ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 2 [May]

ISSN: 1584–2665 [print; online]
ISSN: 1584–2673 [CD–Rom; online]
a free–access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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SOME ASPECTS OF MATERIAL FLOW MODELING IN LOGISTIC FACILITIES

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Abstract: Paper presents basic assumptions for modeling warehouse processes in different types of logistic facilities. These processes are mapped as sequences of warehousing phases, warehouse tasks, material transformations, warehouse operations and activities. Their structure, as well as manner and range of implementation are dependent on type of logistic facility and its main logistic task. Basic assumptions presented in the paper will be used to build a mathematical simulation model of the materials flow in certain types of logistics facilities.
Keywords: warehousing, modeling, warehouse processes, logistic facilities

1. INTRODUCTION

Nowadays, almost every logistic system or supply chain is composed from logistic facilities whose are properly interrelated with each other by material and information flows. Usually, these logistic objects are necessary in order to allow the company performing their key tasks and fulfill customer orders at the appropriate level of quality. Storage facilities are used by these companies to transform the materials and information flow due to the time, place or form. This in turn implies for them the necessity of performing a wide range of activities and logistic processes.

The role of warehouse facilities in every logistics system should be treated as a critical. They provide a wide variety of values–added to materials flowing through them. Very often they are also bottleneck of the logistic system. Therefore, performance, efficiency and accuracy of processes occurring in them should be taken care of. Each chain is in fact as strong as its weakest link. Thus, properly shaping, organizing and controlling of material flows is necessary to efficient and proper functioning of storage facilities. This in turn implies the need for modeling of material flows by warehouse facilities and analysis and evaluation of warehouse processes.

This article presents selected aspects of constructing and organizations of the warehousing processes (processes of material flow through logistic facilities). Authors drew attention to the main problems associated with modeling the warehouse process and presented known methods of modeling them.

2. WAREHOUSING IN TERMS OF A MATERIAL FLOW IN LOGISTIC FACILITIES

The flow of goods in different types of logistic facilities is a strictly defined sequence of transformations performed on these materials. These transformations may relate to the change of time, place or form.

In the first case we are talking about buffering materials in logistic facilities, that is storage. If there is a change of the place, materials are moved within the area of logistic object. However, in case of transformation of the form, materials are processed due to their physical characteristics, i.e.: repacking, consolidating, de–consolidating, co–packing, assembling (VAS – value added services), etc..

Accordingly, the materials' transformations performed in logistic facilities can be divided into transformations correlated with:

- changing the logistic form of material without changing physical characteristics of SKUs (repackaging, consolidation, deconsolidation);
- changing physical characteristics of materials (merging SKUs, co–packing, assembling, etc.);
- changing the logistic form physical characteristics of materials;

- changing of materials in space – transport materials between locations in the warehouse, receiving, shipping,
- storing of materials in time – storage,
- delaying the flow of materials associated with the transfer of information and instantaneous inability to perform on them next transformations – buffering, waiting;
- changing the completeness of logistic description of materials (labeling, stocktaking, addressing).

All above are included in the warehousing (warehouse process). This process is defined as a set of activities related to the receiving, storage, picking and shipping goods, in appropriately adapted for this purpose functional areas, and under certain organizational and technological conditions [1].

Therefore it can be concluded that the warehouse process includes such sub–processes as: receiving, storage, order picking and shipping. Nevertheless, this is a very general approach, because warehouse process (warehousing) may takes many different forms and includes a plurality of sub–components. Selection of process elements and their appropriate connection is determined by the functions and tasks of logistics facility. In fact, other transformations will be carried out in the manufacturing warehouses than in distribution warehouses or cross–docking warehouses.

In modeling the material flows within warehouses should be taken into account the hierarchical structure of the warehouse process. In that structure can be specified five levels, they consist phases of the warehouse process, warehouse tasks, sets of warehouse operations, warehouse operations, and warehouse activities (Figure 1). Different levels differ in details of description of processes, tasks, activities, etc.

Phases of the warehouse process are located on the top (less detailed) level of the structure. They are mapping process' stages and very often are collecting all activities performed in particular areas of warehouse facility. The basic phases of the warehouse include: receiving, put–away, storage, replenishment, order picking, bring out, accumulation, sorting & packing, cross–docking and shipping.

Warehouse tasks are elements of warehouse phases. They define the processes that should be performed within each phase. Respectively, at the next level of warehouse process structure are located sets of warehouse operations. They represent a certain number of repetitions of warehouse operations that are necessary to carry out for purposes of fulfilling particular warehouse tasks. Very often, the number of these repetitions (n–times) results from the daily number of unit loads that should be transformed or pick lists that should be fulfilled. For example, for carrying out order picking process it is necessary to fulfil n pick lists (which indicate customer orders). Operations and activities are the most detailed descriptions of the warehousing tasks. The most often they are simple transport cycles or manipulative cycles. Besides, activities relate to simple movements, motions, physical labour, etc..

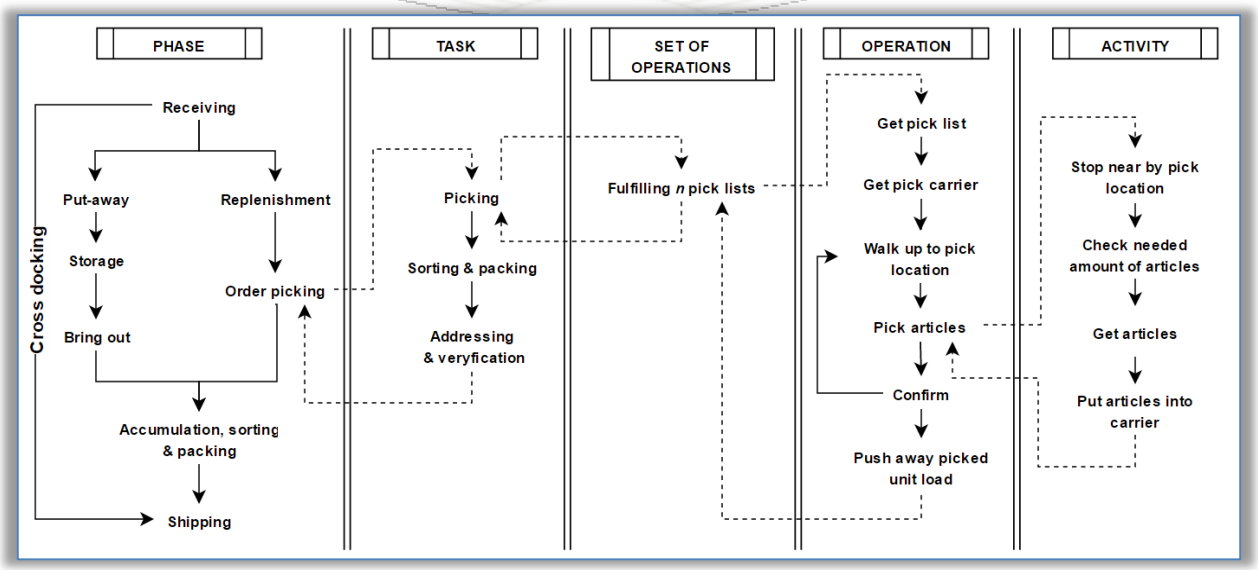

Figure 1 – Hierarchical structure of warehouse process

For the purpose of modeling and mapping warehouse process and materials flow can be also used the structure of the process based on the tasks. To do this, you need to specify individual tasks and operations of this process and properly connect them together (Figure 2). Connections determine the manner and direction of the materials flow. Examples of various tasks of warehouse process and their components are shown below (see also Figure 2).

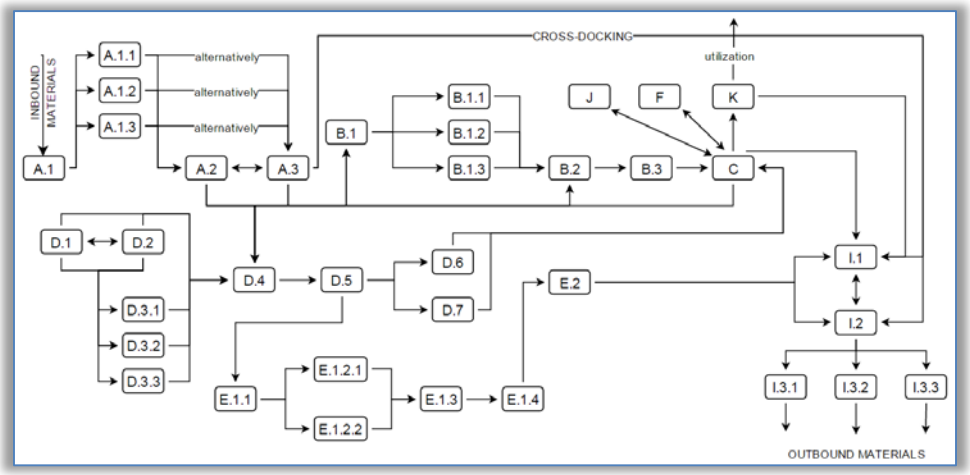

Figure 2 – Structure of warehouse process based on tasks

A. MATERIALS RECEIVING
   1. Materials adoption to the warehouse
      1.1. Unloading means of external transport
      1.2. Transportation of materials from the storage yard to warehouse (after buffering unloaded unit loads from the means of external transport to the storage yard)
      1.3. Internal adoption (materials transport from another facility department)
   2. Identification and controlling of materials
   3. Entrance buffering
B. PUT–AWAY
   1. Transformation of material units to stored form
      1.1. Reformation / repacking material units (due to logistic form)
      1.2. Foiling and protection of material units
      1.3. Labelling of material units
   2. Transport to storage area
   3. Unit placing in a given location of the storage area
C. STORAGE
D. REPLENISHMENT
   1. Identification of demand for SKUs in picking area
   2. Identification and control SKUs available for replenishment
   3. Transformation of unit loads to forms offered in picking area
      3.1. Stripping of unit loads
      3.2. Reformation / repacking material units (due to logistic form)
      3.3. Labelling of material units in accordance with picking form
   4. Transport unit loads to picking area/pick locations
   5. Replenishment of particular pick locations with appropriate amount and type of unit loads
   6. Transport and putting away the remaining material units to the storage area
   7. Transport and putting away the empty units (e.g. pallets) to the designated places
E. ORDER PICKING
   1. Forming mixed unit loads according to customer orders
      1.1. Getting empty carrier (pallet, box, container, etc.), and pick lists
         1.2.1 Movement between pick locations
         1.2.2 Delivering unit loads to fixed picking stations
      1.3. Picking
      1.4. Protection and labelling of picked unit loads
   2. Transport of picked unit load to designated accumulation place
F. CO–PACKING
G. CONSOLIDATION, SORTING
H. DECONSOLIDATION, SORTING
I. SHIPPING
   1. Identification and controlling of materials
   2. Buffering on exit

3. Exiting materials from warehouse
   3.1. Loading means of external transport
   3.2. Transportation of materials from warehouse to the storage yard (buffering and loaded unit loads to the means of external transport)
   3.3. Internal adoption (materials transport to another facility department)

J. STOCKTAKING

K. HANDLING OF DAMAGED UNITS AND MATERIALS RECYCLING

As mentioned above, in order to model warehouse process should be selected such operations that are necessary to carry out logistic task of logistic facility. Then identify the sequence of their execution by their appropriate connecting. A characteristic feature of this approach is detailed description of all phases and activities included in the warehouse process (Fig. 2).

3. RULES OF MATERIAL FLOWS ORGANIZATION IN LOGISTICS FACILITIES

Analyzes and studies related to the warehouse process should begin with the identification of his tasks. These tasks result from technological sequence, which is passed by materials in logistic facilities, starting with receiving, putting–away, replenishing, order picking, shipping etc. [2]. The intensity and scope of these transformations result from the logistic tasks of the logistics facilities. The logistic task in this case is treated as a formal notation of the workload imposed on the warehouse. The workload is referred in quality and quantity terms (what?, how many?, from where?, to where?, when? is transported and handled in a logistic facility).

Identification of the logistic task of warehouse is related to defining:

- the structure of supplies to warehouse – describe amount of unit loads of a given type that appear at the input of warehouse in a certain period of time or his subsequent intervals,
- the structure of shipment from warehouse – – describe amount of unit loads of a given type that appear at the 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 inputs and outputs of unit loads can be presented in the form of integers (if you have access to historical data of logistic facility). However, very often for modeling warehouse process it is necessary to describe these values by empirical probability distributions. In that situation, it should be selected probability distributions adequate for the work specifics of the particular warehouse. Then construct a generators of random values of inputs and outputs from warehouse at certain moments of analysis

Extremely important is also the knowledge of technological and organizational parameters of warehouse process and facility in which it is executed. The main attention in this case should be focused on:

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

In modeling the materials flow in logistic facilities is also important representation of the principles of work organization in this facility. Therefore it is necessary to take into consideration:

- scheduling warehouse process, allocation in time the individual phases and tasks of the process and assigning them timeframes (see e.g. [3,4]),
- organization of employees movement – identifying of routing methods (see e.g. [5,6,7,8]),
- rules of controlling flowing materials through the warehouse – determination of so–called "warehouse logics": from where get units of particular material type (where it is located)?, where to put units of particular material type?, what should be sequence of getting and putting away? who and where has to carried out an operation? [9],

- rules of replenishment of picking area – determination of replenishment levels, below which pick location should be replenished (see e.g. [10,11]),
- rules of storage assignment in functional areas and pick or storage locations (slotting), see e.g. [12,13,14,15],
- rules of processing customer orders, preparing pick lists, etc. (see e.g. [16,17,18]),
- order picking strategies, (single picking, zone picking, batch picking, wave picking, etc.) – see e.g. [18,19,20],
- rules of packaging and constructing unit loads in accordance with requirements of customers and sub–system of external transport (see e.g. [21]).

Due to the scope and complexity of the activities included in the warehouse process, the assessment of its functioning can be carried out using different criteria and different methods. In the literature, the most common evaluation criteria are: effectivity of warehouse process, costs of warehousing, stock turnover, utilization of human resources, utilization of technical resources, warehousing labour consumption, utilization of storage area, etc. [22,23,24,25,26,27,28,29,30].

4. SELECTED METHODS OF MODELLING MATERIAL FLOWS IN LOGISTICS FACILITIES

Analysis and investigation of material flow through logistics system as well as logistic facilities is a multi–step task that requires consideration of a series of technological and organizational assumptions and conditions. At each step researcher has to make certain decisions, which in effect will determine the correctness and reliability of the obtained results. In the literature are many examples of modeling the materials flow through large macro–logistic systems (see e.g. [31,32,33]), logistics systems of cities and enterprises (see e.g. [34,35,36]), as well as various logistic facilities (e.g. [37,38,39,40,41,42]). These publications described many different approaches to modeling the materials flow, from the optimization models by heuristic up to the simulation models.

In case of modeling the materials flow it is very important to consider the possibility of occurrence various types of random phenomena. Sources of random events can be located either in logistic facilities or their management systems, as well as their surroundings. Randomness of processes in the logistic objects very often impacts on using for modeling theory of stochastic processes.

In the literature can be found various stochastic models used for analyzing warehouse operations. As an example might be use basic types of distributions (e.g. Binomial, Bernoulli or geometric) and their derivatives (e.g. urn models) for analysis of order picking systems [43,44,45]. In [43] and [44] presents the analysis of the picking process implemented in one–block and two–block order picking areas. They were using stochastic models to determine localization of pick locations, sequence of visiting them and generate in that way pick route. Yu and De Koster in [45] used this class of models to examine the impact of batch picking and zone picking on order picking system performance.

For analysis and testing of warehouse operations can be also used classical stochastic models, e.g.: models of renewal processes, Markov models, Martingale models [46,47]. That that type of research can be carried out with using other models as well. Such models as: queuing models, including models of queuing with a single server (e.g. M/M/1 and M/G/1), queuing network models and their derived (e.g. "polling models") [48,49].

Table 1 – Stochastic models for warehouse operations

Type	Method	Examples
Classical probabilistic models	Urn models	[43,44]
Classical stochastic models	Renewal processes	[46]
	Markov chains	[47]
Queuing models	The single server queue models	[49]
	Queuing networks	[50]
	Pooling models	[51,52]
Others	Fluid models	[53]
	Petri nets	[54,55]
	Simulation models	[56,57,58,59,60,61,62,63]

5. SUMMARY

Paper presents basic assumptions for modelling flow of materials through logistics facilities. The main attention was paid to issues associated with the designing and mapping of processes in logistics facilities. It is proposed the ways of identifying the components of the warehouse process (including its multi–level hierarchical structure), their organization and interconnections. It also presented basic principles and problems related to the organization of work in logistics facilities according to their

logistic tasks. Considerations presented in this article are preliminary 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 working on the formalization of functional dependencies for different procedures of material flows (through warehouses) and algorithmization of the warehouse processes. Future work are related to preparing different case studies which will prove correctness of material flow modelling methodology presented in paper.

Acknowledgment

The scientific work carried out in the frame of PBS 3 project SYSTEM FOR MODELING AND 3D VISUALIZATION OF STORAGE FACILITIES (SIMMAG3D) financed by the National Center for Research and Development.

Note

This paper is based on the paper presented at The International Conference Management of Technology – Step to Sustainable Production (MOTSP 2016), organized by the Faculty of Mechanical Engineering and Naval Architecture, Croatian Association for PLM and the University of North, in Porec/Parenzo, Istria, CROATIA, June 01–03, 2016.

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