SIMULATION INVESTIGATIONAL METHOD FOR INTERMITTENT PRODUCTION SYSTEMS

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Abstract:

Nowadays, production system process improvement is going through sweeping changes. The trends include an increase in the number of product variants to be produced, as well as the reduction of the production's lead time. These trends were induced by new devices of the industry's 4.0, namely the Internet of Things and cyber physical systems. The companies have been applying intermittent production systems (job production, batch production) in increasing number because of the increase in the number of product variants. Consequently, increasing the efficiency of these systems has become especially important. The aim of development in the long term – not achievable in many cases – is the realisation of unique production with mass production's productivity and specific cost. The improvement of complex production systems can be realized efficiently only through simulation modeling. The intermittent production systems' standardized simulation investigational method has not elaborated so far. In this paper I will introduce a simulation investigational method conception for complex system improvement and also present a practical example in connection with the elaborated method.

1 Introduction

The continuous improvement of production processes based on customer demands is necessary in order to increase or maintain competitiveness. The only companies that can stay competitive in the long term are those that are able to carry out continuous improvement and adapt to external enviromental changes in all the companies' areas [1]. If we take into consideration the sweeping changes in the transformation of the production systems in the last 50 years and the developmental possibilities which arise from the technological progress, then we can understand that process improvement is a very important research area in our days [2]. The general trends are the satisfaction of unique customer demands, as well as the reduction of the production leads time [3, 4]. These trends create some new challenges that can be overcome only with the intensive process improvement of intermittent production systems. Process improvement can refer to the production systems to be realized. Intermittent

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production systems have significant complexity because in the material flow routes for products/product families the technological equipment's operation time and changover time often differs, as do the applied unit load making devices [4, 5]. In practise, the improvement can be basically realised using the lean philosophy's device system [5, 6]. However, the application of simulation modeling technology is becoming more prominent because of the processing's increasing complexity and developmental demand. We can explain simulation as a method for making a computer model on the basis of the real/planned systems; consequently we can examine these systems' status changes [3]. We can classify the simulation models according to several aspects. If the simulation model's input data contain stochastic variables then we can speak about a stochastic simulation model, otherwise the simulation model is deterministic [7].

We can distinguish discrete and continuous simulation models on the basis of another classification aspect. The system's status will be changed in the discrete points of time in the case of the discrete model and at every point of time in the case of the continuous model [8, 9]. Basically, the discrete simulation models are used for the production areas [10, 11]. Simulation modelling has been applied in both continuous production systems [12, 13] and intermittent production systems (for example: process improvement [14], production scheduling [10], etc.). Beside the examination of production systems, simulation modeling has been applied in other areas as well (for example: disaster logistics [15], port logistics [16], air distribution of a tennis hall [17], electric distribution [18]). In the last few years researchers have examined the effects of changing selected parameters [19, 20], evaluation possibilities of system variations [21, 22], application possibilities of real-time simulation [23] and the optimization of assigned manufacturing systems [24, 25] in the field of simulation modeling of the intermittent manufacturing systems. The majority of these studies were related to production processes of one product family and contained several simplifications. These studies do not explain how we can create a simulation investigational model in case of the most complex intermittent manufacturing systems. There is a need for a simulation investigational model for intermittent production systems that is able to analyze the logistics processes of more than one product family. Simultaneously, here the parameters of the logistics processes can differ from each other (e. g. operation times, changeover times, batch sizes, or types of the unit load forming devices), as well can have numerous material flow nodes and backflows. The capability to model such systems is very important because the complexity of manufacturing systems will increase in the future as a result of the diversification of customer needs.

We have carried out numerous research projects [6, 26] in recent years and have gained a great deal of experience in simulation modelling technology. We have elaborated a general simulation investigational method bassed on our experience that is able to create and examine the operation of even the most complex intermittent production systems. Here we introduce the applied framework's most important characteristics and the elaborated simulation method for the making of the simulation examination, and we will present the method's application through a short example related to an intermittent manufacturing system.

2 Introduction of the applied simulations' framework

We applied the Plant Simulations' framework 10.1 for the elaborated simulation investigational method. This framework was made by Siemens Ltd. Naturally the elaborated investigational method can be applied to other simulation frameworks as well (for example: simul8, arena, etc.).

The applied framework most important characteristics are [27]:

– Discrete event-controlled operation: The framework enables the models fast running, because the software will only examine the next important times of event (for example: arrival of a truck, making a product, etc.).

- Object-oriented approach: The framework contains predefined objects whose behaviour can be set with predefined input data columns in most events (we can use simtalk programming language if necessary).
- Graphical display possibility: There are numerous types of diagrams and functions for the created models output data's display.
- Animation display possibility: We can execute the created simulation models running with use of the animation as well.
- Interactive working: Modification of the input data is possible while the simulation is running (the simulations' operation will change because of the modification).

- Connection possibility to external databases: We can execute the connection of the simulations' framework to external databases (for example: Oracle, SQL, ODBC, XML, etc.)

The simulations' framework most important structural elements are:

- Class library: This element contains all the objects for making the simulation model. The class library's one object name is "class," which object parameters can modify abitrarily, as well as creating new classes (by copy or inheritance).
- Toolbox: This element enables faster access to the objects. These objects exist in the class library as well. Consequently, there is a close link between the toolbox's and the class library's objects.
- Modelling area: Actually, a simulation model can be made in a "frame" (the "frame" is a modeling area for the simulation model). We can create several frames within a frame (in horizontal or/and vertical structures) to enhance transparency (for example: if we have to make a simulation model about a manufacturing plant then in this case we can use a frame for the raw material warehouse, another frame for the production system, and so on).
- Console: We can gain some information about the current status of the simulation model objects while the simulation model is running (for example: values of variables, failure messages, etc.).

3 Simulation of investigational method for intermittent manufacturing systems

There are numerous possibilities to improving a production system's logistics processes (for example: reduction of changeover time, reduction of operation time, installation of new technological equipment, etc.). However, their effects are difficult to forecast in the case of intermittent manufacturing systems. In practice, it may occur that an intended improvement will not reach its aim (predefined productivity, etc), which can lead to unsatisfied customer demands. In addition, the long term examination of improvement possibilities can result in a competitive disadvantage. We introduce here the steps for a simulation of investigational method for performing more efficient intermittent production system examinations. With improvement decisions, lead time can be decreased and the decisions efficiency can be increased using the method. Fig. 1 shows the elaborated simulation investigational model's steps.

Step 1. Determination of the simulation examination's aims: There can be numerous objectives regarding the simulation examination of the production systems:

- Elimination of planning failure,
- Comparison of planning alternatives,
- Determination of the logistics system's capability,
- Comparison of the management strategy versions,
- Determination of the more efficient production programme,
- Examination of the planned developement's effects, etc.

Step 2. Definition of the examined system: We have to define the examined system's boundaries (for example: a production line, total production system, etc.).

Step 3. Investigation of the system working: After the examined system's boundaries have been defined, the simulation model maker has to become familiar with material and information flow features of the examined logistics system.

Step 4. Realisation of simulation model of the material flow system: we have to create the examined material flow system's simulation model (this model does not contain the moveable units and unit load making devices), taking into consideration the following. We can simplify the modelling process using standardised objects. Thus, we have elaborated a technological operation object which is able to realise all of the operations' types. We suggest using the simulation model's predefined objects for transportation and warehousing tasks. We can create the basic model with the location of the necessary objects and creation of the material flow relation. We have to complement the simulation model with the Plant Simulation's objects in those cases when we need to carry out such special tasks as human work or special material handling activities. The essential objects of the material flow system to be created are as follows.

1. Technological objects class: We can distinguish four types of technological operations in an intermittent production system:

- Single operation: This technological workplace makes an operation on one product in a work cycle (for example: screwdriving, turning, drilling, etc.).
- Parallel operation: This technological workplace makes an operation on several products in a work cycle (for example: heat treatment, painting, etc.).

- Assembly operation: This technological workplace makes one product out of several products in a work cycle.
- Disassembly operation: This technological workplace makes several products from one product in a work cycle.

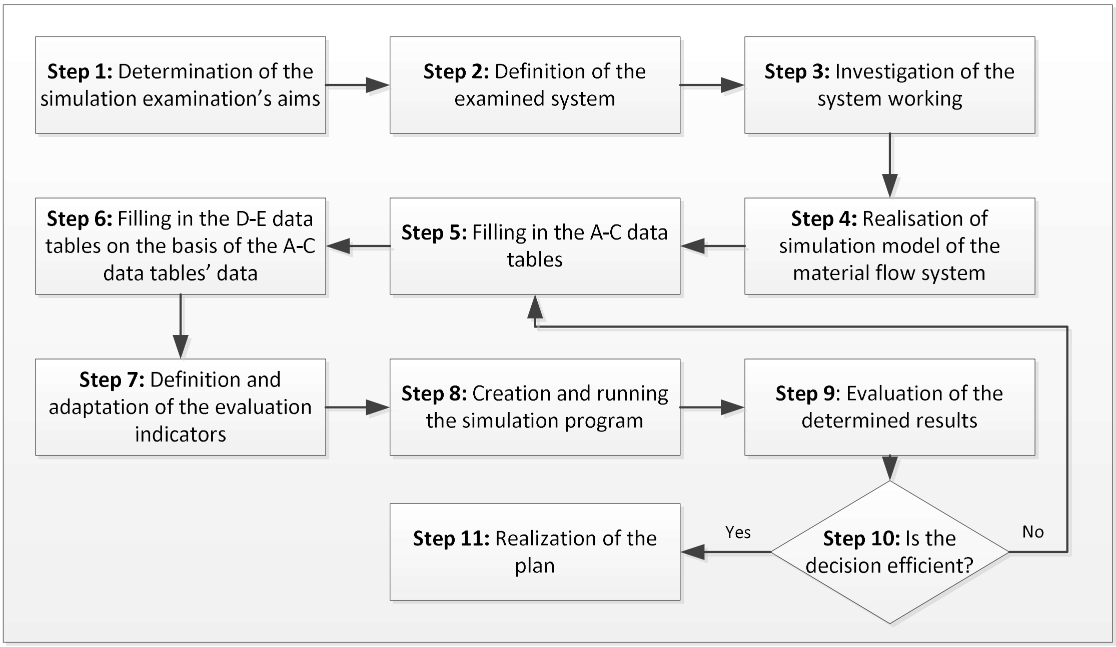

Figure 1. Steps of the simulation investigation method of intermittent manufacturing systems

We have elaborated a simulation object (Fig. 2) for the standardised modelling of all the technological operations. This allows simpler and more standardised object control. If we are required to use a number of technological operation objects then in the interest of transparency we can use the frame object (a frame object can contain one or more technological objects).

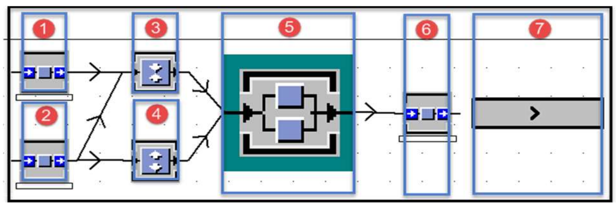

Figure 2. Technological objects class

Introduction of the elements of the technological objects class (Fig. 2):

- Objects 1-2: Input buffer object
- Object 3: Assembly tasks modelling object
- Object 4: Disassembly tasks modelling object
- Object 5: Parallel tasks modelling object
- Object 6: Output buffer. The finished products will go to the next operation on direct mode (product will be transmitted to the next workplace) or indirect mode (unit load will be transmitted to the next workplace). The transmission will take place on the basis of the data table's data for the technological operation (see Step 6).
- Object 7: This object enables the placement of the unit load formation device (the product appearing on Object 6 will be loaded on Object 7's unit load formation device in the case of indirect transmission).

Table 1 presents the objects applied in technological operations (the control of the technological object's operation will be realised on the basis of the technological object's data table, see Step 6).

2. Store object: The modeling of the storage areas can be realized with the store object shown in Fig. 3.
This object's capacity is adjustable and its contents can be queried or modified with use of the programming technical devices.

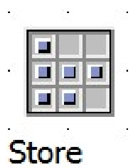

Figure 3. Store object

Table 1. Applied objects in the case of technological operations

Operation type	**Transmission mode**	**Obj. 1**	**Obj. 2**	**Obj. 3**	**Obj. 4**	**Obj. 5**	**Obj. 6**	**Obj. 7**
Simple operation	Direct	X		X		X	X	
	Indirect	X		X		X	X	X
Parallel operation	Direct	X		X		X	X	
	Indirect	X		X		X	X	X
Assembly operation	Direct	X	X	X		X	X	
	Indirect	X	X	X		X	X	X
Disassembly operation	Direct		X		X	X	X	
	Indirect		X		X	X	X	X

3. Line object (Fig. 4): We have to use the line object for simple modelling of the material flow tasks. If we use this object then we can set the most important information, such as this object's acceleration, speed, direction of product movement, as well as capacity. For greater accuracy we can use special objects for specific material handling equipment (for example: forklift, monorail system, etc.).

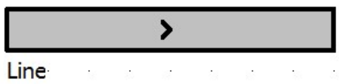

Figure 4. Line object

Step 5. Filling in the A-C data tables: We have to fill in the A-C data tables with the modeled material flow system's data according to the system in Step 4.

A. Manufacturing data table (Table 2): This data table contains the data of the operations of products. The first column of the table contains the finished product's name, Column 2 the input product's name, and Column 5 the output product's name. Column 3 contains the number of incorporated part. Data column 4 contains the indentification of the operation to be realised. Column 6 contains the output product's identification of the unit load formation device, while Column 7 contains the unit load formation device's capacity. Column 8 contains the operational time; Column 9 contains the set up time. We have to write the words “direct” or “ndirect” in Column 7 depending on the transmission mode.

B. Unit load (UL) data table (Table 3): For logistics system modelling the unit load information is essential. This data table contains the manufacturing data table's input and output product names. It shows which kinds of unit load formation device (henceforward: ULFD) we can use, what the ULFD's capacity is, sizes and the stackable unit load's number in the case of one product. In addition, Data column 7 contains the starting inventory data that will be used in the case of the launch of the simulation program.

Table 2. Structure of the manufacturing data table

Name of data column	**Data type**
1. Finished product's name	String
2. Input product name	String
3. Number of incorporated parts	Integer
4. Technological operation's name	String
5. Output product's name	String
6. Unit load formation device's name	String
7. Unit load formation device's capacity	Integer
8. Technological operation's processing time	Time
9. Technological operation's set up time	Time

Table 3. Structure of the unit load data table

Data column's name	**Data type**
1. Product's name	String
2. Unit load formation device's name	String
3. Unit load formation device's capacity	Integer
3. Unit load's width	Integer
4. Unit load's length	Integer
5. Unit load's height	Integer
6. Stackable unit load's number	Integer
7. Product's starting inventory	Integer

C. Production plan data table (Table 4): This table shows when (column 4-5), what (column 1) and how (column 2-3) we need to make a product.

Step 6. Filling in the D-E data tables on the basis of the A-C data tables: We have to fill in the D and E

data tables with data from the A-C data tables. We advise writing a program for this in the case of a large database and manual inputting for smaller databases.
D. Control data table (Table 5): The control data table shows what kinds of operations the parts need to go through in order to make the finished product. The control data table has to be created on the basis of the manufacturing data table's data (the product's manufacturing's process can be built on the basis of the manufacturing data table's data column 1-5). Modification of the product's manufacturing process is done modifying the control data table's data. The control data tables contain a finished product's manufacturing process where the first column's product names are the same. If a product goes through an operation then its name will change. Consequently, the previous operation's output product (Data column 3) will be the following operation's input product (data column 2). The control data table shows how output product (column data 3) proceeds from the input product (column data 2) through the operations (data column 4 and so on). We have to mark those cells' value with "1" where the given product's (line) assigned operation (column) will be realised. A chained list will be created regarding the finished products where the final step's result will be the finished products. The control data table contains all of the finished products' material flow.

Table 4. Structure of the production plan data table

Data column's name	Data type
1. Product's name	String
2. Product's amount	Integer
3. Technological operation's name	String
4. Date	Date
5. Shifts' number	Integer

Table 5. Structure of the control data table

Data column's name	Data type
1. Finished product's name	String
2. Input product's name	String
3. Output product's name	String
4. Technological operation1	String
5.Technological operation2	String
….	String

E. Technological operation data table (Table 6): This data table will be filled on the basis of the production plan, control, and the manufacturing data tables. This data table is created in case of every technological operation, and tables contain the activities to be realized. The data table will show which input product (Data column 2) do we need to work on, what the size of the series is (data column 3), what the material catering's starting station is (data column 4), what the worked product's ULFD is (data column 6) and the ULFD capacity (data column 7). In addition, this data table contains the product processing's operation time (data column 8) and set up time (data column 9). Programming is suggested for bigger databases.

Step 7. Definition and adaptation of the evaluation indicators: we have to define the indicators to be examined while taking into consideration the investigational objectives and then adjust the indicators in the simulation model (for example: maximum stock level, operating costs, etc.).
Most simulation framework systems are able to visualise the examined indicator's data (for example: frequency function, distribution function, diagrams, etc.), which contributes to more efficient decision preparation.

Table 6. Structure of the technological operation data table

Data column's name	Data type
1. Finished product's name	String
2. Input product's name	String
3. Product's number	Integer
4. Source object's name	String
5. Output product's name	String
6. ULFD's name	String
7. ULFD's capacity	Integer
8. Technological operation's processing time	Time
9. Technological operation's setup time	Time

Step 8. Creation and running of the simulation program: we have to run the simulation program in the following way. The first step is creation of the movable units (products, ULFD) and starting stocks on the basis of the unit load data table. Next, the manufacturing processes' control has to be realised on the basis of the technological object data table (every object has such a data table). The data tables' instructions have to be performed line by line. The chosen indicator's value has to be determined by running of the simulation model.

Step 9. Evaluation of the determined results: we have to evaluate the determined indicators' values after the simulation has been run.

Step 10. Making the decision: After the evaluation we have to make decisions about a new examination (Step 5) or realisation of the improvement (Step 11).

4 Application of the elaborated simulation investigational method

In this section we will introduce the elaborated investigational method through an imagined assembly cell's examination.
Steps of the examination:

Step 1. Determination of the simulation examination's aims: The main objective is the determination of the inter-operational store floor area's size. There, the realization of the examination can be necessary in many cases e. g. if the product structure is to be produced or the production plan will change at a relevant complexity manfacturing system in the future [6].

Step 2. Definition of the examined system: the examined manufacturing cell contains 16 stages of operations and 7 stages of inter-operation storage. These objects will get the parts from the manufacturing plant and will send the completion parts to the finished goods storage.

Step 3. Investigation of the system working: we defined the most important characteristics in order to describe the working of the examined system (e. g operational time, mode of the working, changeover time, applied unit load forming device, unit load forming device's capacity, mode of materials handling in case of every product). We want to create a complex manufacturing cell in order to test the method.

Step 4. Realisation of simulation model of the material flow system: we placed the material flow system's objects on the basis of instructions in Section 3 (16 operations, 7 stages of the inter-operational storage, traffic routes), as well as defining the material flow connections between these objects (Fig. 5). The inter-operational storage is realised on the floor level with stacking.

Step 5. Filling in the A-C data tables: Uploading the manufacturing data table (Table 7), unit load data table (Table 8), and the production plan data table (Table 9) with the investigational data. Step 5 in Section 3 gives guidance for interpreting Tables 7-9.

Step 6. Filling in Data tables D and E on the basis of data from A-C data tables: in this step the data of the control data table (Table 10) is input from the manufacturing (A) and the production plan (C) data tables. In addition, the production plan (C), manufacturing (A) and the control (D) data tables' data are input to the technological operation data table (Table 11). We have to fill out a data table for each operation (16 operations). We can automate this upload (for large databases), or we can input it manually (for small databases). Step 5 in Section 3 gives guidance for interpreting Tables 10 and 11.

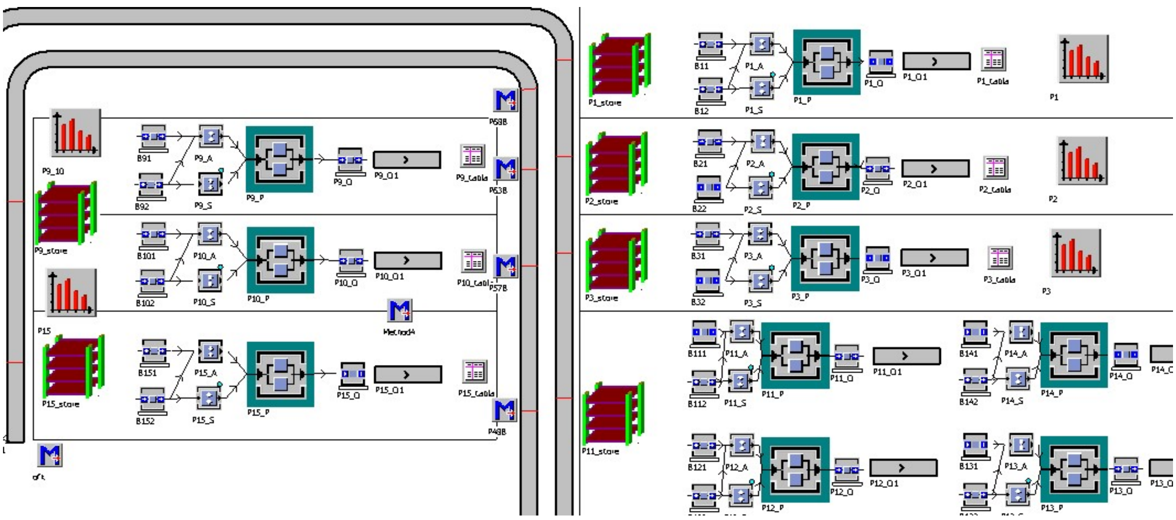

Figure 5. Simulation model of the examined materials handling system

Table 7. Manufacturing data table

Finished product's name	Input product name	Incorporated parts' number [pcs]	Technological operation's name	Output product name	Unit load formation device's name	Unit load formation device's capacity	Techn. operation's processing time [sec]	Setup time [sec]
TR_8K9833021E	TR_8K9833311F_U30	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833329C	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833331C	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	KAU_8T0831135C	2	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833333C	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833335C	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833673B	1	P1	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K9833309E_OP10	1	P1	TR_8K9833309E_OP20	CONT_507827	45	163	7200
……..								

Table 8. Unit load (UL) data table

Product's name	Unit load formation device's [ULFD] name	Unit load formation device's capacity [pcs/ULFD]	Unit load's width [m]	Unit load's length [m]	Unit load's height [m]	Stackable unit load's number [pcs]
KAU_8K0839065B	KLT_6147	50	0,40	0,60	0,02	5
KAU_8K9833311F	CONT_507827	45	1,20	1,80	1,50	4
TR_8K0833111D_L00	CONT_507823	70	1,20	1,80	1,25	4
TR_8K0833111D_U40	CONT_507823	70	1,20	1,80	1,25	4
TR_8K0833111D_UG0	CONT_504033	570	1,80	2,40	0,74	4
TR_8K9833311F_L00	CONT_507827	45	1,20	1,80	1,50	4
….						

Table 9. Production plan data table

Product's name	Product's amount [pcs]	Technological operation's name	Date	Shifts' number
TR_8K9833309E_OP10	50	P1	2016.10.25	1
TR_8K9833309E_OP20	50	P2	2016.10.25	1
TR_8K9833309E_OP50	50	P3	2016.10.25	1
TR_8K9833601_OP40	50	P1	2016.10.25	1
TR_8K9833309E_OP60	50	P10	2016.10.25	1
TR_8K9833305E_OP70	50	P3	2016.10.26	1
TR_8K9833305E_OP80	50	P13	2016.10.26	1
…				

Table 10. Control data table

Finished product's name	Input product's name	Output product's name	P1	P2	P3	P4	P5a	P5b	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
TR_8K9833021E	TR_8K9833311F_U30	TR_8K9833309E_OP10	1															
TR_8K9833021E	TR_8K0833331C	TR_8K9833309E_OP10	1															
TR_8K9833021E	KAU_8T0831135C	TR_8K9833309E_OP10	1															
TR_8K9833021E	TR_8K0833335C	TR_8K9833309E_OP10	1															
TR_8K9833021E	TR_8K0833673B	TR_8K9833309E_OP10	1															
TR_8K9833021E	TR_8K9833309E_OP10	TR_8K9833309E_OP20		1														
TR_8K9833021E	N_90895601	TR_8K9833309E_OP20		1														
TR_8K9833021E	TR_8K9833309E_OP20	TR_8K9833309E_OP50										1						
…																		

Table 11. Technological operations data table for operation P1

Finished product's name	Input product's name	Product's number [pcs]	Source object's name	Output product's name	ULFD's name	ULFD's capacity [pcs/ULFD]	Technological operation's processing time [sec]	Technological operation's setup time [sec]
TR_8K9833021E	TR_8K9833311F_U30	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833331C	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	KAU_8T0831135C	100	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833335C	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	TR_8K0833673B	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TR_8K9833021E	KAU_8K9833603C	50	RAKTAR	TR_8K9833601_OP40	CONT_2105161	100	59	7200
TR_8K9833021E	KAU_8K0839065B	50	RAKTAR	TR_8K9833601_OP40	CONT_2105161	100	59	7200
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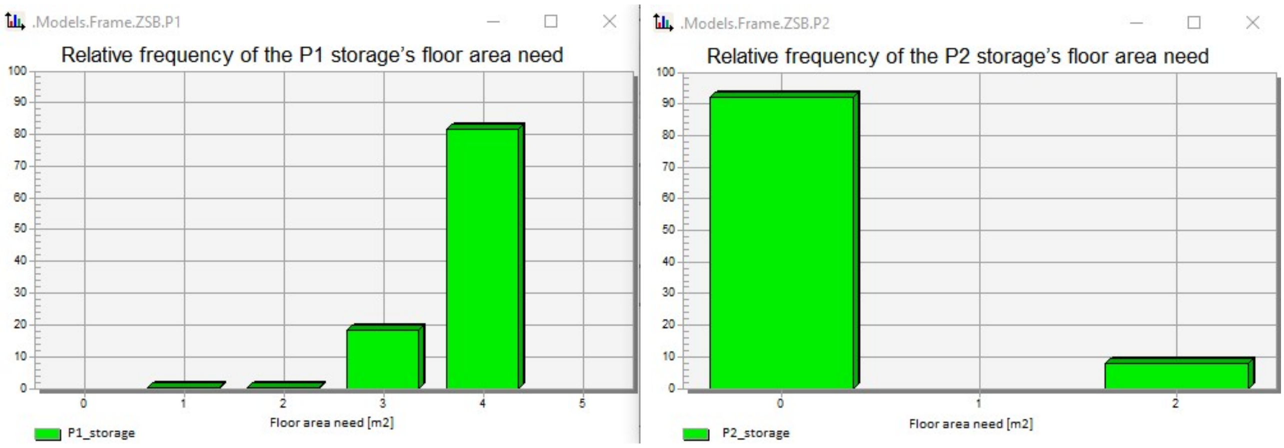

Figure 6. Relative frequency of the storage's floor area need

Step 7. Definition and adaptation of the evaluation indicators: we determined the inter-operational storage area size on the basis of the relative frequency functions related to the reserved area of the inventories (we examined 7 stages of the inter-operational storage). This function introduces the reserved area of the inventories according to relative frequency (the storage will be on floor level and so we can determine the reserved area on the basis of unit load size and the stacking amount).

Step 8. Creation and running of the simulation program: we created a mode in the simulation program that will allow the units to be moved (products, unit loads) automatically, and afterwards it will also automatically execute the manufacturing instructions on the basis of the technological object's data table. The evaluation indicators are determined while the simulation program is running.

Step 9. Evaluation of the determined results: we carried out the evaluation on the basis of the relative frequency function values related to inter-operational storage areas (we examined this function for all 7 stages of the inter-operational storage). We determined the inter-operational storage area size at 100% occurence probability (Fig. 6). If necessary then we can define at another occurence probability.

Step 10. Making the decision: Table 12 introduces the necessary size of the storage areas on the basis of 100% occurence probability.

Table 12. Needed storage area need

Identification of the storage	Needed storage area need [m2]
P1	4
P2	2
P3	3
P5	2
P9-P10	5
P11-P14	20
P15	4

5 Conclusions

After the review of the literature, we can state that majority of the realized simulation examinations were related to production processes of one product family and contained several simplifications. A general simulation investigational method that determines the realization mode of the simulation examination in detail regarding the most complex intermittent manufacturing systems is also needed. This can mean examination of manufacturing systems where the parameters of the logistics processes of product families to be examined can significantly differ from each other (in operation times, changeover times, batch sizes, types of the unit load forming devices, etc.), as well as material flow nodes and backflows occurring. The number of such systems is expected to increase because of the increasing complexity of logistics systems; consequently, we can forecast an increasing need for elaborated simulation investigational methods, as well. Efficiency improvement of the most complex logistics systems will be realized by using the elaborated simulation investigational method introduced here. In the future we plan to work out data structures that enable the automatic creation of the investigation model. If this can be realized then the investigation's lead time will be reduced.

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