applied sciences

MDPI

Article

Decision Support Simulation Method for Process Improvement of Intermittent Production Systems

Péter Tamás

Faculty of Mechanical Engineering and Informatics, Institute of Logistics, University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary; alttpeti@gmail.com; Tel.: +36-(70)-409-5713

Received: 20 August 2017; Accepted: 13 September 2017; Published: 15 September 2017

Abstract: Nowadays production system processes are undergoing 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) 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 realization of unique production, with mass production's productivity and lower cost. The improvement of complex production systems can be realized efficiently only through simulation modeling. A standardized simulation method for intermittent production systems has not been elaborated so far. In this paper, I introduce a simulation method for system improvement and present its application possibilities and a practical example.

Keywords: intermittent production system; simulation; process improvement; investigational method

1. Introduction

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 improvements and adapt to external environmental changes in all the companies' areas [1]. If we take into consideration the sweeping changes in the transformation of production systems in the last 50 years and the developmental possibilities that arise from the technological progress, we can see that process improvement is a very important research area [2]. The general trends are the satisfaction of unique customer demands, as well as a reduction in production lead time [3,4]. These trends create some new challenges that can only be overcome with intensive improvement of intermittent production systems. Process improvement can refer to the production systems to be realized. Intermittent production systems are especially complex because in the material flow routes for products/product families the technological equipment's operation time and changeover time often differ, as do the applied unit load making devices [4,5]. In practice, improvement can be realized by 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 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, 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 modeling has been applied in both continuous production systems [12,13] and intermittent production systems (for example: process improvement [14], production scheduling [10], etc.). Besides the examination of production systems, simulation modeling has been applied in other areas as well (for example: disaster logistics [15], port logistics [16], air circulation in a tennis hall [17], and electric distribution [18]). The objective of the simulation examinations can be the determination of selected system parameters at different model settings [19,20], simulation examination of real-time systems [21–23], or optimizing the workings of assigned systems [24,25] for intermittent manufacturing systems. Such examinations have been carried out by discrete event controlled simulation modeling [19–25] or Petri nets [26–29]. Discrete event controlled simulation modeling has become increasingly important due to its applicability and flexibility. However, the studies have only examined the production processes of one product family (in which the examined products' material flow routes are the same) and/or contain several simplifications.

These studies do not explain how we can create a simulation investigational model in the 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 logistical processes of more than one product family simultaneously, where the parameters of the logistical processes can differ from each other (e.g., operation times, changeover times, batch sizes, or types of the unit load forming devices), as well as having numerous material flow nodes and backflows. The ability 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 [6,30–32] in recent years and have gained a great deal of experience in simulation modeling technology. I have elaborated a general simulation investigational method based on our experience that is able to examine the operation of even the most complex intermittent production systems. Here I introduce the applied framework's most important characteristics and the elaborated simulation method for the making of the simulation examination, present the method's application possibilities, and give a short example related to an intermittent manufacturing system. I wanted to introduce the investigational method's working with real company data as well, but it was not possible due to confidentiality obligations.

2. Introduction of the Applied Simulation's Framework

We applied the Plant Simulations' framework 10.1 for the elaborated simulation investigational method. This framework was made by Siemens PLM Software. 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 [33]:

- Discrete event-controlled operation: The framework enables the model's fast running because the software will only examine the next important event (for example: arrival of a truck, making a product, etc.).
- Object-oriented approach: The framework contains predefined objects whose behavior can be set with predefined input data columns in most events (we can use the simtalk programming language if necessary).
- Graphical display possibility: There are numerous types of diagrams and functions for displaying the created model's output data.
- Animation display possibility: We can also execute the created simulation models with the use of animation.
- 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 connect the simulations' framework to external databases (for example: Oracle, SQL, ODBC, XML, etc.).

The simulation framework's 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 arbitrarily, 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.
- Modeling 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 and/or vertical structures) to enhance transparency (for example: if we have to make a simulation model of a manufacturing plant 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 be 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, decision lead time can be decreased and efficiency can be increased. Figure 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 program.
- Examination of the planned development'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. Realization 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 modeling process using standardized objects. Thus, we have elaborated a technological operation object that is able to realize all operation types. We suggest using the simulation model's predefined objects for transportation and warehousing tasks. We can create a 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 where we need to carry out special tasks such as human work or special material handling activities. The essential objects of the material flow system to be created are as follows.

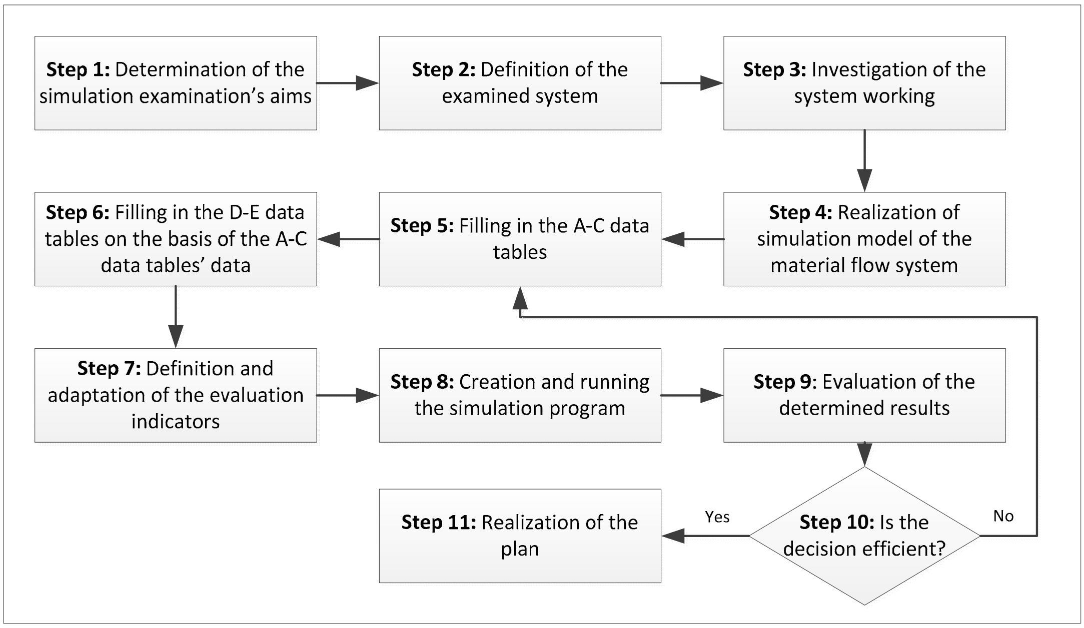

Figure 1. Steps of the simulation investigation method of intermittent manufacturing systems.

(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: screw driving, 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.

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

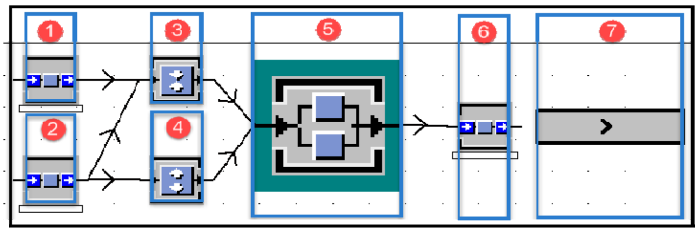

Figure 2. Technological objects class.

Introduction of the elements of the technological objects class (Figure 2):

- Objects 1, 2: Input buffer object.

- Object 3: Assembly tasks modeling object.
- Object 4: Disassembly tasks modeling object.
- Object 5: Parallel tasks modeling object.
- Object 6: Output buffer. The finished products will go to the next operation in direct mode (the product will be transmitted to the next workplace) or indirect mode (the 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 realized on the basis of the technological object's data table; see Step 6).

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

(2). Store object: The modeling of the storage areas can be realized with the store object shown in Figure 3.

This object's capacity is adjustable and its contents can be queried or modified with use of the programming technical devices.

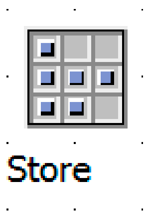

Figure 3. Store object.

(3). Line object (Figure 4): We have to use the line object for simple modeling 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 the incorporated part. Data Column 4 contains the identification of the operation to be realized. 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 "indirect" in Column 7 depending on the transmission mode.

B. Unit load (UL) data table (Table 3): For logistics system modeling 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 Setup 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
4. Unit Load's Width	Integer
5. Unit Load's length	Integer
6. Unit Load's Height	Integer
7. Stackable Unit Load's Number	Integer
8. 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) to make a product.

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. Shift's Number	Integer

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 of the control data table's data. The control data table's contains 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 realized. 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 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 Operation 1	String
5. Technological Operation 2	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 the 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 visualize the examined indicator's data (for example: frequency function, distribution function, diagrams), which contributes to more efficient decision-making.

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 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 realized 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 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 realization of the improvement (Step 11).

4. Possible Applications of a Decision-Making Simulation Method

Continuous changes of the product types and amounts to be produced based on customer needs results in frequent re-planning of the logistics processes of intermittent production systems. The effects of the alteration to be realized can be difficult to forecast because of the examined system's complexity; consequently, it is necessary to reduce the decision risks by high precision determination of different logistics indicators. The value of the needed indicators can be determined by the elaborated simulation investigational method; thus, the improvement decision can be made with minimum risk. We examine a planned system's working by application of the investigational method, where the decision's result can be realization of the examined system or execution of a new examination with modified parameters based on the values of the determined indicators. We have to execute the simulation examinations while obtaining the necessary data for the final decision. This can be a repetitive process. The elaborated investigational method is suitable for the following cases:

(1). Decision support for determination of the storage capacity to be created: Precise determination of the storage capacity needed for a system to be realized can cause significant difficulty because of the complexity of the processes. In such cases the necessary controls and alterations can be executed by the elaborated simulation method.

Most important indicator:

- Maximum stock level: This is how to determine the maximum storage capacity need(s) regarding one or more storage systems. The maximum stock level of the storage system s can be calculated as follows:

$$Q_s^{Max} = \max_{t \in \Theta^S} \{q_{So} + q_{sbz} - q_{skt}\}, \tag{1}$$

where Θ^S is the date when stock movements were executed, q_{So} is the starting stock level, q_{sbt} contains the stocked in amounts, q_{skt} the stocked out product quantities regarding date t.

(2). Decision support for determination of the material handling equipment's efficient utilization: The working strategy and efficiency of the material handling equipment can be difficult to evaluate before the realization of the examined system regarding the intermittent production systems, but the necessary controls and alterations can be executed by using elaborated simulation investigational method.

Most important indicators:

- Rate of the effective route length: This expresses what percentage of the material handling equipment's total traveled route length was executed without an unladen vehicle. The rate of the effective route length in case of the material handling equipment m can be calculated as follows:

$$R_m^U = \sum_{d \in \Theta_m^U} (l_d) / \sum_{d \in \Theta_m} (l_d), \tag{2}$$

where Θ_m is a set containing the identification of the traveled route sections for the material handling equipment m, Θ_m^U includes the identification of the effective route sections, and l_d indicates the length of the route section d according to Equation (2).

- Capacity utilization of the material handling equipment: This introduces what percentage of the material handling equipment's transportation capacity is utilized during the examinational period. The transportation capacity of the material handling equipment m can be defined as follows:

$$C_m^U = \sum_{d \in \Theta_m^U} \left(l_d \cdot c_{m,d}^U \right) / \sum_{d \in \Theta_m} \left(l_d \cdot c_{m,d}^{max} \right), \quad (3)$$

where $c_{m,d}^U$ indicates the delivered products' quantity regarding route section d of material handling equipment m and $c_{m,d}^{max}$ contains the transportable maximum quantity regarding route section d.

- Stock in, stock out and commission efficiency of the material handling equipment: This introduces the material handling equipment's average stock in, stock out and commission quantities per unit time. The average stock in, stock out and commission efficiency of material handling equipment m can be calculated as follows:

$$P_m^i = N_m^i / T_m^i, \quad (4)$$

where $i \in \{SI, SO, CA\}$ can contain 3 kinds of values depend on the type of the examined operation (Stock In, Stock Out, Commission Activity). N_m^i indicates the number of operations in case of operation type i of the material handling equipment m, while T_m^i shows the length of the examinational period regarding operation type i of material handling equipment m.

(3). Decision support for determining the actuation of the technological machines: The working properties and efficiency of technological machines to be applied can be difficult to evaluate for intermittent production systems; however, the necessary controls and alterations can be realized using the elaborated simulation investigational method.

Most important indicators:

- The rate of value-added activities: This introduces that what percentage of the assigned technological machine's examinational period is spent on value-added activities.
- The rate of waiting: This indicator shows what percentage of the assigned technological machine's examination period is spent on waiting.
- The rate of changeover activities: This indicator introduces what percentage of the assigned technological machine's examination period is spent on changeover activities.
- The rate of blocking activities: This indicator shows what percentage of the assigned technological machine's examination period is spent on blocking activities (the machine is not able to move the parts to the following station because the station is occupied).
- Amount of completed products: This shows how many products were completed during the investigational period by the assigned technological machine.

The rate of the value added, waiting, changeover and blocking activities can be calculated as follows:

$$R_e^j = \sum_{o \in \Theta_e^j} (t_o) / T_e \quad (5)$$

where $j \in \{VA, WT, CO, B\}$ indicates the type of examined operation and Θ_e^j contains the operations of technological machine e regarding operation type j. In addition, T_e is the length of the examinational period in the case of technological machine e.

(4). Decision support for determining the application of the human resources.

Most important indicators:

- The rate of value-added activities: This introduces what percentage of the assigned worker's examination period is spent on value-added activities.
- The rate of waiting: This indicator shows that what percentage of the assigned operator's examination period is spent on waiting.

- The rate of changeover activities: This indicator introduces the percentage of the assigned operator's examination period spent on changeover activities.
- The rate of blocking activities: This indicator shows the percentage of the assigned operator's examination period spent idle due to blocking activities (the person is not able to move the parts to the following station because of the station's occupation).
- Amount of completed products: This shows the number of products completed during the investigational period by the assigned operator.

The rate of the value-added, waiting, changeover, and blocking activities can be calculated as follows:

$$R_h^k = \sum_{o \in \Theta_h^k} (t_0)/T_h, \quad (6)$$

where $k \in \{VA, WT, CO, B\}$ indicates the type of examined operation and Θ_h^k contains the operations of the human resource h regarding the operation type k. In addition, T_h is the length of the examinational period in case of the human resource h.

In most cases, the above indicators give appropriate support for making an improved decision, although in some special examinations it may be necessary to examine other indicators as well e.g., if we have to define the floor area for storage instead of storage capacity need). In addition, visualizing the determined indicator values with diagrams can provide relevant help to support decision-making.

5. 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's floor area's size. There can be necessary the realization of the examination in many cases, e.g., if the product structure to be produced or the production plan will change at a relevant complexity manufacturing system in the future [6].

Step 2. Definition of the examined system: the examined manufacturing cell contains 16 stages operations and seven stages of inter-operation storage. These objects will get the parts from the manufacturing plant and send the completed 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. Realization 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, seven stages of the inter-operational storage, traffic routes), as well as defining the material flow connections between these objects (Figure 5). The inter-operational storage is realized on 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.

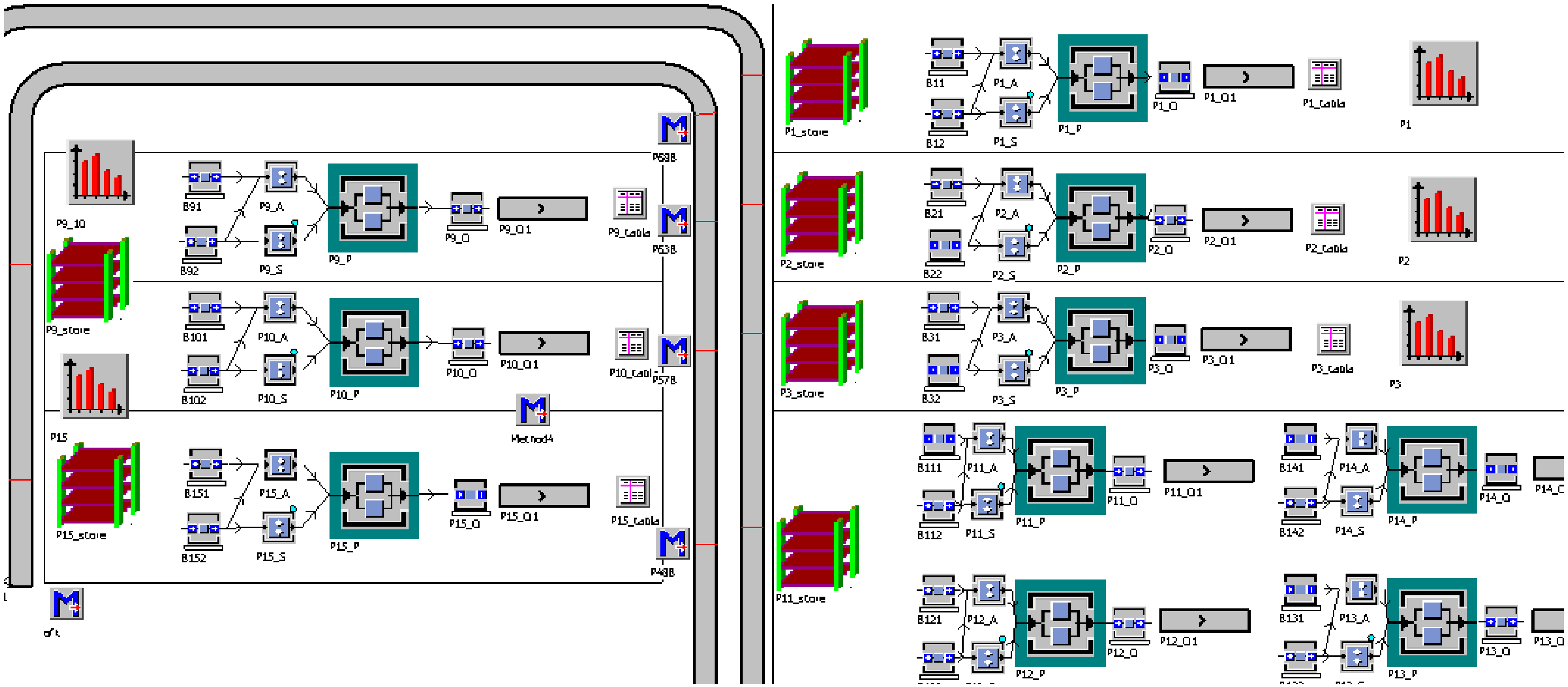

Figure 5. Simulation model of the examined materials handling system.

Table 7. Manufacturing data table.

Finished Product's Name	Input Product Name	Incorporated Part's Number (pcs)	Technological Operation's Name	Output Product Name	Unit Load Formation Device's Name	Unit Load Formation Device's Name	Technological Operation's Processing Time (s)	Setup Time (s)
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_8K0833311F_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	25 October 2016	1
TR_8K9833309E_OP20	50	P2	25 October 2016	1
TR_8K9833309E_OP50	50	P3	25 October 2016	1
TR_8K9833601_OP40	50	P1	25 October 2016	1
TR_8K9833305E_OP60	50	P10	25 October 2016	1
TR_8K9833305E_OP70	50	P3	26 October 2016	1
TR_8K9833305E_OP80	50	P13	26 October 2016	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 (s)	Technological Operation's Setup Time (s)
TK_8K9833021E	TR_8K9833311F_U30	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TK_8K9833021E	TR_8K0833331C	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TK_8K9833021E	KAU_8T0831135C	100	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TK_8K9833021E	TR_8K0833335C	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TK_8K9833021E	TR_8K0833673B	50	RAKTAR	TR_8K9833309E_OP10	direct	1	122	7200
TK_8K9833021E	KAU_8K9833603C	50	RAKTAR	TR_8K9833601_OP40	CONT_2105161	100	59	7200
TK_8K9833021E	KAU_8K0839065B	50	RAKTAR	TR_8K9833601_OP40	CONT_2105161	100	59	7200
. . . . . .								

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 seven 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 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 seven stages of the inter-operational storage). We determined the inter-operational storage area size at 100% occurrence probability (Figure 6). If necessary, we can define the probability of another occurrence.

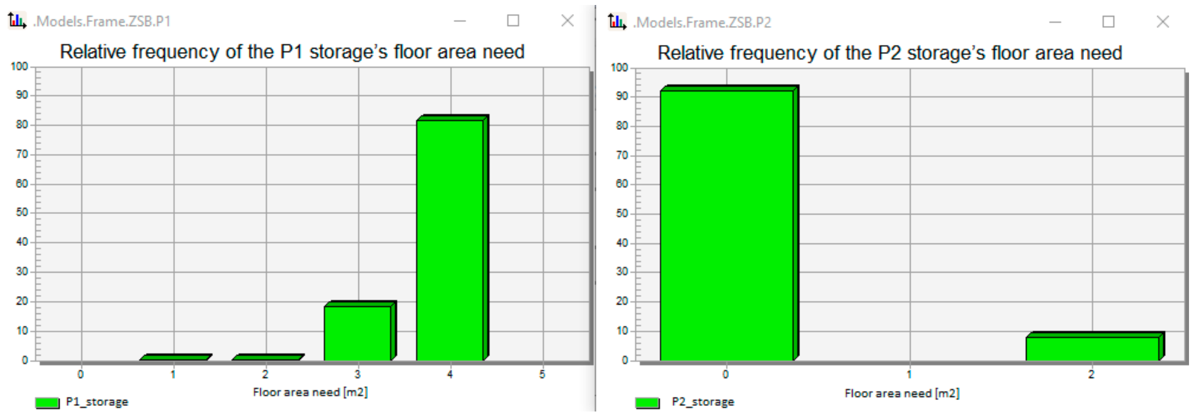

Figure 6. Relative frequency of storage's floor area needs.

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

Table 12. Needed storage area.

Identification of the Storage	Needed Storage Area Need (m^2)
P1	4
P2	2
P3	3
P5	2
P9–P10	5
P11–P14	20
P15	4

The Plant Simulation framework enables us to simply and flexibly determine and visualize the characteristics (e.g., utilization of machines, waiting time of operations, etc.) of arbitrary elements (e.g., material handling equipment, parts, storages, etc.) of the created simulation model by setting the data's creation mode to be visualized.

6. Conclusions

In real-time situations, most companies make efforts to satisfy unique customer needs, thus increasing the complexity of the production systems in the future. In the case of numerous complex logistics systems, application of a decision support simulation method is required for making appropriate improvement decisions.

Such a method examines production systems where the parameters of the logistics processes of product families can significantly differ from each other (in operation times, changeover times, batch sizes, types of the unit load forming devices, etc.) and where material flow nodes and backflows occur.

After a review of the literature, it was found that simulation examinations have tended to be related to production processes of one product family and/or contained several simplifications; I have not found any other elaborated simulation investigational method that enables the realization of simulation examination regarding every type of intermittent production system. In order to eliminate this gap, in this paper I have elaborated and introduced a decision support simulation method based on my practical experience. Realization of the simulation investigational model can take less time than in earlier methods (the modeling steps are clear and simple to implement) and we can also examine every complex intermittent production systems (production systems in the automotive or electronic industries, etc.) using the elaborated investigational method. The method focuses on the indicators of present and the future intermittent production systems that are most important for making a correct improvement decision or for avoiding possible improvement failures (e.g., low productivity, small storage capacity, etc.), without discussing the optimization possibilities of the intermittent production system.

Future aims are to work out data structures that enable the automatic creation of the investigation model. If this can be realized, the investigation's lead time will be reduced. Elaboration and adaptation of several optimization algorithms is another potential research area (e.g., route planning, volume of time schedule of production, etc.).

Acknowledgments: The described research was carried out as part of the EFOP-3.6.1-16-00011 "Younger and Renewing University—Innovative Knowledge City—institutional development of the University of Miskolc aiming at intelligent specialization" project implemented in the framework of the Szechenyi 2020 program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Womack, J.P.; Jones, D.T. *Lean Thinking*; Simon & Schuster Inc.: Delran, NJ, USA, 2008.
2. Rother, M.; Shook, J. *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda*; Lean Enterprise Institute: Cambridge, MA, USA, 2003.
3. Cselényi, J.; Illés, B. *Planning and Controlling of Material Flow Systems*; Textbook; Miskolci Egyetemi Kiadó: Miskolc, Hungary, 2006.
4. Tyagi, S.; Choudhary, A.; Cai, X.; Yang, K. Value stream mapping to reduce the lead-time of a product development process. *Int. J. Prod. Econ.* **2015**, *160*, 202–212. [CrossRef]
5. Košťál, P.; Velíšek, K. Flexible Manufacturing System. *World Acad. Sci. Eng. Technol. Int. J. Mech. Aerosp. Ind. Mechatron. Manuf. Eng.* **2011**, *5*, 917–921.
6. Tamás, P. Application of value stream mapping at flexible manufacturing systems. *Key Eng. Mater.* **2016**, *686*, 168–173. [CrossRef]
7. Bratley, P.; Fox, B.L.; Schrage, L.E. *A Guide to Simulation*, 2nd ed.; Springer: New York, NY, USA, 1987; ISBN 978-1-4612-6457-6.
8. Tako, A.A.; Robinson, S. The application of discrete event simulation and system dynamics in the logistics and supply chain context. *Decis. Support Syst.* **2012**, *52*, 802–815. [CrossRef]
9. Rodic, A.; Mester, G. The Modeling and Simulation of an Autonomous QuadRotor Microcopter in a Virtual Outdoor Scenario. *Acta Polytech. Hung.* **2011**, *8*, 107–122.
10. Gubán, M.; Gubán, Á. Production scheduling with genetic algorithm. *Adv. Logist. Syst. Theory Pract.* **2012**, *6*, 33–44.
11. Sadiku, M.; Tofighi, M. A tutorial on simulation of queueing models. *Int. J. Electr. Eng. Educ.* **1999**, *36*, 102–120. [CrossRef]

12. Erdélyi, F.; Tóth, T.; Kulcsár, G.Y.; Mileff, P.; Hornyák, O.; Nehéz, K.; Körei, A. New Models and Methods for Increasing the Efficiency of Customized Mass Production. *J. Mach. Manuf.* **2009**, *49*, 11–17.
13. Despotović-Zrakić, D.; Barać, D.; Bogdanović, Z.; Jovanić, B.; Radenković, B. Software Environment for Learning Continuous System Simulation. *Acta Polytech. Hung.* **2014**, *11*, 107–122. [CrossRef]
14. Solding, P.; Gullander, P. Concepts for simulation based value stream mapping. In Proceedings of the 2009 Winter Simulation Conference, Austin, TX, USA, 13–16 December 2009; pp. 2231–2237.
15. D'Uffizi, A.; Simonetti, M.; Stecca, G.; Confessore, G. A Simulation Study of Logistics for Disaster Relief Operations. *Procedia CIRP* **2015**, *33*, 157–162. [CrossRef]
16. Leriche, D.; Oudani, M.; Cabani, A.; Hoblos, G.; Mouzna, J.; Boukachour, J.; El Hilali Alaoui, A. Simulating new logistics system of Le Havre Port. *IFAC-PapersOnLine* **2015**, *48*, 418–423. [CrossRef]
17. Sui, X.; Han, G.; Chen, F. Numerical simulation on air distribution of a tennis hall winter and evaluation on indoor thermal environment. *Eng. Rev.* **2014**, *34*, 109–118.
18. Izadi, M.; Razavi, F. Loss reduction in a distribution system by considering interest rate. *Eng. Rev.* **2015**, *35*, 179–191.
19. Rybicka, J.; Tiwari, A. Testing a flexible manufacturing system facility production capacity through discrete event simulation: Automotive case study. *World Acad. Sci. Eng. Technol. Int. J. Mech. Aerosp. Ind. Mechatron. Manuf. Eng.* **2016**, *10*, 712–716.
20. Jilcha, K.; Berhan, E.; Sherif, H. Workers and Machine Performance Modeling in Manufacturing System Using Arena Simulation. *Comput. Sci. Syst. Biol.* **2015**. [CrossRef]
21. Arkadiusz, G.; Antoni, S. Simulation Based Analysis of Reconfigurable Manufacturing System Configurations. *Appl. Mech. Mater.* **2016**, *844*, 50–59.
22. Renna, P. Allocation improvement policies to reduce process time based on workload evaluation in job shop manufacturing systems. *Int. J. Ind. Eng. Comput.* **2017**, *8*, 373–384. [CrossRef]
23. Kitazawa, M.; Takahashi, S.; Takahashi, T.; Ternao, T. Improving a Cellular Manufacturing System through Real Time-Simulation and -Measurement. In Proceedings of the 2016 IEEE 40th Annual Computer Software and Applications Conference (COMPSAC), Atlanta, GA, USA, 10–14 June 2016. [CrossRef]
24. Song, B.; Hutabarat, W.; Tiwari, A. Integrating optimization of simulation for flexible manufacturing system. In Proceedings of the 14th International Conference on Manufacturing Research, Loughborough, UK, 6–8 September 2016. [CrossRef]
25. Hachicha, W.; Triki, H. Manufacturing System Design Based on Axiomatic Design: Case of Assembly Line. *J. Ind. Eng. Manag.* **2017**. [CrossRef]
26. Martinez, J.; Muro, P.; Silva, M. Modelling, Validation and Software Implementation of Production Systems Using High-Level Petri Nets. In Proceedings of the IEEE Conference on Robotics and Automation, Raleigh, NC, USA, 31 March–3 April 1987; pp. 307–314.
27. Hillion, H.P. *Timed Petri Nets and Application to Multi-Stage Production Systems*; Advances in Petri Nets; Springer: New York, NY, USA, 1989.
28. Abdul-Hussin, M.H. Elementary Siphons of Petri Nets and Deadlock Control in FMS. *J. Comput. Commun.* **2015**, 1–12. [CrossRef]
29. Li, Z.W.; Zhou, M.C. Elementary siphons of Petri nets and their application to deadlock prevention in flexible manufacturing systems. *IEEE Trans. Syst. Man Cybern. A* **2004**, *34*, 38–51. [CrossRef]
30. Tamás, P.; Illés, B. Simulation examination of logistics systems in the automotive industry. *J. Prod. Eng.* **2015**, *18*, 69–72.
31. Tamás, P.; Illés, B.; Tollár, S. Simulation of a flexible manufacturing system. *Adv. Logist. Syst. Theory Pract.* **2012**, *6*, 25–32.
32. Dobos, P.; Illés, B.; Tamás, P. Conception for selection of adequate warehousing material handling strategy. *Adv. Logist. Syst. Theory Pract.* **2015**, *9*, 53–60.
33. Available online: https://www.plm.automation.siemens.com/en/products/tecnomatix/manufacturing-simulation/material-flow/plant-simulation.shtml (accessed on 10 August 2017).