported to the node with specified address or particular station or parking location as not to block other vehicles.

All elements (i.e. vertices of the transport network, e.g. loading and unloading stations), through which the vehicles might be directed has got a special attribute assigned which specifies the address (location) of the transport station. For these elements, it is required to enter parameters concerning, among others the time of loading and unloading, the number and types of goods sent or received in loading and unloading stations.

An important element during the construction of simulation model is to determine the **principles of vehicle and transport orders control**. These principles should include the determination of vehicle tracks and this is done by assigning them to specific purposes – the unloading stations or service stations. The main task of planning is to assign a **transport order** to the vehicle available from a **pool of vehicles**. The method of assigning orders can be realized in a static or dynamic manner, resulting from the actual events and states in the model.

Another practical problem is the range of the transport subsystem control principles. Here, it is possible to distinguish two cases:

- 1) global transport control – it allows for the management of all vehicles allocated within the system and assigned transport orders;
- 2) local control of the transport – there is often a need for autonomous rules for certain parts of the transport system which realizes certain tasks; also if there are several independent

transport systems in a model, they can be provided with individual controls.

In the second case, the local rules cover both the pool of vehicles, as well as loading and unloading stations and the transport tracks.

For the assessment of the internal transport systems, most of all the indicators on the efficiency of transport means use and proportion of the time of individual states (of the transport mean) to the total simulation time (operation time of the investigated system) are used. The following (among others) may be included in the states that describe the transport mean: transportation with load, failure, battery charging, empty transport, loading, unloading, inaction, drive to the point of transportation order, etc.

4.3. Enhancing simulation models – application of decision tables

The mapping of the transport systems often requires special strategies. For example the management of the vehicles would have to be organized globally and the disposition of the transport orders should be realized in some special way. In this case, the functionality of the built transport system models can be extended by using the decision tables (DT) [21]. Decision tables describe the logics of the system operation or the process realization depending on the occurring conditions and respective actions in the system. The decision tables define the conditions and describe under which circumstances they will be executed. The table also contains instructions concerning the behaviour of particular element of the model, when the condition is met or not. These mechanisms are very useful for testing complex algorithms controlling the flow of mobile objects (loads, load units, vehicles, persons, etc.) and information flow and they are usually used when it is not possible to realize the assumed objects flow or model behaviour using the standard parameterization and strategy. The decision table notation is borrowed from symbolic logic, and it is developed specifically for solving data processing problems. They are designed to make simple, clear, unambiguous statements. They allow to reach a precise and solid way to represent sophisticated policies, control algorithms and business logic. DTs, similar to *if-then-else* and *switch-case* statements associate conditions with actions to

perform. One of the main advantages of using decision tables as a specification method is that the sophisticated flow logic can be expressed in a compact form in a table by combining rules. The following elements are included in the formal description of the classic decision table:

- condition set $C = \{C_1, C_2, \dots, C_n\}$ – it determines the finite set of possible conditions for the specified decision situation (e.g. condition C_1 – vehicle arrives the reloading station, condition C_2 – on the vehicle there is a X type load);
- condition domain $CD = \{\{Y, N\}\}$ – a set of possible values that can be assigned to the conditions; usually it constitutes the two-element subset of logic values Y (Yes) and N (No); the number of conditions in decision tables determines unequivocally the conditions space – which is the subset of all combinations: $CS = \{Y, N\}^k$ – as an example for the decision table, represented by four conditions, the number of combinations of equals $2^k = 2^4$, which is 16;
- action set $A = \{A_1, A_2, \dots, A_m\}$ – it determines the finite set of possible actions that will be taken

in case of meeting or not meeting the decision rules;

- action domain $AD = \{\{Y, N\}\}$ – similarly as for conditions domain – it determines the set of possible values that will be assigned to the action. The general structure of a decision table is shown in Figure 3.

Using decision tables for solving particular problems, it is possible to integrate both qualitative and quantitative models that perform some calculations (e.g. to determine the value of a condition variable or to execute an action). An important step in constructing decision tables used in the simulation model is the procedure of verification and validation of implemented algorithms. Within the frame of this procedure, first of all the consistency of decision table is checked – the decision table is inconsistent (or it contain contradiction), if there is a pair of overlapping rules and the corresponding actions are different. In addition, the completeness, exclusivity and inclusiveness of rules contained in decision table are examined.

Decision table							
Conditions		Condition combinations matrix					
C_1	\emptyset	1	0	1	0		1
C_2	0	0	1	1	0		1
C_3	0	0	0	0	1		0
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots	...	\vdots
C_n	1	0	0	0	\emptyset		1
Decisions (actions)		Decision rules matrix					
A_1	X	\cdot	\cdot	X	\cdot		X
A_2	\cdot	\cdot	\cdot	\cdot	X		\cdot
A_3	X	\cdot	\cdot	\cdot	\cdot		\cdot
\cdot	\cdot	\cdot	X	\cdot	\cdot	...	\cdot
A_m	X	X	\cdot	X	\cdot		\cdot

Fig. 3. The general structure of a decision table

DOSIMIS-3 simulator also allows the use of decision tables, that can enhance standard discrete-event modeling approach. As in the case of general-purpose programming languages, decision tables can handle local and global variables. In discrete event simulation models decision tables may be used, for example, to:

- locking and unlocking of junctions,
- changing movable object types,
- generating new object types (in sources and in other parts of system),
- choosing one exit among others for an object to depart an module,
- choosing one entrance among others for an object to enter an module,
- elementary arithmetic operations,
- monitoring and control material flow in the system (for example, *a condition*: a buffer in some part of model is full, *an action*: direct movable object to destination with free space).

5. Case study – a model of transport processes in the small cross-docking centre

This chapter considers a model of small cross-docking system. The tested cross-docking centre consists of three incoming docks and four outgoing docks. Transports of loads to the centre arrive to each of the three receiving docks and arrival stream is described with a random time between arrivals of a normal distribution of NORM (35, 10) minutes. Each transport is composed of a random number of palletised load units, determined for each transport and specified by the uniform distribution of UNIF (15, 33). For the purpose of analysis it was assumed that the average time of unloading and / or loading (including passing by the external transport mean) of a single unit load is 20 seconds and reloading processes between docks are realized without the storage phase. Furthermore, it was assumed that each pallet load unit may fall on the one of four output docks with the equal probability (in case of the actual schedule, the target dock is specified on the reload list).

Transportation between the input and output docks is done using three forklift trucks for which the average speed of the transportation is 12 km/h. The distance between any incoming and outgoing dock is 35 m, and the distance between the adjacent incoming and outgoing docks is 7.5 m.

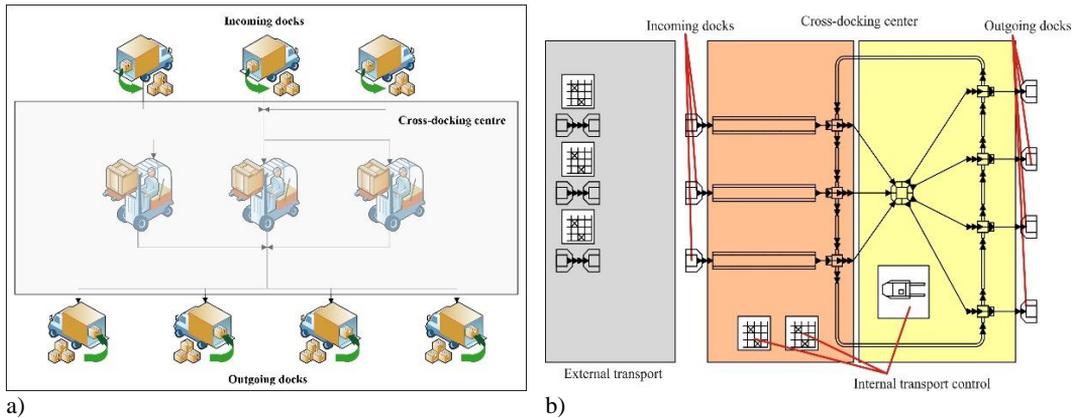
Tab. 1. Summary of the data used in the construction of a simulation model

The time between the transport arrival to each of the three input docks	NORM (35, 10) [min.]
Number of palletised unit load	UNIF (15, 33) [PLU]
Unloading time, loading time from and onto the external transport mean	20 [s]
Number of forklift trucks	3 [pcs]
Forklift trucks average velocity	12 [km/h]
The distance between any incoming and outgoing dock	35 [m]
The distance between adjacent incoming and outgoing docks	7.5 [m]

Within the frames of the study, the simulation model of the described above system was built and the analysis of several variants of transport means motion control inside the cross-docking centre was performed:

- Variant 1) – forklifts remain in place of the last unloading and they wait for the next shipment order; after it occurs, they are moved to the input dock from which the notification was received;
- Variant 2) – free forklifts are sent to the central input dock (labelled as dock 2) and there they wait for the next transport order.
- Variant 3) – the forklift is in advance assigned to one of the input docks and it is directed to this dock when it is free.

The aim of the simulation studies was to compare the simulation three above variants of vehicles control, to determine the statistics of palletised unit load presence in the system and to carry out the analysis of docks use. Figure 5 shows a sketch of the discussed cross-docking centre and a part of the simulation model built in the simulation environment. The model was built in the simulation environment using elements for which the functionality was presented in subsection 4.2, while the algorithms realizing assumed variants of transport system control were implemented with the use of decision tables.



a) Fig. 5. Scheme of the cross-docking warehouse (a) and a part of the internal transport model implemented in the simulation package (b)

Generation of a random number of loads for external transport was implemented in decision table triggered in case of arrival of transport mean to the centre:

– **local variable:**

```
pallet_count:=dice(15,33) - dice
function initializes the generator of pseudo-
random numbers and it returns a number from the
range of (15, 33)1;
```

– **condition:**

```
act_module.exiting=1 - act_module
variable refers to the input dock where the
external vehicle arrived;
```

– **action:**

```
for(i:=1;i<=pallet_count;i:=i+1)
module(1).gen_object(1) - for the
transport arrived to the considered dock, a list of
objects corresponding to palletised unit load is
generated in an amount which equals
pallet_count parameter.
```

In case of determination of the destination dock for the load, the algorithm implemented in the subsequent decision tables has the following form:

– **conditions list:**

```
act_module.f_obj.f_load.type=1 -
carriage with determined load )
act_module.exiting=1 - the carriage
leaves the current dock;
```

– **action:**

```
act_module.f_obj.new_destination(
dice(4,7)) - assignment of the random
output dock number (numbers from 4 to 7) to the
shipment order, realized by the carriage.
```

In turns, the algorithm for the third rule of vehicles disposal after unloading was realized as follows:

– **conditions list:**

```
act_module.f_load.type=0 - empty
carriage
act_module.exiting=1 - the vehicle
leaves the current dock
act_module.f_obj.agv_no=1 -
identification of the carriage number (1)
```

– **action:**

```
act_module.f_obj.new_destination(
1) - the carriage is directed to the input dock
with a number 1.
```

For the evaluation of the simulation results, the basic characteristics determining functioning of the transport system are used. These include among others the time of shipment order realization, transport process duration and the number of serviced shipment orders. The time analyses of transport cycles distinguish transport times and times of the shipment order realization that are not

¹ Random function `dice` generates integer values from the uniform distribution on the interval $[a, b]$; $\text{dice}=\text{round}(a+(b-a)*\text{rand})$, where `rand` is a low level function for generating uniformly distributed pseudorandom numbers and `round` is a function that rounds the real random number to the nearest integers.

identical values. The transport time is counted from the moment of allocation until the deposit in the unloading station, while the duration of the transport order covers the time from the order assigning in the list until the moment of release. Simulation results concerning the statistics of transport cycles for individual variants are summarized in table 2.

Tab. 2. Times of reloading palletised unit load transport cycles in the centre – results of simulation experiments

	Forklift	Max. time [s]	Aver. time [s]	Min. time [s]
Variant 1	1	616,39	265,82	99,59
	2	572,79	268,37	98,4
	3	604,6	263,47	112,59
Variant 2	1	420,6	165,87	39,59
	2	476,39	168,68	38,4
	3	504,6	163,8	76,8
Variant 3	1	423,6	165,72	39,59
	2	476,39	168,08	38,4
	3	507,6	163,84	72,59

In table 2 it can be noticed that variant 2 and 3 do not differ significantly, taking into account the transport cycle times for individual orders and carriages. Much longer cycle times were obtained in case of variant 1 – this results from the adopted strategy of separating carriages after unloading, when these carriages are left at output docks. The following statuses are assigned to the operations related to assignment of shipment orders, vehicles and their service:

- started – it includes the time from the appearance on the list until the assignment of the vehicle to the realization;
- empty drive – it is the time from vehicle assignment to the order service until the moment of taking the load at the loading station;
- transport – it is the time of transporting load from the loading to the unloading station.

Figure 6 presents a diagram of shipment orders realization statuses for variant 1 of performed simulations.

The diagram above shows that each of the three carriages for more than 16% of the simulation time spent on moving without the load, in turn, it is possible to see the long times of waiting for assignment of orders to vehicles (status started), which results in a long queue of shipment orders.

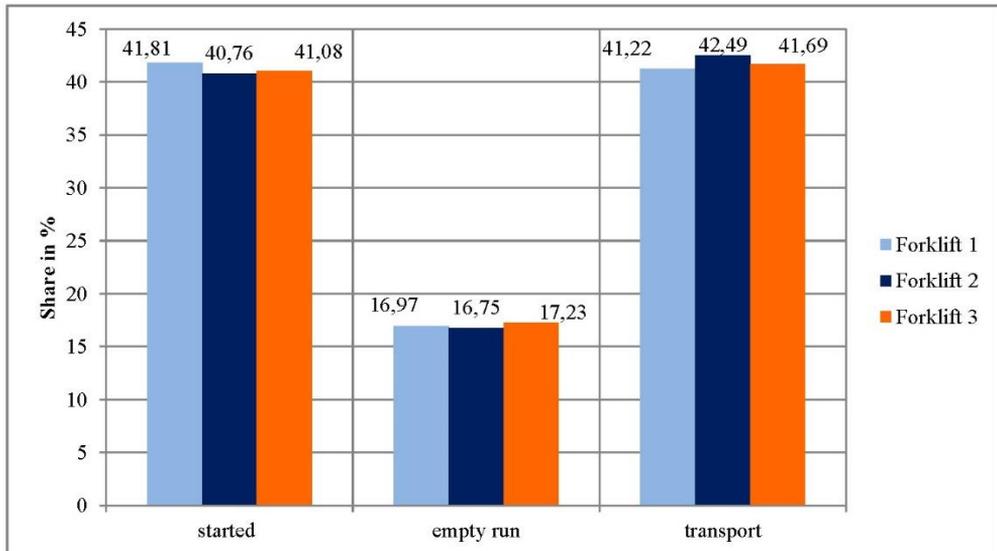


Fig. 6. Diagram of transport orders realization status share for variant 1 of cross-docking terminal model simulation experiments

The diagram above shows that each of the three carriages for more than 16% of the simulation time spent on moving without the load, in turn, it is possible to see the long times of waiting for assignment of orders to vehicles (status started), which results in a long queue of shipment orders. The result of detailed analyses relating cycles of shipment orders realization and the allocation of vehicles to shipment orders there should be the improvement of the quality of the functioning characteristics of the analysed transportation system. Conclusions from such analyses are a valuable component of decision support in logistics facilities.

An analysis of the simulation results makes it possible to evaluate the utilisation of particular

transport means, analyse transport cycles and to monitor the queue of shipment orders (fig. 7), transport process (times between loading and unloading event) or transport order throughput times (times between order activation and unloading event; with additional empty run of vehicle to loading station, example statistics for variant 1 of simulation experiment is shown in figure 8).

Available statistics and calculations make it possible to carry out a comprehensive analysis of the transport system, to identify possible interferences and to compare the characteristics describing the functioning of the system under different circumstances.

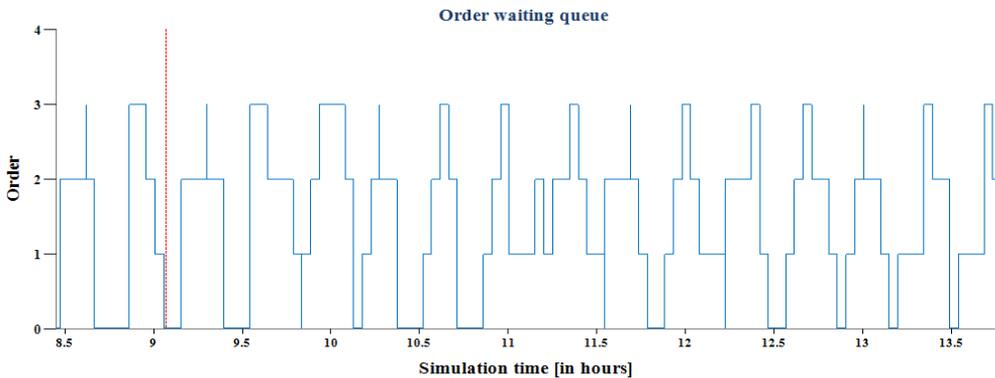


Fig. 7. The queue of transport orders for the transport system which subject to analysis

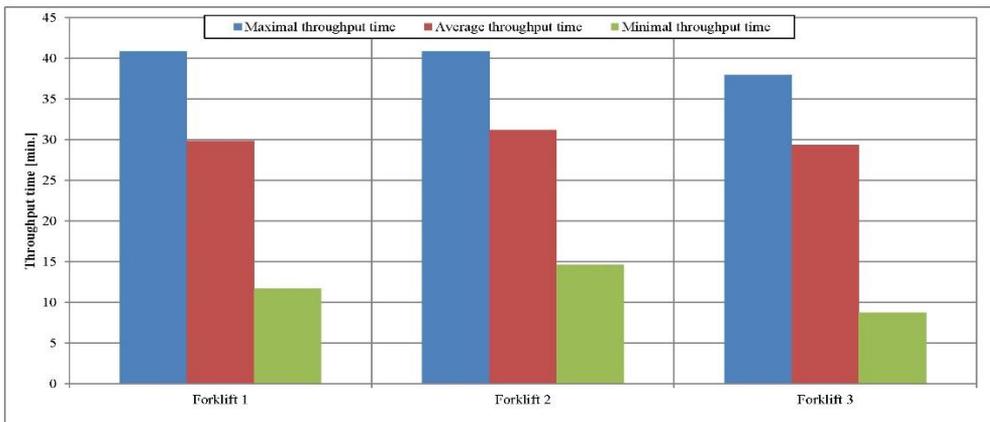


Fig. 7. Diagram of throughput time of order in a transport system

6. Summary and conclusions

To increase the efficiency of loads handling processes in industrial plants or logistic facilities such as distribution centres, warehouses, reloading terminals, there is a necessity to use the moderns and efficient internal transport systems. Taking into account the need for flexible adjust to the requirements of external and intern customers, the control and management of such systems become a challenge. People who make decision in this regard must often determine the optimal transport routes, develop rules for the allocation of transport orders to the available transport means, and at the same time control the vehicles movement to avoid conflicts and transport congestion.

The analysis and evaluation internal transport system operation under realistic circumstances require appropriate methods and tools. Most of real internal transport systems are extensive and complicated taking into account technology, organizational issues and interactions with others systems and processes, so a deterministic investigation of their detailed operation is often infeasible. Effective methods allowing rational decision-making for such multi-criteria problems are presented in the article methods and tools using the discrete event simulation. The rapid growth in the development of such simulation tools and packages make the possibility the design of more detailed and realistic models, the development of more effective and powerful algorithms.

In this paper, the current trends and developments for modelling and simulation of internal transport operations were discussed. The discrete event simulation method combined with the decision tables was applied for modelling of complex control algorithms of the objects flow in the internal transport processes. The analysis of the other types of internal transport systems, including cranes, other warehouse handling operations is planned as part of further studies. Additionally, the analysis of possibility to build hybrid models, in which it is possible to use the solutions allowing the use of optimizing algorithms in addition to the presented heuristic rules will be examined.

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