MODELLING OF WAREHOUSE PROCESSES IN TERMS TO SIMULATION RESEARCH-SIMMAG3D

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Abstract

The paper presents results of research carried out under one of the SIMMAG3D project tasks. Main goal of the project is to prepare system for modelling and 3D visualization of warehouse facilities. Accordingly, in the paper the main attention was paid to the problems of modelling warehouse process in various types of logistic objects. Presented approach to modelling warehouse process allows to carrying simulation researches of selected sub-processes and activities. The model includes transformations of loads and information related with them. Importantly, developed model will be compatible with WMS, which will be source of data needed to the simulation studies. In paper, authors identified basic elements of the warehouse processes in selected organizational and functional variants of warehouses.

Keywords: Modelling, warehousing, SIMMAG3D

1. INTRODUCTION

The productivity and reliability of warehouse are key assets in supply chain and should be constantly measured and improved. Warehouse productivity can be improved in many ways. It could be done by using better suited material handling technologies or through better usage of disposed resources and spaces. But the basic way to increase efficiency of logistics facilities is to appropriate design and construct warehouse process (logistics process implemented in that warehouse). Logistics process could be defined as a sequence of changes of logistics system states occurring between the initial and the final state of that system. Changing the logistics system state is correlated with place, time and form transformations of materials and information [1].

Current logistics is basically oriented on customer needs. Because of that, logistics process could be also defined as a sequence of activities designed in such a way, that as a result of their implementation the logistics service will be created [2]. The final customers are only interested in results of logistics process (logistics service). However, in the interest of logistics is shaping logistics process in such way that it will be economically efficient. Very often to achieve this, must be performed a multi-step process of finding a suitable organizational variant of the logistics process. This in turn is related to necessity of developing a mathematical model of the warehouse process, as well as carrying out simulation studies using that model.

Analysis of commercially available tools for simulation indicate that they very often do not allow mapping warehouse processes effectively and with the required accuracy. This is primarily about the possibility of analysing the individual logistics units with identification of their location in space. Furthermore, because of the need of having the specific data for research, it is essential that the simulation tool will be compatible with WMS systems. Because of that, we start research about mathematical modelling warehouse process, what after its implementation (with 3D visualization of warehouse and its stock) could be used for improving real logistics facilities.

2. WAREHOUSE PROCESS MODELLING ASSUMPTIONS

The initial and essential step in modelling warehouse process is identification and analysis of its logistics tasks. These tasks usually result from technological sequence, which warehouse units are subject to - starting from receiving, by put-away, replenishment, order picking until shipping [3]. Size and scope of these transformations results from main functions and tasks of logistics facility. Therefore, in this case logistics task is a formal notice of cargos transformed by the warehouse facility.

Description of tasks and requirements that must be fulfilled by warehouse process concerns definition of:

- the structure of warehouse shipment and supplies - describe amount of unit loads of a given type that appear at the input and output of warehouse in a certain period of time or his subsequent intervals,
- technological, organizational and cost parameters of warehouse process,
- measures and criteria for evaluation of warehouse process.

Quantitative description of cargos inputs and outputs can be integers (historical data of logistics facility is needed), however, very often it is necessary to describe these values by probability distributions. It is very useful in case of using simulation methods to analyse warehouse processes.

For modelling warehouse process the knowledge of its technological and organizational parameters is extremely important. The main attention in this case should be focused on [4]:

- identification of functional areas and their basic functions, as well as tasks and warehouse operations assigned to them,
- identification the area and capacity of functional areas and assigning to them warehouse locations,
- identification and characterization of non-mechanical equipment in functional areas (e.g. type and layout of storage racks) - important for the assigning materials and transport means to functional areas,
- identification of connections between functional areas - defining areas of internal transport, internal transport roads (important for estimating the distance between these areas),
- identification and parameterization of labour resources (transport means, employees) used in warehousing, etc.

It is also very important to correctly represent the principles of work organization in logistics facility. Therefore, it is necessary to take into consideration:

- scheduling warehouse operations,
- organization of employees movement - identification of routing methods,
- rules of replenishment of picking area - determination of replenishment levels, below whose pick locations should be replenished,
- rules of storage assignment in functional areas and pick (storage) locations - slotting,
- rules of processing customer orders, preparing pick lists, etc.,
- order picking strategies (single picking, zone picking, batch picking, wave picking, etc.)
- rules of packaging and constructing unit loads in accordance with requirements of customers and sub-system of external transport.

Warehouse process is defining as a set of activities correlated with receiving, storage, order picking and shipping material goods, in an appropriately adapted for this purpose areas and under certain organizational and technological conditions [5]. Therefore, it can be assumed that warehouse process consist of cargo receiving, storage, order picking and shipping. Nevertheless, this is a very overall approach, because warehouse process may take many different forms, and include a plurality of sub-processes. Basic transformations related to warehouse process whose are considered in this research (according to [3], [6], [7]) are:

- place transformation - intended change of unit loads locations carried by internal transport,

- time transformation - intended stop of unit loads for buffering, storage or because of inability to performing the subsequent sub-processes,
- form transformation - intended change of type, species, physical characteristics of unit loads or they number, amount.

Table 1 presents examples of the most common sub-processes and activities included in warehouse process and specifies basic transformations related to them.

Table 1 The most common sub-processes and activities included in warehouse process

Sub-process	Activity	Transformation
Receiving	Unloading	place
	Cargo identification and control	time
	Buffering	time
Put-away	Transport to storage area	place
	Placing unit loads in storage location	place
Storage	-	time
Replenishment	Transport to order picking area	place
	Transformation of unit loads to form offered in order picking	form
	Replenishment to pick locations	place
	Placing remaining unit loads in storage location	place
	Placing in selected location empty bins (pallets)	place
Order picking	Replenishment to pick locations	place
	Preparing items for picking	form
	Picking items	place
	Sorting, packing, preparing picked unit loads for transport	form
	Transport of prepared unit loads to selected place in order picking area	place
	Transport of prepared unit loads to buffer	place
Co-packing	Transport of unit loads to co-packing stations	place
	Preparing items for co-packing	form
	Creation new SKU (e.g. promotional SKU sets, combined SKU)	form
	Packaging, labelling, tagging, foiling, etc.	form
	Transport of prepared unit loads to selected place of buffer	place
Consolidation, deconsolidation, sortation	-	form (quantity)
Shipping	Buffering	time
	Cargo identification and control	time
	Loading	place
Material return policy, utilization	Cargo identification and control	time
	Buffering	time
	Loading	place
Crossdocking	Transport from input buffer to output buffer	place

The complexity of activities included in warehouse process, as well as their variability in time, causes that reasonable seems to be using dynamic models for modelling that kind of processes. Exemplary simulation model of warehouse process is shown in next paragraph.

3. SIMULATION MODEL OF WAREHOUSE PROCESS

Warehouses could transforming a lot of many different types of unit loads. So, we assumed that we have set ***R*** of such different logistics types of unit load (1), where *r* is particular logistics type of unit load and $\overline{R}$ is the number of all logistics types. Unit loads of particular types are represented by set ***N***(*r*) (2).

$$\boldsymbol{R} = \{r : r = 1,\ldots,\overline{R}\} \tag{1}$$

$$\boldsymbol{N}(r) = \{n(r) : n(r) = 1,\ldots,\overline{N(r)}\}, r \in \boldsymbol{R} \tag{2}$$

All transformations of unit loads in warehouse are given by the set ***P***, where *p* is particular transformation of unit load and $\overline{P}$ is the number of all transformations.

$$\boldsymbol{P} = \{p : p = 1,\ldots,\overline{P}\} \tag{3}$$

Elements of the set ***P*** can be additionally divided into sets ***PM***, ***PT***, ***PP***, which are sets of transformations of place, time and form. If *p*-th transformation concerns transformation of places, then $kp(p) = 1$, if it concerns transformation of time, then $kp(p) = 2$, or if it concerns transformation of form, then $kp(p) = 3$.

$$\boldsymbol{PM} = \{p \in \boldsymbol{P} : kp(p) = 3\} \tag{4}$$

$$\boldsymbol{PT} = \{p \in \boldsymbol{P} : kp(p) = 2\} \tag{5}$$

$$\boldsymbol{PP} = \{p \in \boldsymbol{P} : kp(p) = 1\} \tag{6}$$

Any warehouse fulfil specified logistics task ***ZL***. This task include many activities and processes which are caused and carried out according to so called internal orders. We assumed that set ***Z*** is a set of internal orders, where *z* is particular internal order and $\overline{Z}$ is the number of all internal orders.

$$\boldsymbol{Z} = \{z : z = 1,\ldots,\overline{Z}\} \tag{7}$$

Internal orders in warehouse process include sequence of transformations on selected logistics units. Therefore, we assumed that set ***R***(*z*) is a set of unit load types included in *z*-th internal order, set ***N***(*r,z*) is a set of unit loads *r*-th type included in *z*-th internal order and set ***P***(*z*) is a set of transformations included in *z*-th internal order:

$$\boldsymbol{R}(z) = \{r \in \boldsymbol{R} : \lambda(r) = 1\}, z \in \boldsymbol{Z} \tag{8}$$

$$\boldsymbol{N}(r,z) = \{n(r) \in \boldsymbol{N}(r) : \lambda 1(n(r)) = 1\}, r \in \boldsymbol{R}(z), z \in \boldsymbol{Z} \tag{9}$$

$$\boldsymbol{P}(z) = \{p \in \boldsymbol{P} : \lambda 2(p) = 1\}, z \in \boldsymbol{Z} \tag{10}$$

where: if in *z*-th internal order are included logistics units of *r*-th type $\lambda(r) = 1$; if in *z*-th internal order is included *n*(*r*)-th logistics units of *r*-th type $\lambda 1(n(r)) = 1$; if in *z*-th internal order is included *p*-th transformation of logistics units $\lambda 2(p) = 1$.

In reference to the above, the logistics task can be formally presented as:

$$\boldsymbol{ZL} = \left[\boldsymbol{R}(z), \boldsymbol{N}(r,z), \boldsymbol{P}(z) : r \in \boldsymbol{R}(z), z \in \boldsymbol{Z}\right] \tag{11}$$

Realization of logistics task needs to using labour resources (workers, warehouse equipment). These labour resources in model are represented by set ZP, where *zp* is particular labour resource and $\overline{ZP}$ is the number of all labour resources.

$$\boldsymbol{ZP} = \{zp : zp = 1,\ldots,\overline{ZP}\} \tag{12}$$

In warehouse process could be used different types of labour resources, e.g. different types of warehouse equipment, different types of transport means, workers with different types of skills. Therefore, set ***M***(*zp*) is a set of labour resource types.

$$\boldsymbol{M}(zp) = \{m(zp) : m(zp) = 1, \dots, \overline{M(zp)}\}, zp \in \boldsymbol{ZP} \quad (13)$$

Besides, warehouse structure can be divided into elements ***GS***, e.g. functional areas, unit load locations or connections between them - road of internal transport. These elements, as well as labour resources have specified characteristics ***FS*** (e.g. surface and capacity of functional areas, labour costs, technical readiness indexes, speed, efficiency, productivity). Warehouse logistics tasks is also implemented under specified rules, logics or strategies ***ZR*** (e.g. storage assignment method, picking strategy, routing method, replenishment method, assigning labour resources to task method).

Considering above, model of the logistics facility ***MOL*** can be defined as follows:

$$\boldsymbol{MOL} = \langle \boldsymbol{ZL}, \boldsymbol{ZP}, \boldsymbol{GS}, \boldsymbol{FS}, \boldsymbol{ZR} \rangle \quad (14)$$

where: $\boldsymbol{ZL}$ is logistics task of warehouse, $\boldsymbol{ZP}$ are labour resources, $\boldsymbol{GS}$ is structure of logistic facility, $\boldsymbol{FS}$ are characteristics of logistics facility elements, $\boldsymbol{ZR}$ are specified rules, logics or strategies of warehouse process.

For research, we need to observe changing of states of selected elements. These elements are unit loads and labour resources (transport means, workers, and its combinations). As the impact of the environment on a logistics facility we consider delivery, customer orders, as well as the disruptions for warehouse process (e.g. accident situations and randomness in unit loads handling).

It should be noted that, both the intensity of inputs of logistics unit loads and transformations of these unit loads are time dependent. Therefore, we assumed that, set ***T*** is a set of moments of logistics facility work where *t* is particular moment and $\overline{T}$ is the number of all moments.

$$\boldsymbol{T} = \{t : t = 1, \dots, \overline{T}\} \quad (15)$$

States of selected elements of logistics facility are also analysed in particular moments. State of the whole facility is determined by states of its particular elements. State of *n*(*r*)-th unit load of *r*-th type in *t*-th moment we define as $x(r, n(r), t)$ and state of *m*(*zp*)-th labour resource of *zp*-th type in *t*-th moment is define as $y(zp, m(zp), t)$.

$$\mathbf{X}(r,t) = \left[x(r,1,t) \quad (\dots) \quad x(r,n(r),t) \quad (\dots) \quad x(r,\overline{N(r)},t) \right] \quad (16)$$

$$\mathbf{Y}(zp,t) = \left[Y(zp,1,t) \quad (\dots) \quad Y(zp,m(zp),t) \quad (\dots) \quad Y(zp,\overline{M(zp)},t) \right] \quad (17)$$

So, state of the whole facility in *t*-th moment can be defined as follows:

$$\mathbf{SO}(t) = [\mathbf{X}(t), \mathbf{Y}(t)] \quad (18)$$

$$\mathbf{X}(t) = \begin{bmatrix} \mathbf{X}(1,t) \\ (\dots) \\ \mathbf{X}(r,t) \\ (\dots) \\ \mathbf{X}(\overline{R},t) \end{bmatrix} \qquad \mathbf{Y}(t) = \begin{bmatrix} \mathbf{Y}(1,t) \\ (\dots) \\ \mathbf{Y}(zp,t) \\ (\dots) \\ \mathbf{Y}(\overline{ZP},t) \end{bmatrix} \quad (19)$$

State of the whole facility in *t*-th moment results from its previous state, from internal orders generated in (*t*-1)-th moment and from disruptions in *t*-th moment. Set of internal orders generated in *t*-th moment and set of disruptions in that moment are defined as follows:

$$\boldsymbol{Z}(t) = \{z \in \boldsymbol{Z} : \tau(z) = 1\}, t \in \boldsymbol{T} \quad (20)$$

$$\boldsymbol{A}(t) = \{a(t) : a(t) = 1, \dots, \overline{A(t)}\}, t \in \boldsymbol{T} \quad (21)$$

Considering above, and treating the process as a series of subsequent changes in the system, warehouse process can be formally represented as:

$$\mathbf{SO}(t) = f(\mathbf{SO}(t-1), \boldsymbol{Z}(t-1), \boldsymbol{A}(t)), t \in \boldsymbol{T} \quad (22)$$

The scope of the research requires consideration of representation states of each logistics unit in modelled process. Locations of these units in system and time which remains to end of servicing each of them should be also taken into account. Similarly, in the case of states of labour resources. They should be identified according to their localization and occupancy (busy, idle, etc.). Internal orders in model are represented as a lists of logistics units that need to be serviced in particular way and in particular location or transported between some locations.

4. CONCLUSION

Paper presents basic assumptions for simulation model of logistics processes in warehouses. The main attention was paid to formal and mathematical representation of warehouse process. Presented research includes dynamical aspects of warehouse process and possible changing its states in time.

Developed simulation model allows to analysing transformations of individual logistics units with precise identification of their localization in logistics facility. This allows to use in implementation of that model the various procedures and heuristics (e.g. routing heuristics, storage assignment). Thus, this model will be allowing constructing the tool that will be able to map the logistics processes with required accuracy. In addition, this tool will be compatible with the WMS systems.

Considerations from in this paper are results of research carried out within the project SIMMAG3D. Its goal is to develop the system for modelling and visualization warehouse facilities in the 3D. The system will be constructed on the basis of mathematical models, computational algorithms and functional relations, which are needed in designing the warehouse facilities. Currently, the authors are developing simulation model of warehouse process and algorithmization of the warehouse activities.

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