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DECISION MAKING STRATEGIES FOR WAREHOUSE OPERATIONS

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Abstract: *The paper presents issues related to design and organization of warehouse processes. Draws attention to problems of modelling logistics facilities and processes occurring in them. Paper also points out the essence of correct operation of warehouses and associated with this risks for supply chain. Warehouse processes have been properly defined and divided into smaller components, like: phases of process, activities, sets of procedures, procedures or working movements. Paper presents various possible configurations of warehouse processes, which were named as warehouse strategies. Warehouse process strategy is a part of warehousing. It determines the sequence of warehouse operations. These operations are related to internal transport, cargo form transformation and cargo buffering. In paper it is noted that the warehouse strategy depends on the several technical and organizational factors and is associated with a certain probability. This probability can be estimated based on data analysis concerning logistics processes in the specified warehouse facility. As shown in case study, appropriate selection of warehouse strategies determines possibility of fulfilling customer order in time and costs that are acceptable for him.*

Key words: *warehousing, warehouse strategy, modelling, decision making*.

1. Introduction

At a time like the present companies (not only transport and logistics) cooperate within net of logistics facilities interrelated by material, information and financial flows. This is necessary to ensure that these companies can perform their key activities and fulfil customer orders under specific quality requirements. Storage facilities are important segments in material flow, mainly used to transform materials due to the time, place and form (storage, picking, consolidation, deconsolidation, sorting, etc.). This in turn triggers a wide range of internal logistics processes in warehouses which can be subjected to different strategies of warehouse operations.

Warehouse operations are crucial for logistics services quality since warehouses are sources of specific costs and errors. Warehousing processes add new value to materials through simple production processes and making reserves. At the same time warehouses can be a bottlenecks impeding smooth material flow in the system. Poor work organization in warehouse facilities lead to major disruptions in supply chains (fig. 1). And so, shipping delays in upstream elements of supply chain will lead to significant delays in subsequent cells. As a result, final consumers will receive goods in time that is far from expected. On the other hand, warehouse facilities buffer and smooth materials flows through storing excessive flows and making reserves. Therefore, efficiency, effectiveness and accuracy of processes in logistics facilities are crucial for logistics networks operations.

One of the solutions reducing risk of interference in supply chain is appropriate conceptualization and organization of warehouse processes including configuration of material flow paths in warehouse for particular customer orders. This requires a series of decisions concerning the selection of warehouse process strategy.

2. Warehouse facility and processes modelling

Warehouses perform processes resulting from processes in the supply chain, including: material flows buffering (storage), material division (e.g. order picking) and simple processing (packaging), consolidation and deconsolidation, as well as redirecting.

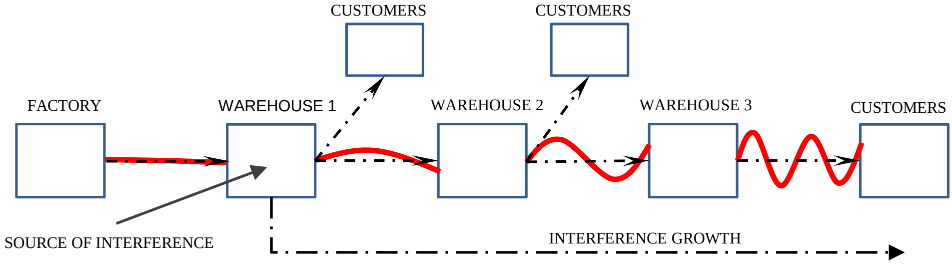

Fig. 1. Disturbances in materials flow generated by storage facilities in supply chain

Designing and organization of logistics infrastructure and supply chains are widely analysed in literature (Berry, 1968; Bozer et. al., 2005; Jacyna-Gołda, 2014; Roberts et. al. 1972). For over 50 years many authors have presented different approaches to this issue. A large number of publications concerns review and comparative analysis (e.g. Frazelle, 2008; Gu et. al., 2010; Jacyna et. al., 2016; Rouwenhors et. al., 2000; Żak, 2014).
Due to the fundamental warehouse feature which is capacity, warehouses are regulators of material flows under varying operating conditions in supply chain. Variability of warehouse operating conditions is determined by dynamically changing customer needs, customers structure and randomness in logistics process.
Sources of randomness are located either in warehouse facilities or their management systems as well as in its environment. Since randomness is characterizing warehouse processes, the theory of stochastic processes is used to its analyse.
Three main groups of processes are distinguished in a typical model of warehouse facility: input (entry) processes, service processes and output (exit) processes (fig. 2). This division allows for identification and selection of suitable mathematical model of the processes.
Various stochastic models for analysing warehouse operations and related warehouse strategies can be found in the literature. Different types of event distributions are applied for analysis of order picking systems (e.g. Binomial, Bernoulli or geometric) and their derivatives (e.g. urn models) (Chew et. al., 1999; Le-Duc et. al., 2005; Yu et. al., 2009).
Chew et. al., 1999 and Le-Duc et. al., 2005 present the analysis of the picking process implemented in one-block and two-block order picking areas. They use stochastic models to determine localization of pick locations, sequence of visiting them and generate in that way the pick route. Yu and De Koster (Yu et. al., 2009) use this class of models to examine the impact of batch picking and zone picking on order picking system performance.

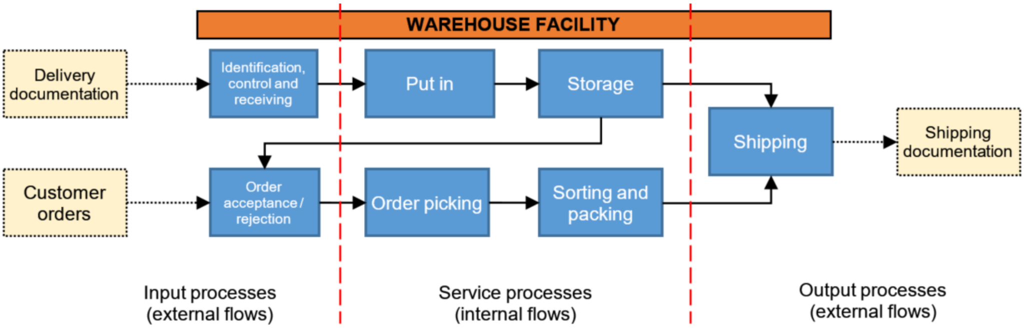

Fig. 2. Warehouse operations description using stochastic processes

Classic stochastic models, e.g.: models of renewal processes, Markov models, Martingale models can be used for analysis and testing of warehouse operations (Bozer et. al., 1990; Gue et. al., 2006). 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" (Bozer et. al., 2005; Lee, 1997).

Table.1. Stochastic models for warehouse operations

Type	Method	Examples
Classical probabilistic models	Urn models	Chew et. al., 1999; Le-Duc et. al., 2005
Classical stochastic models	Renewal processes	Bozer et. al., 1990
	Markov chains	Gue et. al., 2006
Queuing models	Single server queue models	Lee, 1997
	Queuing networks	De Koster, 1994
	Pooling models	Bozer et.al., 1999; Gong et. al., 2008
Others	Fluid models	Bartholdi et. al., 2001
	Petri nets	Hsieh et. al., 1998; Lin et. al., 1995
	Simulation models	Macro et. al., 2002; Rosenblatt et. al., 1988; Stadtler, 1996; Kłodawski et. al., 2012; Kłodawski et. al., 2013; Lewczuk et. al., 2013; Karkula, 2014

Interesting approach to estimation of technical potential of warehouse facilities is presented Wasiak (Wasiak, 2011). Author defines and presents simulation model for estimation of logistics system potential. Model allows to analyse process of material flows in various systems and under warehouse strategies. It also includes randomness to describe material flows and serving processes.
Kłodawski et. al., 2013 present research on the impact of order picking area layout on order picking efficiency. Picking process simulations are carried out for different layouts (the problem of congestion in the picking area, queuing and blocking during the process). On the base of obtained results, authors present the best layouts of picking area for analysed conditions.
Simulation approach to design picking systems with dynamic SKU allocation is presented by Lewczuk et. al., 2013. Customer orders arrival (e.g. time, volume) is characterized by the corresponding probability distributions. Orders are queuing and then can be carried out in different variants – depending on the current state of picking system. The probability of each variant is estimated at the entry of customer order to system. That probability depends on the events that occurred in process so far, availability of certain materials, equipment availability, etc.
Due to the complexity of the warehouse processes usually particular issues are considered separately. It impedes evaluation of the warehousing processes in total. Therefore, a comprehensive approach to problem of warehousing modelling is required (Jacyna-Gołda, 2015). A holistic approach to that problem allows for proper assessment of the warehouse and supply chains operation.

3. Elements of warehouse process

3.1. General characteristics of warehouse processes

Warehouse process is defined as a set of activities, including receiving, storage, picking, replenishment, retrieval and shipping of material units in facilities adapted for this purpose (functional areas, zones) and under certain organizational and technological conditions. Each of these activities is characterized by a corresponding sequence of actions which has to be performed to realize objectives or tasks of respective phases of warehouse process. It is closely related to the transformation of materials and information by resources like workers, internal transport means, equipment and warehouse management system.
Transformations performed on materials in warehouse facilities are performed according to:

- logistics form of material without changing physical characteristics of SKUs (repackaging, consolidation, deconsolidation);
- physical characteristics of materials (merging SKUs, co-packing, assembling, etc.);
- logistic form physical characteristics of materials;
- moving materials within space - transport materials between locations in the warehouse, receiving, shipping,

- storing materials (buffering, storage),
- delaying material flows 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 (labelling, stocktaking, addressing, etc.).

Warehouse process can be also divided into three basic groups of sub-processes: input processes, service processes and output processes (see fig. 2). For proper modelling of materials flow within a warehouse facility the hierarchical structure of warehouse process should be taken into consideration. So, model of warehouse process on the required level of detail, requires mapping such elements as: phases of process, activities, sets of procedures, procedures or working movements.

Phases of the warehouse process are located on the top (less detail) of the structure. The basic phases of warehousing are: receiving, put-away, replenishment, storage, order picking, retrieval, shipping, cross-docking, etc. Set of phases is described by $\boldsymbol{FP}$, where $\boldsymbol{FP} = \{f: f = 1,2, \dots, F\}$.

Warehouse activities are elements of phases. They determine what should be done in each of such phases. Set of warehouse activities was described by $\boldsymbol{CP(f)}$ where $\boldsymbol{CP(f)} = \{c_k^f: k = 1,2, \dots, CP(f)\}$. For each phase a vector of warehouse activities can be defined $\boldsymbol{f} = \langle c_k^f: c_k^f \in \boldsymbol{CP(f)} \rangle$.

On the next level of warehouse process structure sets of procedures are located. Sets of procedures determine number of iterations of warehouse procedures carried out to fulfil particular warehouse tasks. Very often, the number of warehouse procedures iterations results from daily number of ordered material units that must be transformed or the number of picking lists that must be accomplished. Sets of procedures are described by set $\boldsymbol{GZ}(c_k^f)$, where $\boldsymbol{GZ}(c_k^f) = \{c_{k,l}^f: l = 1,2, \dots, C(f,k)\}$. For each warehouse activity vector of sets of procedures can be defined $\boldsymbol{c_k^f} = \langle c_{k,l}^f: c_{k,l}^f \in \boldsymbol{CP}(c_k^f) \rangle$.

Procedures and working movements are the most fragmented elements of tasks performed in the warehouse process. In most cases they are transport cycles or handling cycles. Procedures are described by set $\boldsymbol{Z}(c_{k,l}^f) = \{c_{k,l,z}^f: z = 1,2, \dots, CP(f,l,k)\}$ and working movements by set $\boldsymbol{R}(c_{k,l,z}^f) = \{c_{k,l,z,s}^f: c_{k,l,z,s}^f = 1,2, \dots, CP(f,l,k,z)\}$. For each set of procedures a vector of procedures can be defined $\boldsymbol{c_{k,l}^f} = \langle c_{k,l,z}^f: c_{k,l,z}^f \in \boldsymbol{Z}(c_{k,l}^f) \rangle$ and for each procedure a vector of working movements can be defined $\boldsymbol{c_{k,l,z}^f} = \langle c_{k,l,z,s}^f: c_{k,l,z,s}^f \in \boldsymbol{R}(c_{k,l,z}^f) \rangle$.

Implementation of various phases of warehouse process forces changes in warehouse facility states. States of warehouse facility are referred to particular moments of time. Each state of warehouse facility is determined by the state of its individual components at individual moments. Daily working time of warehouse was divided into $\boldsymbol{T}$ moments. Set of numbers of such moments was defined as $\boldsymbol{T} = \{1, 2, \dots, t, \dots, T\}$.

The state of warehouse facility in moment t results from its previous states. Hence, it results from the earlier processes and internal orders generated at previous moments as well as from disturbance of process at the t moment. Set of numbers of internal orders that inputted at t moment and numbers of disturbance of process at the t moment was defined as follows:

$$\mathbf{Z}(t) = \{z \in \mathbf{Z}: \tau(z) = 1\},\ t \in \mathbf{T} \tag{1}$$

$$\mathbf{A}(t) = \{a(t): a(t) = 1, \dots, \overline{A(t)}\},\ t \in \mathbf{T} \tag{2}$$

Considering above as well as the general definition of the process as a series of successive changes in system, warehouse process was formally written as follows:

$$\mathbf{SO}(t) = f(\mathbf{SO}(t-1), \mathbf{Z}(t-1), \mathbf{A}(t)),\ t \in \mathbf{T} \tag{3}$$

As it was mentioned previously, warehouse process is divided into phases. Selected phases are detailed in the next chapter.

3.2. Selected phases of warehouse process

Receiving

Receiving is the first phase (set of activities, procedures and working movements) that is carried out on materials delivered to the warehouse facility (***f1***). The basic elements (activities) of receiving are: unloading (c_1^{f1}), identification (c_2^{f1}), control (c_3^{f1}), and buffering (c_4^{f1}). So, this phase ***f1*** can be defined as a vector:

$$\boldsymbol{f1} = \langle c_1^{f1}, c_2^{f1}, c_3^{f1}, c_4^{f1} \rangle \tag{4}$$

Example of material receiving in warehouse facility was shown in fig. 3.

Put away to storage

Put away to storage is a phase in which received materials are transported to storage areas and then are put in particular location. The elements of this phase may embrace preparing units of material for storage (preformation, repackaging, labelling, safety) insofar as they have not been done already during the receiving phase. Put away to storage is associated with storage assignment (assignment material units to a particular location in storage area). It is done according to strictly defined policies, methods and algorithms. Example of putting away material to storage was shown in fig. 4. The basic activities of put-away phase (***f2***) are: material identification in buffering area (c_1^{f2}), material transport form buffer to storage area (c_2^{f2}). Phase ***f2*** can be defined as a vector:

$$\boldsymbol{f2} = \langle c_1^{f2}, c_2^{f2} \rangle \tag{5}$$

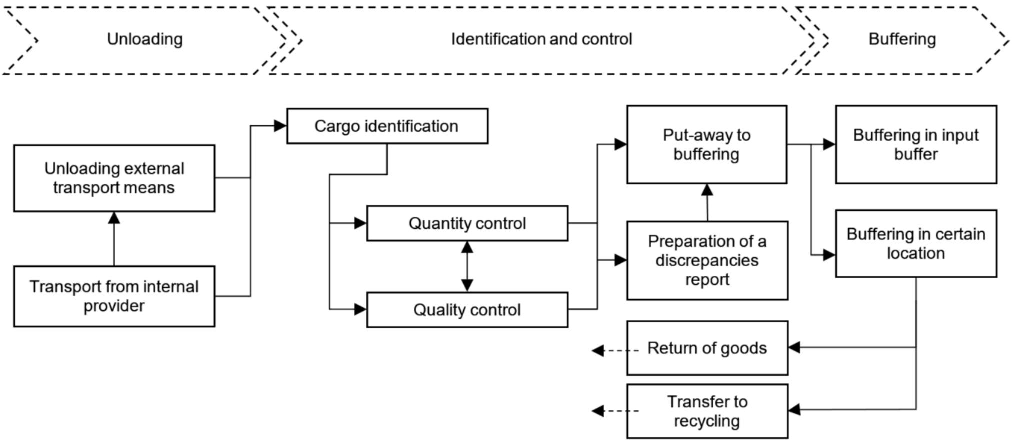

Fig. 3. Process of material receiving in warehouse facility

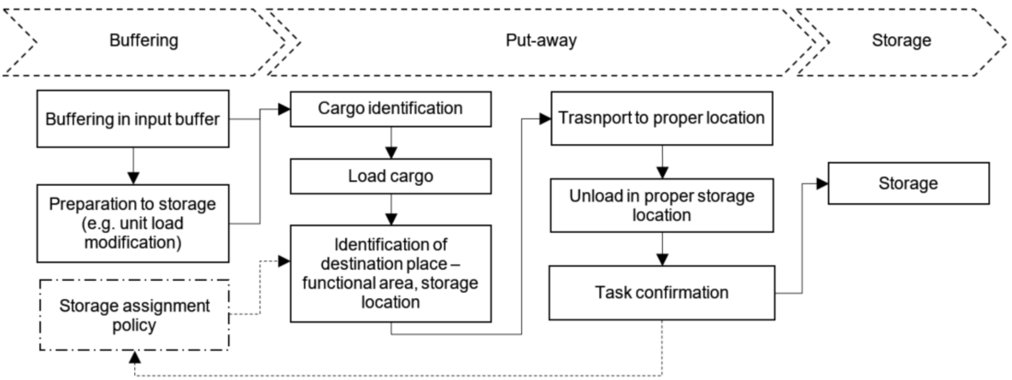

Fig. 4. Phase of putting away material to storage

Replenishment (order picking area)

Replenishment is that phase of warehouse process which is responsible for feeding picking area with suitable quantity of particular SKUs (suitable quantity means that, in a given period, it will allow to pick all customers' orders). Replenishment is done according to two basic scenarios. In the first one, order picking area is replenished by material units taken from a storage area. Second scenario concerns replenishing from input buffer.

Depending on the picking strategy and technology order picking area can be replenished by pallet units, cartons, pieces or other. Therefore, in that phase of process additional activities related to preformation larger units to smaller form can be dome. Example of replenishment phase was shown in fig. 5.

The basic activities of replenishment phase (***f3***) are: identification of replenishment needs and material availability in storage and buffer areas (c_1^{f3}), transport materials to picking area (c_2^{f3}), unit load disassembling and replenishing certain pick locations (c_3^{f3}), remaining materials or carrier return (c_4^{f3}). Phase ***f3*** can be defined as a vector:

$$\boldsymbol{f3} = \langle c_1^{f3}, c_2^{f3}, c_3^{f3}, c_4^{f3} \rangle \tag{6}$$

Retrieval

Retrieval is a sequence of activities to move materials from storage areas to appropriate locations in consolidation areas, to be prepared for shipments. In most cases retrieval starts in storage area and ends in buffering place in shipment area, but it can embrace additional processes. Typically, these processes are to add value to shipped materials. Adding value means co-packing, consolidation, sorting, assembling, labelling or configuring products. These activities are done in separated areas which are supplied from storage areas. The example of retrieving process is presented in fig. 6.

The basic activities of retrieval phase (***f4***) are: identification storage location of retrieved material load (c_1^{f4}), transport materials to buffer area (c_2^{f4}). Phase ***f4*** can be defined as a vector:

$$\boldsymbol{f4} = \langle c_1^{f4}, c_2^{f4} \rangle \tag{7}$$

Cross-docking

Crossdocking is a specific type of warehousing process. It is implemented in terminals of different types. Crossdocking is composed of receiving and shipment processes like in typical warehouse but storage is omitted. Putting away materials into storage constructions is time consumptive and requires travelling long distances. Since materials subjected to crossdocking processes stay in facility no longer that 24 hours, but usually no more than few hours, space effective racking systems are not use for the general smoothness of material flow.

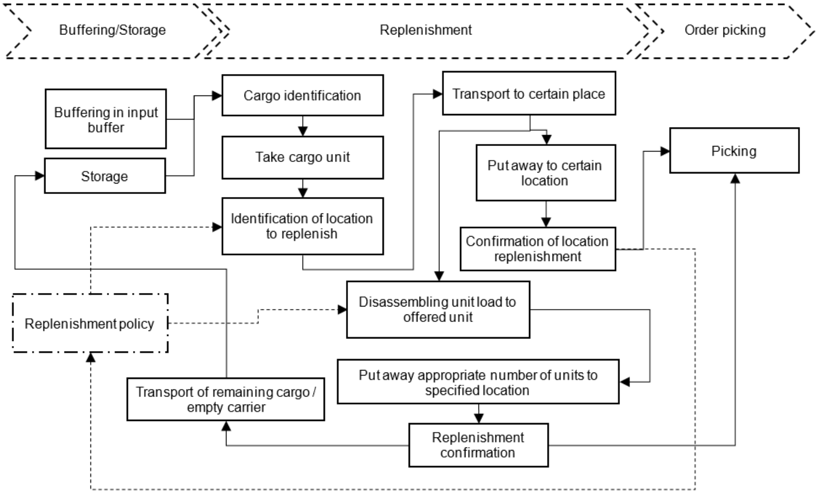

Fig. 5. Example of replenishment phase in warehouse process

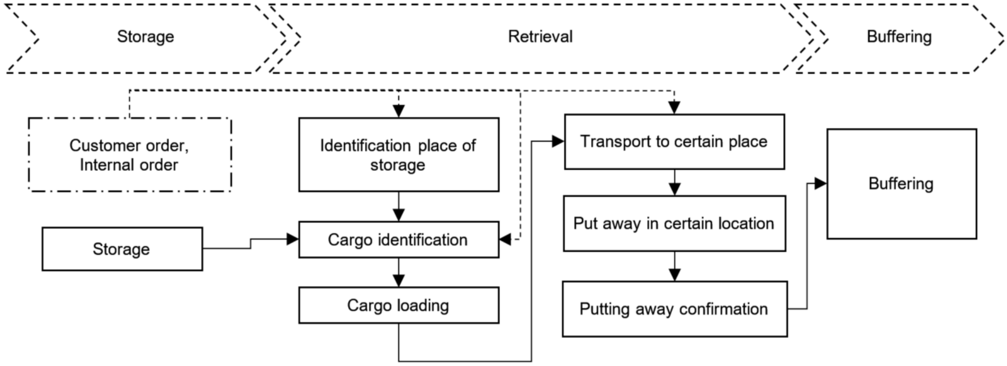

Fig. 6. Example of retrieval phase in warehouse process. Retrieving materials from storage areas with subsequent and following stages of that process.

Crossdocking process may contain division, sorting or forming loading units. Order-picking processes are not typical for crossdocking but are allowed and carried out. The example of crossdocking process is presented in fig. 7.

The basic activities of cross-docking phase (***f5***) are: material identification in input buffer and transport to sorting, packing place (c_1^{f5}), sorting, packing, labelling (c_2^{f5}), transport materials to output buffer area (c_3^{f5}). Phase ***f5*** can be defined as a vector:

$$\boldsymbol{f5} = \langle c_1^{f5}, c_2^{f5}, c_3^{f5} \rangle \tag{8}$$

The simplest variant of crossdocking phase includes only one activity - transport of materials from input buffer to output buffer.

3.3. Warehouse process strategy

Depending on the basic tasks of a warehouse facility, structure and size of customer orders or the industry, many strategies of warehouse process implementation can be formulated. Strategy of warehouse process is a variant of implementation of the process determining the sequence of handling and storage operations, which are applied to certain materials in the receiving and shipping phase. Strategy then is a map of warehouse technologies implemented to transform material streams. Proper selection of strategy depends on the size and form of work orders and has a significant impact on the performance of the process and the realization of orders in a specified by the customer time.

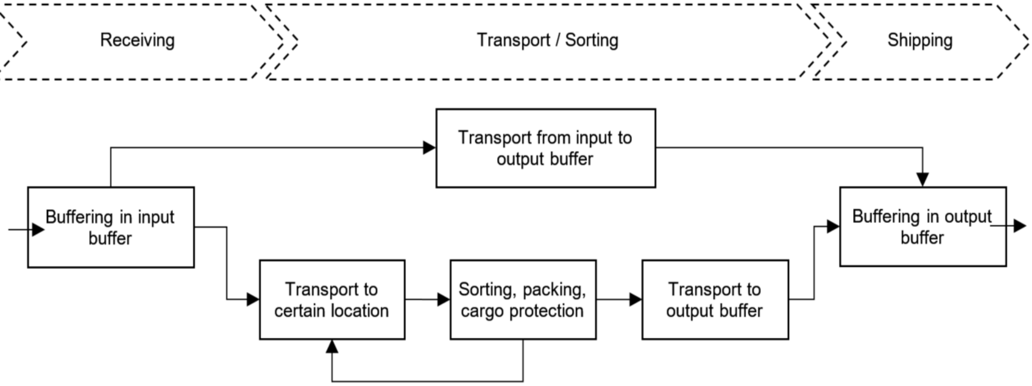

Fig. 7. The elements of warehousing process. Crossdocking with subsequent and following stages of that process

To the simplest and most common variants of warehouse process consists of receiving, put-away, storage and then, when it is necessary, the retrieval and shipping to the customer (fig. 8).

The second variant of implementation of the warehouse process occurs when incoming orders are for nonhomogeneous material units (fig. 9). Then replenishment processes to feed picking area must be performed to make order-picking possible.

A specific variants of transition of materials through warehouse like cross-docking are also implemented (fig. 10).

Another specific variant of transition of materials through the warehouse is a situation in which units received to the warehouse do not pass quantitative or qualitative control at the entrance and are transmitted to the return to the sender or disposal.

Nevertheless, for more detailed presentation of different variants of transition of materials through logistics facilities, transition process should be divided into two parts. The first one comprises a sequence of actions performed on the materials until their storage and/or offer (in the picking area), while the second concerns the activities carried out on the materials after these phases of the warehouse process.

4. Selecting strategy of warehouse process– case study

4.1. General assumptions

For verification of proposed approach an example was proposed:

1) For each strategy a sequence of nodes representing particular phases is specified. The first node is for beginning of the route of movement and the last is the end.
2) A set of possible configurations of the process (strategies) at the entrance is known for realized process. The elements are strings whose elements are pairs combining physical points in the warehouse space and the functional area to which a given point belongs (initial pair includes point of entry to the warehouse). Also set of possible configurations of the process (strategies) on exit is known, which elements are the same as defined strings (final pair includes point of exit from the warehouse), ie.
   a. The beginning and the end of each strategy is specified in the nodal points appropriate for handling deliveries and shipments.
   b. Each element of the strategy of the movement of materials within the logistics process belongs to the set of transformations of material streams implemented by facility.
   c. The end of each of elements of the strategy of logistics service implementation in warehouse facility is the beginning of the next element of the strategy.
3) Depending on the transformed material (belonging to the appropriate material group) and its state in a given time period there are different strategies of the transition defined by appropriate strategies.

For a given supply it is possible to determine a set of strategies, the implementation of which will lead to the counting supplied materials to the stock. Similarly, it is possible to designate a set of strategies that will lead to the realization of a particular shipment.

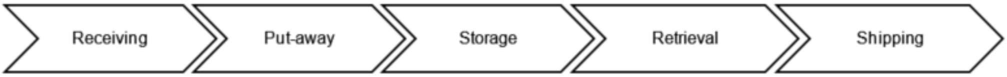

Fig. 8. Example No. 1 of a variant of transition of materials through the warehouse facility

Fig. 9. Example No. 2 of a variant of transition of materials through the warehouse facility

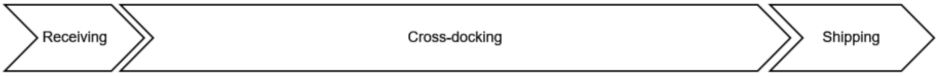

Fig. 10. Example No. 3 of a variant of transition of materials through the warehouse facility

Implementation of shipping or delivery in the warehouse can occur according to several different strategies depending on the situation. The number of possible strategies is known.

The probability of selecting a specific transition strategy is dependent on the technical and organizational factors. Strategies, reflecting standard (desirable) process flows, are more likely than others. The main factor influencing the choice of strategy is:

– in case of deliveries – free space in the areas (e.g. available pallet spaces in buffering area on entrance, available storage space in storage area).
– in case of shipments – availability of ordered materials in the appropriate functional areas (eg. availability of materials in the order picking area or in the storage area).

Therefore, the probability of selecting a particular strategy is dependent on technical and organizational factors, wherein selecting a strategy that reflects a standard (desirable) process flow is more likely than the other. If there is no material ordered or it will not be in the functional area of the estimated time of collection, the probability of choosing the strategy that supports this area is 0. Similarly, when at the estimated time of adoption of the material in a particular functional area will not be enough space to store, buffer or handle the unit in it.

4.2. Selection of the warehouse process strategy based on the probability of the transition of material through the warehouse

For each shipping or delivery task, it is possible to determine the decision-making situations tree, to specify a probability of implementing particular strategies of warehouse process. Exemplary tree of implementation strategy for a single shipping task is shown in fig. 11.

In the example shown in fig. 11 the implementation of task shipping can finish by collection of material (green colour), suspension of issuance (delay treated as an error of use - orange colour) or cancellation of performance of a task (causing losses, customer dissatisfaction – red colour). Selection of further components of the strategy in the decision tree is done with a certain probability, e.g. path selection, taking into account the ability to collect from the order picking area (relation 1-4) occurs with probability $P(X_{1.15})$:

$$\begin{aligned}P(X_{1.15}) &= P(X_{3.4})\cdot P(X_{4.15}) + \\ &+P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.12}) + \\ &+P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.6})\cdot P(X_{6.7})\end{aligned} \tag{9}$$

Accordingly, for each shipment or delivery, it is possible to determine the sequence of events, from which one will be a selected implementation strategy described by probability of occurrence.

Fig. 11 shows nine different strategies to pass materials through the warehouse for the implementation of order incoming to the warehouse facility. Five of the strategies leads to success, i.e. collection of the material and implementation of shipping to the customer at the right time. Therefore, the probability of timely implementation of shipping task (P_R) can be determined based on the equation (10):

$$\begin{aligned}P_R &= P(X_{3.4})\cdot P(X_{4.15}) + P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.12}) + \\ &+P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.6})\cdot P(X_{6.7}) + \\ &+P(X_{3.9})\cdot P(X_{9.16}) + P(X_{3.9})\cdot P(X_{9.10})\cdot P(X_{10.17})\end{aligned} \tag{10}$$

In addition, it is possible to predict the losses that may incur a warehouse facility with a certain probability as a result of:

- shipping delay P_S (fig. 11):

$$\begin{aligned}P_S &= P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.6})\cdot P(X_{6.8})\cdot P(X_{8.14}) + \\ &+P(X_{3.9})\cdot P(X_{9.10})\cdot P(X_{10.11})\cdot P(X_{11.14})\end{aligned} \tag{11}$$

- shipping cancellation P_C (fig. 11):

$$\begin{aligned}P_C &= P(X_{3.4})\cdot P(X_{4.5})\cdot P(X_{5.6})\cdot P(X_{6.8})\cdot P(X_{8.13}) + \\ &+P(X_{3.9})\cdot P(X_{9.10})\cdot P(X_{10.11})\cdot P(X_{11.13})\end{aligned} \tag{12}$$

Increasing the capacity of the order picking area OPA (fig. 11) will increase the probability $P(X_{4.15})$ of finding desired SKU in the area. But at the same time may cause a prolongation of picking cycles, and this will lead to a decrease in productivity of the shipping process. This indicates that all reorganization, investment works and technological change in the warehouse facilities should be multifaceted analysed. Indeed, any change can significantly affect component processes of the warehouse strategies, the probability of choosing the strategy, and thus the productivity and the cost of operation of the entire process and warehouse facility (and, consequently, the supply chain).

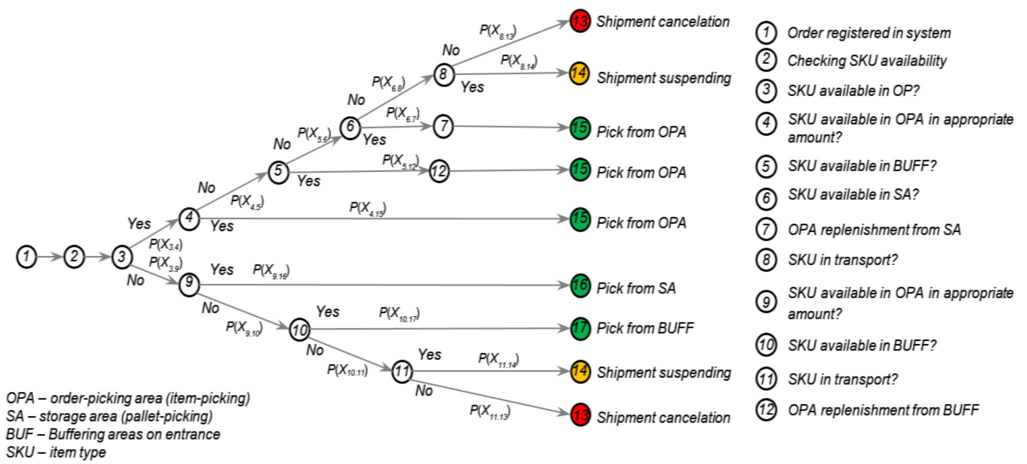

Fig. 11. Strategy of the transition feasible when it is necessary to collect the assortment located in the warehouse.

5. Summary

The proper and uninterrupted operation of warehouse facilities is extremely important. It affects directly the correct operation of the entire supply chains, and thus the economic success of companies involved. Efforts should be made to ensure that the processes realized in the warehouse facilities are properly designed and planned. This requires the preparation of a number of strategies that will be used to carry out the tasks flowing into a logistics facility. Proper selection of a warehouse strategy determines the ability to perform a task in a specific, acceptable by the customer time and costs. The choice of sequence of specific warehouse activities (strategy) to complete the order is also dependent on a number of technical and organizational factors and associated with a certain probability. This probability can be estimated on the base of data analysis concerning the course of logistics processes in a particular warehouse facility. The value of the probability of selection of a particular strategy variant of logistics service of materials can be modified, e.g. through investments and modernizations to increase the technological potential (performance, capacity) of functional areas of the warehouse, or by organizational activities related to the allocation of resources to tasks in time.

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