SELECTION OF PRODUCTION SOURCING METHOD USING PROCESS SIMULATION

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Abstract

The paper presents an analysis of warehouse and production processes for component sourcing and finished goods receiving using BPMN notation in the iGrafx IT environment. The authors in the paper presented the developed model of how production is sourced and its impact on the production process. The model is the result of optimization work for enterprises carried out within the activities of the Lukasiewicz Research Network - Poznan Institute of Technology and research work at the School of Logistics. In order to accurately depict the processes and their interrelationship between each other, the model also includes the production process for a finished product having a preset structure of the structure. The results of the simulation studies of the model for the following variables are also presented: variances in the handling of supplies for production and receipt of products, allocation of necessary resources for the implementation of processes, and availability of resources. Simulation validation of these variants allows to conclude that the developed model of the production supply process is universal and implementable in business practice for the purpose of conducting efficiency analyses of production supply processes.

Key words: BPMN Notation, iGrafx software, multi-criteria analysis, manufacturing, production procurement

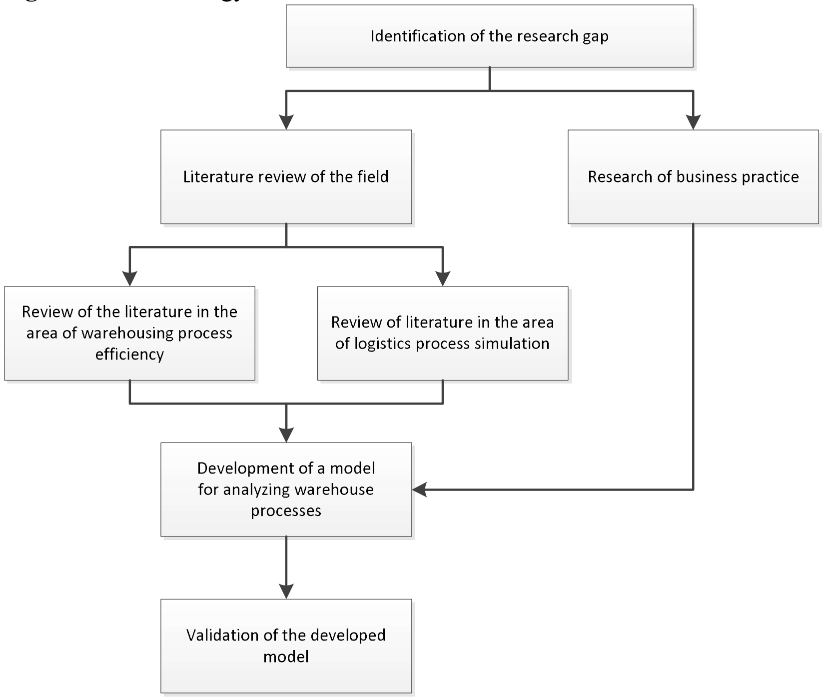
1. INTRODUCTION

The efficiency of warehousing processes in handling production has a major impact on the performance of production systems. The warehousing process includes operational activities related to the storage of goods and all manipulative activities performed in accordance with specific organizational and technological conditions. Manipulative activities include the flow of material goods (receipt, movement within the warehouse, issuance to production, receipt of goods from production) and the collection and processing of goods (picking, preservation). In addition to handling activities, the warehousing process also includes activities involving the flow of information. Particularly at the level of warehousing processes, as well as at the level of production processes, there is a tendency to continuously improve existing processes for optimization purposes. These requirements are forcing companies to implement increasingly efficient processes using organizational and technological solutions. A very important aspect of warehouse process efficiency is currently the implementation of IT systems and innovative technologies. However, as these implementations should be based on optimally organised warehouse processes, a fundamental step in our research is to identify the key operational activities that affect the efficiency of warehouse processes even before the implementation of innovative technologies.

2. RESEARCH METHODOLOGY

The research presented in this paper presents both the literature review on the subject and a consideration of the practical aspects of implementing warehousing processes in supply chains. Therefore, the analyses conducted are the result of research work, concerning the impact of warehousing on the supply processes efficiency, and the observation of business practice, feeding the developed model with reliable data for validation. Figure 1 shows the logic of the ongoing research work in this regard.

Figure 1 Methodology of conducted research



Source: own study

The use of the case study method makes it possible to discover the state of the phenomenon under study, which the results of quantitative research can only suggest. The case study, compared to other research methods, offers a more extensive range of techniques and tools for data acquisition and analysis. Sources of data can include observations, interviews, data and documents from companies, journal papers, surveys. The numerous possibilities for obtaining data mean that the case study method is not methodologically limited in terms of data analysis (George, 2019). A case study should be considered as a single and limited research process that aims at detailed analysis using multiple research techniques over a long period of time (Shani, Coghlan, 2021). In the literature on the verifiability of models through case studies, different views can be found on the number of variants carried out that must be analysed for the study's conclusions to be scientific. The dominant view suggests conducting between four and ten case studies (Eisenhardt, Grabner, 2007; Yin, 2009; Ponelis, 2015). Taking into account the specifics of the efficiency of the warehousing process, the authors considered that conducting a simulation analysis for a minimum of four case study variants would allow validation of the developed model.

The following paper will describe the study of the storage process in a manufacturing company through the implementation of organizational solutions. The organizational solutions consisted of variances in work shifts, the distribution of working hours for handling deliveries and releases, and the appropriate allocation of the necessary resources for the implementation of processes. The main criteria for selecting the most efficient process were:

- handling of assumed commodity flows within 1 day,
- human resource utilization rates of 80%,
- lowest process handling costs.

3. SPECIFICS OF EFFICIENCY OF WAREHOUSE AND PRODUCTION PROCESSES

The peculiarities of warehousing processes make it necessary to focus on those factors that have a key impact on the continuity of material flow in terms of production handling (Zuchowski, 2022). In the scientific research on logistics management, one can find many factors - processes and resources, affecting the overall process of warehousing (Kolinski, Sliwczynski, 2015; Shah, Khanzode, 2017; Md Hanafiah, et. al. 2022). Therefore, it should be concluded that warehouse management should focus on ways to improve the efficiency of processes, both internal and external supply chain, and to continuously monitor and evaluate the results obtained. The research problem identified in the course of literature studies and observations in enterprises, is to carry out an assessment of the efficiency of the warehouse process, taking into account a multidimensional analysis of the dependencies occurring within the process, as well as the connections with other processes that affect the continuity of the flow of materials in the production process.

The efficiency of warehousing processes is an issue of great importance from the point of view of the organization of processes taking place in the enterprise and in the supply chain (Lukinskiy, Lukinskiy, Merkuryev, 2017; Richards, 2021). Increasing efficiency is therefore an important factor in controlling activities.

However, it should be noted that despite the numerous references in the literature regarding efficiency, in business practice efficiency analysis is not used to the extent that it guarantees effective support for decision-making processes taking place in the enterprise. Studies conducted on the identification of difficulties in conducting comprehensive process efficiency analysis confirm the low degree of use of these analytical tools in business practice (Yan, et al., 2019). It should be noted that almost half of the surveyed enterprises do not perform such analysis or are not aware of it. This should be considered an unsatisfactory result and confirms the generally held opinion that efficiency analysis is a complicated process and difficult to use in practice, especially due to the lack of universal analytical tools to support its performance. However, the results also testify to the growing awareness of the need to perform efficiency analysis to improve competitive positions in the market.

Analyzing the literature on the subject, it should be noted that there is no unambiguous analytical method, taking into account a comprehensive analysis of the efficiency of warehouse processes in both financial and technical-organizational aspects, along with the interrelationships and feedbacks that occur.

Analyzing the warehouse process in terms of efficiency, it is necessary to identify the goals and objectives of effective warehouse management, which are presented in Table 1.

Table 1 Goals and objectives of effective warehouse management

Goals	Tasks
Maximizing the use of storage space, achieved through appropriate actions in the design, construction and commissioning of the warehouse, and responding to ongoing changes	Ensuring the availability of adequate technical and personnel resources to achieve the planned level of activity - possible only with close cooperation with the company's management
	Ensuring a flow of goods that meets delivery and shipment requirements - requires cooperation between the warehouse and the procurement and sales departments;
Minimize the use of handling operations - in the first step, unnecessary operations are eliminated, and in the second step, the aim is to reduce the time of performing necessary operations	Constantly planning, controlling and maintaining the use of all resources held - is done at the operational level and can be based on production plans and orders placed with suppliers (in the case of a supply warehouse) or sales plans and orders from customers (distribution warehouse);
	Continuous monitoring, evaluation and improvement of the warehousing process according to established criteria - should be based on selected indicators and metrics reflecting the course of the process

Source: own study based on (Niemczyk, 2016, pp. 73-86)

Granting the validity of the thesis that warehouse management has a significant impact on the operation of the enterprise, it is clear that it is necessary to strive for continuous improvement of warehouse operations. Among the most important factors for increasing the efficiency of warehouse operations are (Kolinski, Sliwczynski, 2015, pp. 178-179):

- adjusting the flow to the capacity of the warehouse - the determination of the capacity of the warehouse should be taken as a starting point. Based on it, working with other departments of the company, the schedule of deliveries and shipments should be set in such a way as to avoid the piling up of work during the day and the excess of cargo units flowing through the warehouse,
- use of storage space - refers to the efficient use of the available height of the storage area,
- rationalization of the paths traveled by employees and goods - this factor is most important for the picking process; besides, efforts should be made to eliminate or shorten the paths traveled by employees without goods,

- use of personnel - when analyzing this factor, it is necessary to pay attention to three criteria: the workload of employees over time, the competencies and powers they possess, and the constancy of employment,
- effective circulation of information - has a key impact on the implementation of all phases of the warehousing process. Any disruption in the flow of information (especially in the picking and issuing phases) can result in delays in the execution of orders.

One of the most widely used methodologies for mapping business processes is that based on the SCOR - Supply Chain Operations Reference Model (Chen, et al. 2020). It should be noted that the necessity to exchange operational data of the process, taking into account the division into operations and transactions, as well as initiating events, documents and output reports, is the basis for the dimensioning and operational preparation of processes in accordance with the BPMN concept (Abouzid, et al. 2022; Stajniak, Guszczak, 2011).

BPMN (Business Process Model and Notation) notation is a graphical notation for describing business processes. It was developed as part of the Business Process Management Initiative and is currently maintained by the Object Management Group consortium. The current version of the standard is 2.0. In earlier versions, the name BPMN was developed as Business Process Modeling Notation. The big advantages of this notation are its unambiguity, its suitability for both ERP and Workflow software process descriptions, and the fact that it is supported by more than 70 tools.

Of the products present on the Polish market, this notation is supported by iGrafx, ADONIS, Borland and IBM tools, among others. One of the most widely used simulation tools in enterprises is iGrafx Process. The iGrafx Process IT environment allows editing of elaborate process diagrams for clear presentation and comprehensible simulation at a later time.

Both in the literature and in business practice, one can find numerous ways of reflecting processes occurring in enterprises, for analytical purposes. Simulation methods take into account the passage of time and the variability of control parameters, and therefore seem appropriate for the presentation of process dynamics (Golroudbary, et al. 2019). They make it possible to analyze the impact of the size and intensity of the flow of materials (parts, components) on load distribution in warehouse systems, analyze constraints (including bottlenecks), critical flow levels for queuing and downtime in the warehouse, as well as the impact on the performance characteristics of warehouse equipment (diagnostics).

Conducting simulations makes it possible to analyze the process in terms of various variants, which are verified in a virtual way, a way that does not affect the real-time operation of the process. However, based on well-developed control parameters that are consistent with the actual state, it is possible to conclude with high probability that the analyzed process variant has a chance to be realized in economic reality. Any simulation requires the definition of basic principles (Dullinger, 2009, p. 3):

- in the case of complex processes subjected to simulation, it is necessary to properly select the simulation tool and model in detail the parameters of the analyzed process and the system in which it operates, define the input data and define the objective,
- in the case of flexible processes subjected to simulation, it is necessary to frequently change the values of control parameters,
- basing the analysis on average parameter values carries the risk of misinterpretations,
- simulation must be carried out in a timely manner to achieve the greatest benefit.

The simulation model design procedure includes the following steps (Mourtzis, 2020):
- identification of the object to be simulated, using one of two approaches: top-down, in which the main process is subject to detailing into sub-processes and activities; bottom-up, which begins by defining all activities to group them into sub-processes and main processes in the next stage,
- development of diagrams of the process being simulated using IT tools (the number of hierarchy levels depends on the detail of the process being analyzed),
- collection of input data and parameters, and then entering them into the simulation model,
- validation of the model, which boils down to comparing the behavior of the simulation model with the actual behavior of the system in question.

Simulation is one of the methods of quantitative analysis of decision-making problems, the main advantage of which is the ability to evaluate solutions without implementing them in market reality. Computer assisted analysis and evaluation of the efficiency of logistics processes in logistics enterprises depends on the reliability of input data, derived from information systems (Anisimov, Anisimov, Saurenko, 2020). The specifics of the warehousing process, makes computer simulation widely used. It should be stated that the choice of the IT environment used during process simulation depends on the complexity of the problem being analyzed. A very common solution is the use of spreadsheets for simulation, which, however, can be used only for simple simulations that do not require graphical depiction of the implementation of the process. Specialized simulation programs allow the execution of simulations over a wide analytical range, and often require the programming of dedicated macro-definitions. The complexity of the storage process makes the construction of simulation models time-consuming and error-prone. However, one can find numerous empirical analyses in the literature, using simulations, that address both the entire process (Szczepański et al, 2019), as well as only a selected, very often complex part of it (Li et al., 2021). One can also find numerous literature references to simulation analyses of processes with different specificities and in different aspects, concerning:

- financial analysis of the cost-effectiveness of the course of the logistics process and prediction of potentially obtained effects (Meade, S. Kumar, A. Houshyar, 2006),
- optimization analysis aimed at reducing resource consumption (Tang, Meng, 2021),
- analysis of operational results of logistics process execution and value stream mapping (Jing et al., 2021).

Process simulation capabilities have a significant impact not only on the implementation of warehouse processes, but also on logistics processes throughout the supply chain. The process integration of the supply chain, as well as the identification of cause-effect relationships and feedbacks, is increasingly reported in the scientific literature (Golinska-Dawson et al., 2023; Dubisz, et al., 2023; Blöchl, M. Schneider, 2016; Trojanowska, et al., 2018; Akpinar, 2021; Kluska, 2021). This demonstrates the growing interest in simulation procedures as transparent research methods, especially in the field of management science.

4. MODEL OF WAREHOUSE PROCESSES FOR PRODUCTION SUPPLY - BASIC ASSUMPTIONS

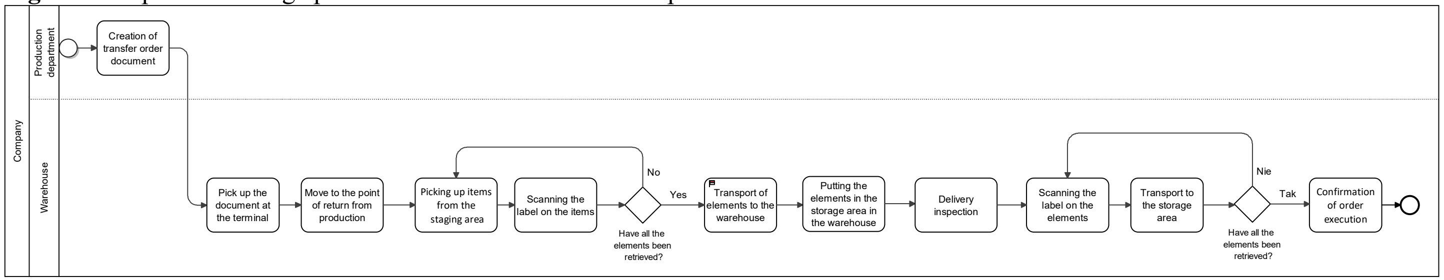
The main research problem of organizational solutions in the warehouse process model for production supply was to analyze its efficiency, taking into account the process configuration, its parameterization based on changes in the volume of material flows related to production, the formation of the demand for human resources and internal transport resources, and its impact on the production process.

As an example of the research process, the process implemented in a post-production warehouse serving the production line of a finished product was taken. The process flow diagrams are shown in Fig.1 to Fig.3.

The research of organizational solutions of storage and production process models was carried out in iGrafx Process 2011 program using simulation. Conducting simulations in iGrafx required transforming process maps into models by parameterizing them, viz:

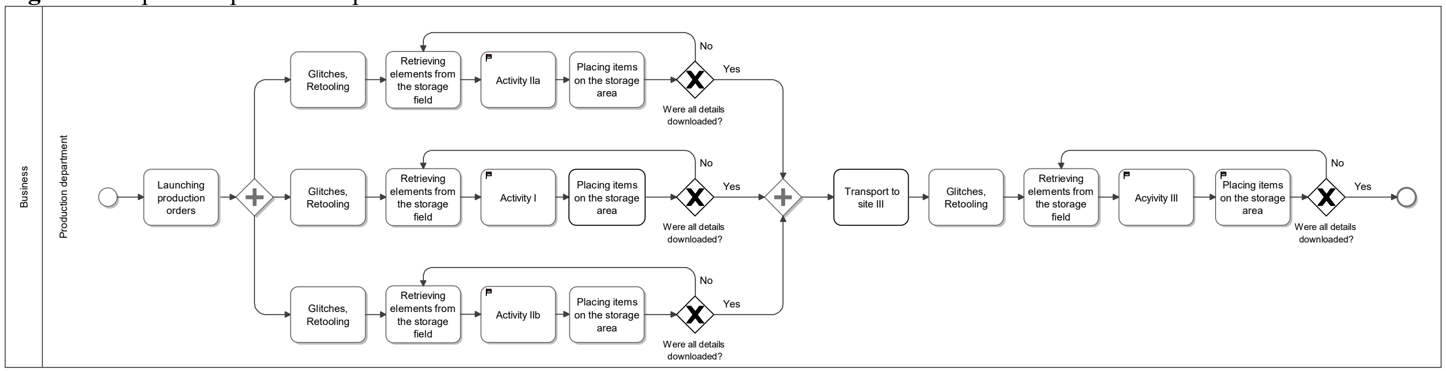
- defining dependencies in the process,
- defining the type of resources and assigning them to execution in individual activities,
- determining the costs of individual resources,
- determining the duration of individual activities,
- determining the work schedules of individual company departments,
- determination of the frequency of service of the production line in terms of delivery and reception,
- definition of transactions (parameters of commodity and information flows processed in process activities),
- defining the type of transaction generator.

Figure 2 Map of the storage process - release of materials for production



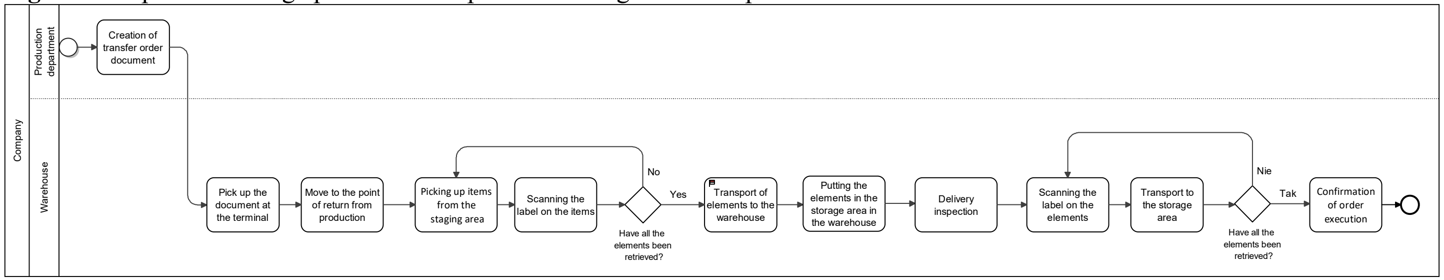
Source: own study

Figure 3 Map of the production process



Source: own study

Figure 4 Map of the storage process - receipt of finished goods from production



Source: own study

Resources

The storage process model defines three types of resources:
- Labor (employees),
- Equipment I (internal transportation equipment),
- Equipment II (positions - production machinery).

Employees carrying out processes were divided according to department into:
- Production worker - production department
- Warehouse worker - warehouse.

Internal transport equipment was divided into:
- lift trucks,
- lift trucks guided.

For each resource, the parameters of cost, work schedule, possible overtime, number of individual resources were determined and then the resources were assigned to individual activities. A summary of the entered data for resources in the processes is shown in Table 2.

Table 2 Resources in the storage and production process

	Resource	Hourly Rate [PLN/h]	Cost of use [PLN/h]	Schedule	Overtime	Resource Assignment
1	Production foreman	40	10	Firm	-	Production department
2	Machine operator	30	5	Firm	-	Production department
3	Cart operator	24	5	Firm	-	Production department
4	Position - Machine	0	100	Firm	-	Production department
5	Warehouseman	24	5	Firm	-	Warehouse
6	Forklift operator	24	5	Firm	-	Warehouse
7	Lift truck	0	5	Firm	-	Warehouse
8	Lift truck	0	2	Firm	-	Warehouse/Production Department

Source: own study

A variable number of resources were simulated.

Activity durations

In the developed storage process model, the durations of process activities were divided into two groups:
- fixed, concerning the preparation of editing and approval of documents,

- variable, concerning the execution of cargo handling activities in the process.

Fixed and variable times are introduced at the simulation stage with the help of transaction, scenario attributes. A summary of the introduced sample times in the processes is shown in Table 3.

Table 3 Unit times of activities in the process model

PROCESS PHASE	ACTIVITY	BENCHMARK UNIT	ATTRIBUTE	TIME UNIT [MIN]
Release of materials for production	Create document demand for raw materials and semi-finished products	doc	Ww_t1	2,50
	Edit document Wm	doc	Ww_t2	1,00
	Getting the order to the terminal	doc	Ww_t3	0,30
	Transfer to the storage address	jł	Ww_t4	1,00
	Picking	jł	Ww_t5	1,56
	Picking release carrier	poz	Ww_t6	1,00
	Move to storage address	poz	Ww_t7	1,56
	Pick up and deposit the indicated quantity of goods on the carrier	jł	Ww_t8	2,50
	Transport of goods to inspection area	jł	Ww_t9	1,56
	Control of picking	jł	Ww_t10	1,00
	Complete and improve the order picking	jł	Ww_t11	2,50
	Formation and securing of the delivery unit	jł	Ww_t12	1,50
	Labeling of the delivery unit	jł	Ww_t13	0,50
	Transportation to the production storage area	jł	Ww_t14	1,56
	Confirmation of completion of the doc. Wm	doc	Ww_t15	0,50
	Quantitative control in the production storage area	jł	Ww_t16	0,10
Production process	Putting elements on the storage area	pcs	Pp_t1	0,5
	Picking elements from the storage area	pcs	Pp_t2	3
	Activity I	pcs	Pp_t3	0,5
	Putting elements on the storage area	pcs	Pp_t4	0,5
	Picking elements from the storage area	pcs	Pp_t5	3

	Activity II a	pcs	Pp_t6	0,5
	Putting elements on the storage area	pcs	Pp_t7	0,5
	Picking elements from the storage area	pcs	Pp_t8	4
	Activity II b	pcs	Pp_t9	0,5
	Putting elements on the storage area	pcs	Pp_t10	0,5
	Picking elements from the storage area	pcs	Pp_t11	15
	Activity III	pcs	Pp_t12	0,5
	Putting elements on the storage area	jł	Pp_t13	2,5
Pickup of products from production	Creation of a document transfer order	doc	Dw_t1	2,50
	Downloading the document to the terminal	doc	Dw_t2	0,30
	Move to the point of departure from production	jł	Dw_t3	1,56
	Picking up elements from the storage area	jł	Dw_t4	1,00
	Scanning the label on elements	jł	Dw_t5	0,10
	Transport of elements to the warehouse	jł	Dw_t6	1,56
	Putting elements on the storage area from the storage area at the warehouse	jł	Dw_t7	0,50
	Scanning the label on elements	jł	Dw_t8	0,10
	Checking the delivery	jł	Dw_t9	2,00
	Transport to the storage area	jł	Dw_t10	1,56
	Confirmation of order completion	doc	Dw_t11	0,50

Source: own study

The operations described as activity I, IIa, IIb and II have been deliberately generalised, as they concern production operations that were not the subject of the research carried out. The data used for the simulations are real, but due to the object of the research being warehouse processes, no attempt was made to infer and optimise strictly production processes.

Schedule of work

In the developed storage process model for the study, a standard work schedule was adopted in which the following were defined:

- days of work,
- working hours.

Days of work
The model adopted the company's standard working days of Monday through Friday.
Working hours
The model assumes three-shift operation.
Frequency of production handling
The variability of production service frequency was simulated.

Transactions - parameters of commodity and information flows

In order to determine the basic results of the efficiency of the storage process run during process simulation, transactions were defined parameters of goods and information flows that will feed the developed models. It was assumed that transactions as well as activity durations will be entered into the model using export from an external file. A transaction generator will be used for this, the configuration and working principle of which is described below.
In the developed models, transactions were divided into two groups concerning:
- information flows,
- commodity flows.

A summary of the proposed transactions - parameters of commodity and information flows is shown in Table 4. Transactions - flow parameters will be entered into the model from an external file (Ms. Excel) at the simulation stage using the transaction attributes defined in the models, scenario.

Table 4 Transactions - parameters of commodity and information flows in the process model

No	PHASE OF PROCESS	PARAMETER NAME	ATTRIBUTE
1	Delivery of materials for production	Number of delivered documents	Number of delivered documents
2		Number of items on release documents	Wyd_ number of positions
3		Number of elements on release	Wyd_ number of units
4		Number of homogeneous elements on release	Wyd_ unit number of pieces
5		Number of elements completed on release	Wyd_ number of units set
6	Production	Picking from the staging area	PP1_ number of units
7		Activity I	PP2_ number of units

No	PHASE OF PROCESS	PARAMETER NAME	ATTRIBUTE
8		Putting the elements on the staging area	PP3_ number of units
9		Transport to staging area III	PP4_ number of units
10		Picking from the staging area	PP5_ number of units
11		Activity IIa	PP6_ number of units
12		Putting the elements on the collecting fields	PP7_ number of units
13		Transport to stand III	PP8_ number of units
14		Picking the elements from the staging area	PP9_ number of units
15		Activity IIb	PP10_ number of units
16		Putting the elements on the collecting fields	PP11_ number of units
17		Transport to stand III	PP12_ number of units
18		Picking up elements from the staging area	PP13_ number of units
19		Activity III	PP14_ number of units
20		Putting the elements back on the staging area	PP15_ number of units
21	Picking up products from production	Number of documents in delivery	Dost_ number of doc
22		Number of items on documents	Dost_ number of units
23		Number of items in delivery	Dost_ number of units
24		Number of homogeneous items in the delivery	Dost_ unit number of pieces
25		Number of elements completed in the delivery	Dost_ number of units set

Source: own study

Transaction generator type

A generator that is automatically created and assigned to this starting point will be used to enter transactions into the process model. Of the generators available in iGrafx Process 2011, a sequential generator was selected to enter transactions into the model during simulation:

- unit times of individual process activities,
- transactions resulting from commodity flows in the warehousing and production process.

The magnitude of commodity and information flows results from the design of the finished product, its structural complexity viz:

- the number of details that make up a subassembly,
- the number of subassemblies and details making up the finished product,
- the method of packaging of details, subassemblies in the production and transport processes,
- the adopted daily production volume.

The structure of the construction of the finished product and the method of packing of details and subassemblies in the production and storage process are shown in Table 5.

Table 5 The structure of the structure of the finished product and how the details and components are packed in the production and storage process

50	Number of components or parts per finished product [pcs]	Components	Detail	Number of parts per component [pcs]	Place of the process				Method of packaging in internal transport					
Production volume [pcs]					Stand I	Stand IIa	Stand IIb	Stand III	Components	Quantity in container [pcs]	Number for containers for pjł [pcs]	Detail	Quantity in the container [pcs]	Number of containers for pł [pcs]
Finished product	1	I	Detail 1	4	X			X	I	1	2	Detail 1	50	4
			Detail 2	4	X							Detail 2	50	4
			Detail 3	4	X							Detail 3	50	4
	1	II	Detail 4	4		X		X	II	1	2	Detail 4	20	4
			Detail 5	4		X						Detail 5	20	4
	1	III	Detail 6	3			X	X	III	1	2	Detail 6	10	3
			Detail 7	3			X					Detail 7	10	3
	6	-	Detail 8	-				X	-	-	-	Detail 8	15	4

Source: own study

A summary of transactions - volumes of goods and information flows is shown in Table 6.

Table 6 Transactions - volumes of material and information flows for the process model

No	PROCESS	ATTRIBUTE	BENCHMARK UNIT	VOLUME OF DAILY FLOWS
1	Delivery of materials for production	Wyd_ number of docs	doc	24
2		Wyd_ number of items	item	8
3		Wyd_ number of items	item	24
4		Wyd_ number of items unit	item	24
5		Wyd_ number of elements set	item	0
6	Production	PP1_ number of pieces	piece	600
7		PP2_ number of pieces	piece	600
8		PP3_ number of pieces	piece	50

No	PROCESS	ATTRIBUTE	BENCHMARK UNIT	VOLUME OF DAILY FLOWS
9		PP4_ number of pieces	item	25
10		PP5_number of pieces	piece	400
11		PP6_number of pieces	piece	400
12		PP7_number of pieces	piece	50
13		PP8_number of items	item	25
14		PP9_number of pieces	piece	300
15		PP10_number of pieces	piece	300
16		PP11_number of pieces	piece	50
17		PP12_number of items	item	25
18		PP13_number of pieces	piece	450
19		PP14_number of pieces	piece	450
20		PP15_number of pieces	piece (item)	50
21	Receiving products from production	Dost_number of docs	doc	24
22		Dost_number of items	Item on doc	1
23		Dost_number of items	item	50
24		Dost_number of unit items	item	50
25		Dost_number of items of sets	item	0

Source: own study

Simulation validation of the developed model

The simulation of the storage process involved changing:
- frequency of production handling,
- the number of available resources assigned to carry out activities in the process,

The following models were adopted for the simulation:
- model 1 - handling production once per shift,
- model 2 - handling production once per shift,
- model 3 - handling production twice per shift,
- model 4 - handling production three times per shift.

For each model, two scenarios were considered with:
- a limited number of resources,
- an unlimited number of resources.

One of the primary objectives of process modeling and simulation is to measure the time
and costs associated with the process and to identify bottlenecks in the process. Simulating logistics processes in iGrafx software allows generating many statistics on process execution times, activity waits and unit costs, number of resources, e.g:

- actual process execution time,
- general statistics of transactions (service time, service waiting time, working time, blocking time),
- detailed statistics of transactions carried out by individual departments,
- resource costs
-

With regard to resource statistics, it is possible to obtain the total time or cost of resources consumed or their average values. Most often they are related to:

- overall resource utilization,
- detailed use of resources in individual departments,
- detailed statistics of activities in the process in relation to resources (service time, service waiting time, working time, blocking time).
-

In turn, statistics on bottlenecks in the process can be presented in the form of, for example:

- the number of transactions that were waiting for resources,
- waiting times for resources if resources are busy or are unavailable,
- waiting times for resources in individual departments.
-

The following parameters obtained from the simulations were selected for further detailed analysis from the process study:

- process service time,
- working time,
- total production time,
- resource waiting time,
- labor time utilization,
- number of resources,
- overall resource utilization,
- resource costs,
- number of finished goods produced.
-

The simulation results for each model and scenario are shown in Table 7.

Table 7 Simulation results of process execution for assumed models and scenarios

Specification		Model 1		Model 2	
		SC1	SC2	SC1	SC2
Operating time [h]		173,35	173,92	172,84	257,21
Operating time [h]		118,48	173,85	167,91	174,08
Total production time [days]		4,93	1,25	7,00	3,16
Resource waiting time [h]		277,88	0	249,67	169,54
Number of pieces of finished product produced.		50	50	50	50
Time utilization [%]	Production worker	38,16	63,84	60,74	24,52
	Warehouse worker	1,95	11,62	2	4,54
	Lift trucks	4,48	11,84	3,14	3,53
	Elevator trucks	1,99	7,88	1,61	2,93
	Machines	40,95	72,11	28,78	25,68
Number of resources	Production worker	18	28	18	26
	Warehouse worker	6	4	6	4
	Lift trucks	2	3	2	4
	Elevator trucks	1	1	1	1
	Machines	4	9	4	10
Costs	Production worker	67 441,00 zł	29 760,00 zł	94 724,00 zł	65 616,00 zł
	Warehouse worker	17 541,00 zł	3 360,00 zł	24 658,00 zł	7 763,00 zł
	Lift trucks	106,00 zł	106,00 zł	106,00 zł	106,00 zł
	Elevator trucks	215,00 zł	215,00 zł	215,00 zł	215,00 zł
	Machines	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł
	Waiting for resources	13 894,00 zł	0,00 zł	12 483,50 zł	8 477,00 zł
	Total	**111 197,00 zł**	**45 441,00 zł**	**144 186,50 zł**	**94 177,00 zł**

Source: own study

Results

The selection of the most effective model and scenario was based on the calculated indicators:

- unit cost of production of 1 piece of finished product,
- service time of 1 piece of finished product,
- production time of 1 piece of finished product,
- cost per hour of department downtime resulting from waiting for needed resources,

using multi-criteria analysis assigning weights to each criterion. The results of the multi-criteria analysis are presented in Table 8.
According to the adopted criteria, the most efficient solutions are models 1 and 2 based on scenario 2 (unlimited number of resources).
The other process implementation models are inefficient compared to the selected ones due to:

- higher unit costs of production of 1 finished product,
- longer handling and production times of the finished product.

Table 8 Results of multi-criteria analysis

Index	JM	Model 1		Model 2		Model 3		Model 4		
		SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2	
Unit cost of production of 1 unit of finished product	[zl/pcs]	2 223,94 zł	908,82 zł	2 883,73 zł	1 883,54 zł	-	1 900,88 zł	2 303,32 zł	1 632,36 zł	
Handling time of 1 unit of finished product	[h/pcs]	3,47	3,48	3,46	5,14	-	5,50	3,49	5,69	
Production time of 1 unit of finished product	[day]	4,93	1,25	7,00	3,16	-	2,02	5,23	1,64	
		Multi-criteria analysis								Weight criteria
		2,043	5,000	1,576	2,413	-	2,391	1,973	2,784	5
		4,012	3,975	4,000	2,688	-	2,513	3,966	2,428	4
		0,761	3,000	0,536	1,187	-	1,856	0,717	2,287	3
Total points		6,816	11,975	6,111	6,287	-	6,760	6,656	7,498	
Place in the ranking		3	**1**	7	6	-	4	5	2	

Source: own study

In order to identify possible bottleneck processes, delays in the production process resulting from the need for additional changeovers and production machine faults were modelled for the selected model. Delays were simulated separately for each machine/station and collectively for all of them. The sizes of possible delays from 0.5 to 2h were assumed. The obtained results are shown in Table 9.

Table 9 Results of bottleneck analysis

Specification		Model 1					
		SC2					
		No downtime	Machine 1	Machine 2	Machine 3	Machine 4	All
Service time [h]		173,92	190,57	184,87	180,9	192,92	123,1
Operating time [h]		173,85	160,09	155,36	148,19	160,09	75,62
Total production time [days]		1,25					
Resource waiting time [h]		0	3,5	4,51	0,53	2,61	153,36
Number of pieces of finished product produced		50	46	48	46	46	21
Use of working time [%]	Production worker	63,84	67,24	66,24	66,21	67,36	54,57
	Warehouse worker	11,62	11,61	11,62	11,61	11,61	9,19
	Lift trucks	11,84	11,84	11,84	11,84	11,84	6,67
	Elevator trucks	7,88	7,88	7,88	7,88	7,88	6,23
	Machines	72,11	71,63	71,93	71,74	71,65	37,98
Number of resources	Production worker	28	28	28	28	28	28
	Warehouse worker	4	4	4	4	4	4
	Lift trucks	3	3	3	3	3	3
	Elevator trucks	1	1	1	1	1	1
	Machines	9	9	9	9	9	9
Costs	Production worker	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 110,00 zł
	Warehouse worker	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 260,00 zł
	Lift trucks	106,00 zł	106,00 zł	106,00 zł	106,00 zł	106,00 zł	66,00 zł
	Elevator trucks	215,00 zł	215,00 zł	215,00 zł	215,00 zł	215,00 zł	170,00 zł
	Machines	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł	7 700,00 zł
	Waiting for resources	0,00 zł	175,00 zł	225,50 zł	26,50 zł	130,50 zł	7 668,00 zł
	Total	**45 441,00 zł**	**45 616,00 zł**	**45 666,50 zł**	**45 467,50 zł**	**45 571,50 zł**	**47 974,00 zł**
Unit cost of production of 1 unit of finished product	[PLN/pc]	908,82 zł	991,65 zł	951,39 zł	988,42 zł	990,68 zł	2 284,48 zł
Handling time of 1 unit of finished product	[h/pc]	3,48	4,14	3,85	3,93	4,19	5,86
% of finished products produced	[%]	100	92	96	92	92	42

Source: own study

Analysing the results from the above table, it can be concluded that:
- the most critical for continuity are outages at machine /station 1 and 4 which results in:
    - a decrease in production by 8% (from 50 pieces to 46 pieces),
    - an increase in handling time of 1 piece of finished product by about 19% ÷ 20%,
    - an increase in production costs by about 9% ÷ 9.1%
- the occurrence of downtime on all machines/stations results in:

- a decrease in production by 58%,
- an increase in handling time of 1 unit of finished product by about 68.3%,
- an increase in production costs by about 151.3%.

5. CONCLUSION

In this paper, the authors presented simulation validation of the developed model of the production procurement method. Simulation validation also allows for multiple predictive simulations, based on which it was possible to identify dependencies and feedbacks in the processes. Simulation validation was based on multiple case studies, which can be considered representative of the specifics of warehouse processes.

In this paper, the authors presented the problem of analysing the processes taking place in the warehouse at production supply lines. The conducted research dealt with both aspects of operational efficiency and economic efficiency of warehouse processes. This analytical approach allows for a comprehensive analysis of warehouse processes.

The research carried out is characterised by a high level of detail, focused on operational data. The simulation research indicates that the detail of data and attributes simulated should be as high as possible. However, the research does not answer the question of the necessity of such a detailed analysis of operational data, but it does confirm the fundamental importance of analysing warehouse processes at the operational level as a basis for implementing optimisation measures, including the implementation of IT systems and innovative solutions. The direction of further research will therefore be an attempt to simplify the analysis of data subjected to simulation and the introduction of process changes resulting from the implementation of innovative solutions.

6. REFERENCES

Abouzid, I., Bekali, Y. K., & Saidi, R. (2022). *Modelling IoT Behaviour in Supply Chain Business Processes with BPMN: A Systematic Literature Review*. Journal of ICT Standardization, 439-468.

Akpinar M.E., (2021). *A logistic optimization for the vehicle routing problem through a case study in the food industry*. LogForum 17 (3), 387-397

Anisimov, V., Anisimov, E., & Saurenko, T. (2020). *Efficiency of ensuring the survivability of logistics information and control systems*. In E3S Web of Conferences (Vol. 217, p. 07025). EDP Sciences.

Chen, Q., Hall, D. M., Adey, B. T., & Haas, C. T. (2020). *Identifying enablers for coordination across construction supply chain processes: a systematic literature review*. Engineering, construction and architectural management, 28(4), 1083-1113.

Dubisz, D., Golinska-Dawson, P., & Kolinski, A. (2023). *Impact of Standardized*

Reusable Packaging on a Supply Chain Design and Environmental Efficiency. In Design, Simulation, Manufacturing: The Innovation Exchange. Cham: Springer Nature Switzerland, pp. 102-112

Dullinger K. H., (2009), *Simulation in der Logistik - neue Anwendungsfelder*, LogForum, Vol. 5, Issue 3, s. 1-12

Eisenhardt K., Graebner M., (2007), *Theory building from cases: opportunities and challenges*, Academy of Management Journal, Vol. 50, No. 1, p. 25-32

George, A. L. (2019). *Case studies and theory development: The method of structured, focused comparison*. Springer International Publishing, pp. 191-214

Golinska-Dawson, P., Werner-Lewandowska, K., Kolinska, K., & Kolinski, A. (2023). *Impact of market drivers on the digital maturity of logistics processes in a supply chain*. Sustainability, 15(4), 3120.

Golroudbary, S. R., Zahraee, S. M., Awan, U., & Kraslawski, A. (2019). *Sustainable operations management in logistics using simulations and modelling: A framework for decision making in delivery management*. Procedia Manufacturing, 30, 627-634.

Jing, S., Hou, K., Yan, J., Ho, Z. P., & Han, L. (2021). *Investigating the effect of value stream mapping on procurement effectiveness: a case study*. Journal of Intelligent Manufacturing, 32, 935-946.

Kluska K., (2021). *Automatic simulation modelling of warehouses*. LogForum 17 (1), 59-69

Kolinski, A., & Sliwczynski, B. (2015). *Evaluation problem and assessment method of warehouse process efficiency*. Business Logistics in Modern Management.

Li, X., Yang, X., Zhang, C., & Qi, M. (2021). *A simulation study on the robotic mobile fulfillment system in high-density storage warehouses*. Simulation Modelling Practice and Theory, 112, 102366.

Lukinskiy, V., Lukinskiy, V., & Merkuryev, Y. (2017). *Supply chains efficiency increasing based on the modelling of logistics operations*. International Journal of Simulation and Process Modelling, 12(3-4), 196-206.

Maylor H., Blackmon K., (2005), *Researching Business and Management*, Polgrave Macmillan, New York

Md Hanafiah, R., Karim, N. H., Abdul Rahman, N. S. F., Abdul Hamid, S., & Mohammed, A. M. (2022). *An innovative risk matrix model for warehousing productivity performance*. Sustainability, 14(7), 4060.

Meade D. J., Kumar S., Houshyar A., (2006), *Financial analysis of a theoretical lean manufacturing implementation using hybrid simulation modeling*, Journal of Manufacturing Systems, Vol. 25, Issue 2, s. 137-152

Mourtzis, D. (2020). *Simulation in the design and operation of manufacturing systems: state of the art and new trends*. International Journal of Production Research, 58(7), 1927-1949.

Niemczyk A., (2016), *Warehouse processes in enterprises*, Kolinski A. (ed.), Logistics Management - modern development trends, Poznan School of Logistics Press, Poznan 2016, p. 73-86; DOI: 10.17270/B.M.978-83-62285-25-9.1.5

Ponelis, S. R. (2015). *Using interpretive qualitative case studies for exploratory research in doctoral studies: A case of information systems research in small and medium enterprises*. International Journal of Doctoral Studies, 10, 535.

Richards, G. (2021). *Warehouse Management: The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*. Kogan Page Publishers.

Shah, B., & Khanzode, V. (2017). *A comprehensive review of warehouse operational issues*. International Journal of Logistics Systems and Management, 26(3), 346-378.

Shani, A. B., & Coghlan, D. (2021). *Action research in business and management: A reflective review*. Action Research, 19(3), 518-541.

Sliwczynski, B., Kolinski, A. (2016). *Controlling supply chains: Theory and practice*, Nova Science Publishers, New York

Stajniak, M., & Guszczak, B. (2011). *Analysis of logistics processes according to BPMN methodology*. In Information technologies in environmental engineering (pp. 537-549). Springer, Berlin, Heidelberg.

Szczepański, E., Jachimowski, R., Izdebski, M., & Jacyna-Gołda, I. (2019). *Warehouse location problem in supply chain designing: a simulation analysis*. Archives of Transport, 50(2), 101-110.

Tang, L., & Meng, Y. (2021). *Data analytics and optimization for smart industry*. Frontiers of Engineering Management, 8(2), 157-171.

Trojanowska, J., Kolinski, A., Galusik, D., Varela, M. L., & Machado, J. (2018). *A methodology of improvement of manufacturing productivity through increasing operational efficiency of the production process*. In Advances in Manufacturing. Springer International Publishing, pp. 23-32

Yan, Z., Ismail, H., Chen, L., Zhao, X., & Wang, L. (2019). *The application of big data analytics in optimizing logistics: a developmental perspective review*. Journal of Data, Information and Management, 1(1), 33-43.

Yin R. K., (2009), *Case Study Research. Design and Methods*, SAGE Publications, Thousand Oaks

Żuchowski W., (2022). *The smart warehouse trend: actual level of technology availability*. LogForum 18 (2), 227-235