Modelling and Simulation of the Order Realization in the Serial Production System

Robert Bucki, Bronislav Chramcov

***Abstract*—**The paper highlights the problem of mathematical modelling of the sample logistic production system where production stands are arranged in series. The production stands are equipped with tools which are used during the production process. If a tool is completely worn out, it needs to be replaced or regenerated. The problem consists in determining the best order realization sequence in order to minimize the total production time. The idea of time scaling by means of the simulation method is proposed in order to determine the best possible order realization time. Heuristic algorithms are used to control the production process. The criteria are given to either maximize the production output or minimize the lost flow capacity of the production stands or minimize the tool replacement time. A possibility of simulation of such production systems is outlined.

***Keywords*—**Mathematical modelling, optimization, heuristic algorithm, computer simulation, production systems.

I. Introduction

DESIGN of production (manufacturing) systems or selection of a suitable sequence of orders is one of the most important issues for managers of manufacturing companies. The main problem consists in the fact that bringing the system to a standstill due to its failures or maintenance of the production series system can generate high costs because during the MTTR (Mean Time To Restore) of one machine, all other machines of the series cannot continue the production process. This problem has been well studied in the research literature with the primary focus being on how to improve system efficiency. Over the past three decades a large amount of research has been devoted to the analysis and modelling of production line systems. Papadopoulos and Heavey present a comprehensive literature review of related papers [1]. One of the critical design factors is the allocation of buffer storage structures with certain capacities between stations. For example, a simulation model was proposed to define the optimal dimension of the buffer with regard to the maintenance policy [4]. This model can simulate a system of units that can have very different characteristics, such as productivity or reliability, and also it can simulate an inter-operational buffer between them. The model is used to determine the buffer dimension trend depending on the cost of the buffer. A generalized meta-model is developed in the work [6] It incorporates simulation and neural network modelling applications in order to determine the optimum buffer storage capacities between the stages of a serial production flow line. The procedure is based on generating a set of representative buffer storage capacities from all possible combinations; simulating the line with selected capacities; using the simulation output to train a neural network model; and evaluating all possible capacity combinations to select the best capacities. It is also possible to use the Markovian production system model with a bottleneck [5]. Another work [3] compares the performances of push, pull, and hybrid production control systems for a single line of the multi-stage and continuous process using simulation as a tool. The study is inspired by a production scheduling problem in a large aluminium rolling and processing factory in Istanbul.

In many cases the functionality, performance and throughput of production systems depend heavily on the selection of a suitable sequence of orders. The main objectives of order sequencing in production systems are minimization of set-up times, continuous and optimal use of capacities, reliability of delivery, minimization of stock and throughput time as well as avoidance of undue system states. The complexity of the task of order sequencing usually requires the employment of heuristic methods rather than analytical approaches. In this context computer simulation especially discrete event simulation (DES) can be used. The possibilities and limits of simulation employed to create optimal order sequences for flow-shop production systems are outlined as well as discussed and some examples are given in the work [2]. In the DES field, a whole range of application and academic works have come into existence; for instance in the work [7] the author pointed out the significance of simulation in management and control systems in support of the decision-making process. The inclusion and exploitation of these simulation models enables online decision-taking in systems where it is not possible to precisely calculate the consequences of such decisions.

Minimizing production costs has always been one of the most important goals in mathematical modelling of every production activity [8]. However, minimizing production costs may lead to the increase of the total production time [10]. In consequence, this approach increases the loss of the residual

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capacity [12]. To avoid this and other obstacles emerging from analyzing the production environment, there is a need to introduce optimization criteria which will be responsible for channeling the flow of material [11]. E-commerce systems form a standard environment and support of business activities and can be characterized by a wide range of parameters. Parameters describe individual e-commerce system components, are important indicators of e-commerce system status and are of great importance for Business Process Management (BPM). All e-commerce system parameters must be continuously monitored and more precisely measured. Different parameters can be categorized [16]. Mathematical modelling forms the background for preparing control of each production environment [15]. The situation of logistic control for production schedule is usually more complicated in practice and we need to use an integrated approach to solve the problem [9]. New modelling and system design techniques are required for information technologies that can support the enterprise in achieving and sustaining the necessary flexibility [14]. The paper analyses the serial production system in which charge elements are passed through the production stands arranged in series. We consider the serial production system without buffers between the production stands. The process continues as long as all elements of the order vector are realized. There are heuristic algorithms given. Each heuristic algorithm determines an element of the order vector. This element is later passed through the subsequent production stands. Optimization criteria are responsible for choosing the production strategy. The main goal of each production strategy is to optimize a certain area of production activity. The possibility of simulation model design of such production systems is outlined.

II. Problem formulation – general assumption

A. Mathematical description of serial production system

Let us assume there is a production system in which the machines M_i , $i=1,...,I$ are arranged in series (see Fig. 1). The vectors of charges W as well as the vector of orders Z are given. It is assumed that each product can be manufactured from any element of the charge vector. We also assume that used charge vector elements are immediately supplemented which means that we treat it as infinite source of energy.

$$\boxed{W \to M_1 \to \ldots \to M_i \to \ldots \to M_I \to Z}$$

Fig. 1: The scheme of the serial production system

Each machine in the production system carries out a different production operation. These operations are realized subsequently. Let us introduce the vector of orders (products) in the form (1), where z_n is the nth production order.

$$Z = [z_n], n = 1 \ldots N \tag{1}$$

Let $D = [d_{n,i}]$ be the matrix of procedures to be carried out to realize the nth element of the vector Z. The elements of this matrix take the values in accordance to the form (2).

$$d_{n,i} = \begin{cases} 1 & \text{if the } n\text{th production order is realized} \\ & \text{by the } i\text{th production stand,} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Having assumed the above we can introduce the life matrix of the serial production system for a brand new tool in the form (3).

$$G = [g_{n,i}] \ , \quad n = 1 \ldots N, \quad i = 1 \ldots I \tag{3}$$

Where $g_{n,i}$ the number of the nth product units which can be realized in the ith production stand before the tool in this stand is completely worn out and requires an immediate replacement (as a result of this usage the stand i-1, $i=2 \ldots I$ is brought to a standstill). The life matrix is shown in the matrix form (4).

$$G = \begin{bmatrix} g_{1,1} & \cdots & g_{1,i} & \cdots & g_{1,I} \\ \vdots & & \vdots & & \vdots \\ g_{n,1} & \cdots & g_{n,i} & \cdots & g_{n,I} \\ \vdots & & \vdots & & \vdots \\ g_{N,1} & \cdots & g_{N,i} & \cdots & g_{N,I} \end{bmatrix} \tag{4}$$

The elements of the matrix G take the values according to the form (5).

$$g_{n,i} = \begin{cases} \psi & \text{if the } n\text{th product is realized in the} \\ & i\text{th production stand, } \psi = 1 \ldots \Psi, \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

If the number ψ is reached for the given nth element of the vector Z, the tool has to be replaced by a new one.

B. The state equations

The order vector Z changes after every production decision according to scheme (6). The stage k, $k = 1,...,K$ is the moment at which the manufacturing process at any production stand begins or ends. We need to consider that decisions are made at the stage $k-1$, $k = 1,...,K$.

$$Z^0 \to Z^1 \to \ldots \to Z^k \to \ldots \to Z^K \tag{6}$$

The order vector is modified after every decision about production accordance with specification (7).

$$z_n^k = \begin{cases} z_n^{k-1} - x_n^k & \text{if the number of units } x_n^k \text{ of the } n\text{th order is realized at the } k \text{ stage,} \\ z_n^{k-1} & \text{otherwise} \end{cases} \quad (7)$$

The state of the discussed serial production system changes in the production course according to scheme (8).

$$S^0 \to S^1 \to \ldots \to \ldots \to S^k \to \ldots \to S^K \quad (8)$$

The state of the production stand in case of production the nth product changes according to the form (9). This state take the values specified in the form (10).

$$s_{n,i}^0 \to s_{n,i}^1 \to \ldots \to s_{n,i}^k \to \ldots \to s_{n,i}^K \quad (9)$$

$$s_{n,i}^k = \begin{cases} s_{n,i}^{k-1} & \text{if no } n\text{th product is realized in the } i\text{th stand at the } k\text{-1 stage,} \\ s_{n,i}^{k-1} + x_n^k & \text{otherwise} \end{cases} \quad (10)$$

Now we can define the matrix of state of the production system at the stage $k-1$ in the form (11), where $s_{n,i}^{k-1}$ is the number of units of the nth product already realized in the ith stand with the use of the installed tool.

$$S^{k-1} = \begin{bmatrix} s_{1,1}^{k-1} & \ldots & s_{1,i}^{k-1} & \ldots & s_{1,I}^{k-1} \\ \vdots & & \vdots & & \vdots \\ s_{n,1}^{k-1} & \ldots & s_{n,i}^{k-1} & \ldots & s_{n,I}^{k-1} \\ \vdots & & \vdots & & \vdots \\ s_{N,1}^{k-1} & \ldots & s_{N,i}^{k-1} & \ldots & s_{N,I}^{k-1} \end{bmatrix} \quad (11)$$

Let b is the number of production stand, where the tool has to be replaced with a new one, $1 \le b \le I$. The state of the production stand in case of replacement of tools changes in the way according to the specification (12).

$$s_{n,i}^k = \begin{cases} s_{n,i}^{k-1} & \text{if } i \ne b \text{ at the } k\text{-1 stage,} \\ 0 & \text{if } i = b \text{ at the } k\text{-1 stage,} \end{cases} \quad (12)$$

If tools in all stands are totally worn out, then $S = G$ and need an immediate replacement to enable the production process.

C. The flow capacity of the production system

On the basis of the above assumptions we can determine the flow capacity of the ith production stand for the nth element of the order vector Z in the form (13), where variable $p_{n,i}^{k-1}$ is the number of units of the nth production order, which still can be realized in the ith stand.

$$p_{n,i}^{k-1} = g_{n,i} - s_{n,i}^{k-1} \quad (13)$$

After that, we can define the matrix of flow capacity of the production system at the stage $k-1$ in the form (14).

$$P^{k-1} = \left[p_{n,i}^{k-1} \right] \quad (14)$$

These assumptions are made for simplicity reasons. However, in the production process, after completing realizing the nth product in the ith stand, we check if there is a possibility to manufacture another product in the discussed stand. If so, another element from the order vector is realized in the ith stand as long as the flow capacity of the stand enables the whole nth product realization. We assume that production in the ith stand is resumed only then if there is enough flow capacity to manufacture at least one element n. If there is not enough capacity to realize the whole element n, the tool in the ith stand is replaced with a new one and the production process is resumed.

D. Type of manufacturing procedure

For serial production system it is possible to propose manufacturing procedures in these two types:

1. Orders are realized in sequence (manufacturing of the order may begin when the previously realized one leaves the serial production system). This procedure guarantees us that no product blocks manufacturing another element from the order vector. Its disadvantage consists in the need of waiting for completing manufacturing of a certain product before resuming the manufacturing process. This results in not using the available capacity of the whole production system. Moreover, during the production course tools must be replaced.
2. Orders are realized simultaneously which means that if a manufactured element n leaves a production stand; the next one can enter it on condition that there is no need to replace the tool in the given stand responsible for accepting the element of the order vector. Otherwise, it has to wait for entering possibility in the preceding production stand.

E. Total manufacturing time

Let us define the production times of the nth production order in the ith production stand in the matrix form (15).

$$T^{pr} = \begin{bmatrix} \tau_{1,1}^{pr} & \ldots & \tau_{1,i}^{pr} & \ldots & \tau_{1,I}^{pr} \\ \vdots & & \vdots & & \vdots \\ \tau_{n,1}^{pr} & \ldots & \tau_{n,i}^{pr} & \ldots & \tau_{n,I}^{pr} \\ \vdots & & \vdots & & \vdots \\ \tau_{N,1}^{pr} & \ldots & \tau_{N,i}^{pr} & \ldots & \tau_{N,I}^{pr} \end{bmatrix} \quad (15)$$

If $\tau_{n,i}^{pr} \le \tau_{n,i+1}^{pr}$, then the ith production stand becomes blocked and the nth product is kept in this stand. If

$\tau_{n,i}^{pr} > \tau_{n,i+1}^{pr}$, then the production stand i+1 accepts the nth product. The elements of the matrix T^{pr} take the following values specified in the form (16).

$$\tau_{n,i}^{pr} = \begin{cases} \psi' & \text{the } n\text{th product realization time in the } i\text{th production stand}, \psi' = 1 \ldots \Psi', \\ 0 & \text{if the product is not realized in the } i\text{th production stand} \end{cases} \tag{16}$$

Let us define the vector (17) of replacement times for the tool in the ith production stand, where τ_i^{repl} is the replacement time of the tool in the ith production stand.

$$T^{repl} = \left[\tau_1^{repl} \quad \ldots \quad \tau_i^{repl} \quad \ldots \quad \tau_I^{repl}\right] \tag{17}$$

Let us calculate the total manufacturing time of all elements from vector Z. It is given by (18) for products realized in sequence and in the form (19) for products realized simultaneously.

$$T = \sum_{n=1}^{N}\sum_{i}^{I}\tau_{n,i}^{pr} + \sum_{k=0}^{K}\sum_{i}^{I} y_i^k \tau_i^{repl} \tag{18}$$

$$T = \sum_{n=1}^{N}\sum_{i}^{I}\tau_{n,i}^{pr} + \sum_{k=0}^{K}\sum_{i}^{I} y_i^k \tau_i^{repl} - \Delta\tau^{sim} \tag{19}$$

Variable $\Delta\tau^{sim}$ represents the total time during which two or more elements n, ($n = 1,\ldots,N$) are manufactured simultaneously during the whole production process, however in different stands, $N = 1 \;\Rightarrow\; \Delta\tau^{sim} = 0$. The coefficient y_i^k takes the values according to the specification (20).

$$y_i^k = \begin{cases} 1 & \text{if the replacement procedure of the tool in the } i\text{th stand is carried out}, \\ 0 & \text{otherwise} \end{cases} \tag{20}$$

III. Production Criteria

The criteria presented hereby in the vector of criteria $Q = [Q_1, Q_2, Q_3]$ are to either maximize the production output or minimize the lost flow capacity of the production stands or minimize the tool replacement time. Let us propose production criteria for the serial production system. Firstly it is possible to define the production maximization criterion in the form (21), where x_n^k is the number of units of the nth element of the order vector realized at the kth stage.

$$Q_1 = \sum_{k=1}^{K} q_1^k = \sum_{k=1}^{K}\sum_{n=1}^{N} x_n^k \rightarrow max \tag{21}$$

Secondly, it is possible to use the lost flow capacity criterion in the form (22), where parameter y_i^k is the lost flow capacity of the ith stand at the kth stage.

$$Q_2 = \sum_{k=1}^{K} q_2^k = \sum_{k=1}^{K}\sum_{i=1}^{I} y_i^k \sum_{j=1}^{J_i} p_{n,i}^k \rightarrow min \tag{22}$$

Finally, we can use the minimal tool replacement time criterion in the form (23), where variable τ_i^{repl} is the replacement time of the used tool in the ith stand.

$$Q_3 = \sum_{k=1}^{K}\sum_{i=1}^{I} y_i^k \tau_i^{repl} \rightarrow min \tag{23}$$

IV. Heuristic Approach to Control of the Production Process

In order to control the logistic process we need to implement heuristics which determine elements from the vector Z for the production process. The following control algorithms are put forward.

A. The algorithm of the maximal order

This algorithm chooses the biggest order vector element characterized by the biggest coefficient γ_n^{k-1} in the state S^{k-1}. To produce element a, the condition in the form (24) must be met, where $\gamma_n^{k-1} = z_n^{k-1}$.

$$(q^k = a) \Leftrightarrow \left[\gamma_a^{k-1} = \max_{1\le n\le N}\gamma_n^{k-1}\right] \tag{24}$$

The above approach is justified by avoiding excessive bringing the production line to a standstill in order to change an element to be manufactured. If in state S^{k-1} only minimal orders were chosen, in consequence the number of orders might be reduced. Such control is favorable because the serial production line will not be blocked and must be stopped only in order to replace the tools in certain stands (on condition that the replacement process disturbs the flow of the material).

B. The algorithm of the minimal order

This algorithm chooses the smallest order vector element characterized by the smallest coefficient γ_n^{k-1} in the state S^{k-1}. To produce element a, the condition (25) must be met, where $\gamma_n^{k-1} = z_n^{k-1}$.

$$(q^k = a) \Leftrightarrow \left[\gamma_a^{k-1} = \min_{1\le n\le N}\gamma_n^{k-1}\right] \tag{25}$$

The above approach is justified by the need to eliminate the elements of the order vector Z which could be sent to the customer just after the nth product leaves the production line on condition that the customer sets such a requirement.

C. The algorithm of the relative order

This algorithm chooses the order characterized by the maximal relative order coefficient γ_n^{k-1} in the state S^{k-1}. To produce element *a*, the condition (25) must be met, where $\gamma_n^{k-1} = \frac{z_n^{k-1}}{z_n^0}$.

$$(q^k = a) \Leftrightarrow \left[\gamma_a^{k-1} = \max_{1\le n\le N} \gamma_n^{k-1}\right] \qquad (266)$$

It is justified by the assumption that the orders are realized successively that is to say each order element z_n^{k-1} in state S^{k-1} are reduced partly. It is expected that such control is advantageous when some parts of the order are needed earlier and the rest can be manufactured later.

D. Random choice of order vector elements

Random choice of products for manufacturing may be the only way of minimizing the production time if other available algorithms fail to deliver a satisfactory solution. This problem can be solved by the simulation method repeating calculations thousands of times. The results of such research for a certain criterion generate a histogram approximated by a normal distribution. The best up-to-date time scale gives criterion index *q*. In case of a minimization problem, probability $P(t<q)$ can be expressed. It means further simulation experiments may let us obtain a better time scale, with index $t<q$. If the boundary value of this probability is given (e.g. 1%), it is the condition to finish the experiments.

V. Time Scaling – the Simulation Method

The general block diagram of time scaling with the use of the simulation method is shown Fig. 2. The problem consists in determining the best random time scale and the probability of obtaining a better time scale by means of the subsequent simulation procedure.

For the given serial production system being in the initial state S^0, the best time scale of manufactured orders *Z* must be determined. The simulation process should consist in determining the manufactured order number n at random and determining the successive state S^k on the basis of the given state.

If after a certain production stages (lower than *N*), the flow capacity of all technological routes equals zero, then a certain stand s_i with the fully worn tool which is to be replaced is selected at random on condition that after the replacement the flow capacity of at least one route enables resuming the production process. As a consequence, indexes Q^l are calculated for each random time scale. Number *L* of random time scales can be assumed optionally.

For a chosen optimization index of time scales (e.g. time *T* of orders *Z* manufacturing) the following data can be logged:

- indexes T^l of random time scales,
- the best time scale at the present moment which is characterized by T_{min}.

After finishing *L* simulation experiments, a histogram is obtained (for indexes T^l) and the probability of obtaining a better time scale than presently the best available is calculated $P(T<T_{\min})$. If this probability is bigger than the assumed boundary value (e.g. 1%), the next *L* experiments are carried out which means *L* random time scales are determined. The evaluation procedure of the best time scale at the present moment is repeated.

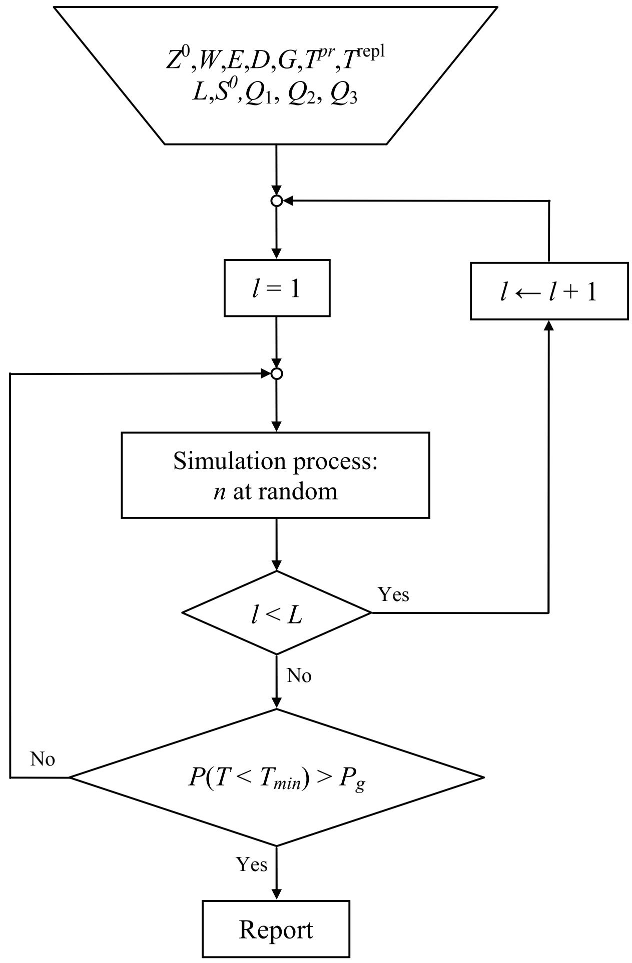

Fig. 2: Searching for the best time schedule

VI. Simulation Software – Possibility to Improve Serial Production System Efficiency

Currently, there is a wide range of simulation environment offering an extremely wide spectrum of possibilities for the modelling and simulation of manufacturing, logistic and other queuing systems [17,18]. These environments can be broken down into three main classes.

The first class includes general simulation languages like Simula, C++SIM, GPSS/H, AweSim, Simscript, BaseSim, CSIM 19, JavaSIM and others. In essence, these are specific programming languages whose inputs and outputs are presented in the form of textual data. In order for a user to be able to exploit all of the characteristics of a specific application to its limits, they must not only have modelling experience – but also, they need to be a relatively gifted programmer. The simulation languages named above are ideally suited to solving the most varied tasks, which results from their great degree of flexibility. As regards their demands on time, it goes without saying that one has to emphasize the relatively lengthy preparation of such models in the careful writing of the source code. The second class of environments relates especially to software packages which use graphic interfaces between the simulation language being used and the user themself. This category includes, to name just a few, MapleSim 4, AutoMod, Quest, and Arena. In this case, it is possible to create a model either in a graphical form or with the assistance of source codes. This also ensures a certain degree of flexibility. Equally, the output can also be depicted graphically; today, most frequently through the assistance of visualisations of the modelled problem. From the time perspective, we can safely say that the period needed for the creation of the model is shortened, since one can use the much-favoured “Drag & Drop” method. The third class concerns the generation of simulators which have appeared on the market over the past ten years or so thanks to the marked expansion and sophistication of computer graphics. For these types of environment, there is practically no need to programme anything at all or only in exceptional cases. Representatives of this class include for instance Renque, ProModel, Tailor II, FACTOR/AIM and the often mentioned Witness [26]. Process analysis using the Witness simulation environment has been conducted, for instance, in the lens manufacturing process flow of the firm in order to identify improvement prone areas and improvement alternative solutions were proposed [19]. The other work illustrates the use of computer simulation by Witness to design the production of a manufacturing company that produces snow melting modules. The analysis presented hereby focuses on the production design process and compares the performance of new design with the existing system performances [20]. The Witness environment was to be used also for simulation of the ophthalmology service of Regional Military and University Hospital of Oran in Algeria [21] or for analysis of the best layout for an industrial plant [22]. Our workplace deals with the use of computer simulation in order to achieve more efficient production in manufacturing and production systems [23]. In our case, the possibilities of such a use were demonstrated for instance to verify the functionality of suggested designs for the production lines of the company Continental Automotive Systems Czech Republic s.r.o. [25] or in the course of designing solutions designed to increase productivity and the discovery of bottlenecks in the short-barrel (pistol) production line [24].

The Witness simulation environment is the product of the British Lanner Group company [26] and is one of the most successful world class environment for the simulation of manufacturing, queuing and logistic systems. It is used in support of the decision-making process of senior management when resolving organisational, technical and operational problems associated especially with the restructuralisation and upgrading of the enterprise´s processes. Witness helps to limit risk in the course of implementing changes within an organisation by enabling management to create an interactive version of visually understandable simulation models of complex enterprise processes and to analyze and optimize them. Witness also enables its user to test various variants of changes to a system as well as to evaluate their eventual impact on the behaviour of the processes. It is possible to identify bottlenecks in the production process, and to evaluate the costs and benefits of potential changes prior to even purchasing the requisite plant and equipment or to increase the performance of an organisation without the need to expand resources and so on. The models in the Witness environment program depict the movement of materials or customers within the system, the states of individual elements, the operations performed as well as the actual use of resources. At the same time records are made of all of the events that have occurred or occur in the system. Thereby, the user can track the dynamics of the process and also has at their disposal the requisite data to be able to evaluate the effective performance of a given system on the basis of the selected criteria. It is also possible to perform "what-if" analyses. The simulation run can be stopped whenever it is necessary. It is also possible to make changes to the parameters of the system e.g. the size of some predefined elements like interoperation buffer stores, the number of employees in a shift, the directional flows of materials or the state of essential matrixes e.g. the matrix of flow capacity and then quite simply continue with the simulation process. Thereby, the consequences of exemplary changes can immediately be tracked.

The core of the Witness environment system is complemented by the Witness Optimizer modules for the optimisation of processes, depicted in a virtual reality environment for the ease of mutual exchanges of information between the environment of the Witness and Microsoft VISIO environments which are linked to the CAD/CAM systems. The documentation of models and the acquisition of knowledge and information can be carried out by means of an extensive set of data. The Witness simulation package is capable of modelling a variety of discrete (e.g. part-based) and continuous (e.g. fluids and high-volume fast-moving goods) elements. Depending on the type of element, each of them can be in any of a number of “states”. These states can be idle (waiting), busy (processing), blocked, in-setup, broken down, and waiting labour (cycle/setup/repair). Witness models are based on template elements. These may be customised and combined into module elements and templates for reuse. The most basic discrete modelling elements are *Parts*, *Buffers*, *Machines* and *Conveyors*. Other discrete modelling elements include multiple types of tracks and vehicles, labour, carriers, shifts, variables and part attributes. The behavior of each element is described on a tabbed detail form in the Witness user interface. Parts are simply objects that travel from one location to another. They may be pulled passively into the model by the simulation, pushed into the system by an active part arrival schedule, arrive from a part file, be created via a "production" machine, or any combination of the above. Buffers are simply passive storage areas of finite capacity. Buffers can be configured as "delay" buffers, where parts must stay in for a minimum amount of time. They can be configured as "dwell" buffers, where they cannot stay in the buffer any longer than a specific time. A part can be optionally ejected from a buffer if it violates any of these conditions. Combinations of First-In-First-Out / Last-In-First-Out sequencing are possible, as well as the ability to have parts pushed to and pulled from locations in the buffer other than the front and rear. Machines are the workhorses of Witness. The standard machine elements can be single, batch, production, assembly, multistation or multicycle. Machines can be defined with Setup and Breakdown parameters, useful for modelling real-life failures, retooling, preventive maintenance, etc.

The possibilities of making use of the Witness simulation environment are herein presented in the form of two simulation studies that were performed within the framework of cooperative ventures between our workplace and industrial partners.

A. Construction of the model of the serial production system in the Witness environment

Model design of this type of production system is not so difficult in the Witness environment. The production orders can be modelled as the element of the *Part* type. Parameters of each order can be defined by means of part attributes. Attributes are characteristics or features of a part. In our case we could create *Size*, *Time_Realization*, *Stands* and *Replacement_Number* attributes. The *Size* attribute specifies the number of order units. The *Time_Realization* should define the production times of the production order in the each production stand. The *Stands* attribute specifies the stands where the order is realized and the *Replacement* attribute stores the numbers of units which can be realized in each production stand before the tool in this stand is completely worn out. The element of *Part type-Production_Order* which represents the production order is a passive type. The input procedure of this element into the discussed model could be realized by means of the *PartFile* type element. This element uses a text file where the name, the input time and other compulsory attributes of *Production_Order* part are stored. All production orders are input into the model at one time. They are stored in the element of the *Buffer* type.

Each machine (production stand) in the production system is modelled in the Witness environment with help of the element *Machine of Single* type. Parameters of each element are set by means of the tabbed detail form. The *Cycle Time* parameter is considered as an attribute of the element *Part* as a production stand carries out realization of a few production orders with a different realization time. It is possible to model

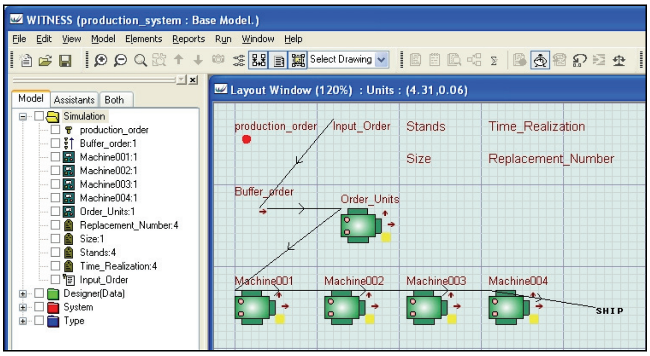

Fig. 3: An exemplary model in the Witness environment

Requirement for replacement of a tool by means of the *Setup* page of the element *Machine*. The *Setups* page enables to model time that the machine takes to set up or retooling. In our case, the retooling takes place after the specified number of operations. This number is stored in the *Replacement_Number* attribute.

Choosing the order for production can be modelled with the use of the *Machine* element of the *Production* type. On the base of the specified algorithm this element pulls the order from a certain buffer and should produce the number of units of the selected order. The number of units is stored in the *Size* attribute. The example of the model with 4 production stands is shown in Fig. 3.

VII. Conclusion

The problem presented in the paper discusses the issue of the serial production system. The system delivers ready products corresponding with the elements of the order vector. The main goal is to fulfil the task set by the criteria introduced in the paper. There is also a possibility to implement a two- or three-criterion model. Such models may lead to delivering a solution which would satisfy criteria included in the discussed model only partly as there should be bounds added. Heuristic algorithms proposed in the paper enable the operator to choose the satisfactory production sequence on the basis of which a certain element of the order vector is determined to be realized. The use of one specified algorithm does not mean that we will achieve the result satisfying the given criterion. We should try to verify another algorithm and decide which one minimizes the order realization time, the loss of residual capacity and the total replacement time or satisfies a hypothetical customer's demand not specified hereby. Another idea already used in previous works is to simulate the combination of heuristic algorithms [13]. By means of this method, we can combine two or more algorithms. It also seems reasonable to draw products for manufacturing. To achieve the satisfactory result, a big number of simulations must be carried out. In conclusion, it must be admitted that a simulator imitating real environment should be built to continue this work. Simulation experiments carried out in the synthetic environment may deliver an answer which heuristic approach is the expected one for a certain criterion. The idea of time scaling by means of the simulation method on condition a satisfactory number of simulation experiments is carried out seems to able to deliver the satisfactory result minimizing the total order realization time.

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