Information Control of the Autonomous Production System

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***Abstract*—**The paper highlights the problem of mathematical modelling of the autonomous production system in which there are production stands equipped with exactly the same machines arranged in a series. Each machine can perform a number of operations by means of a specified tool predefined from the set of tools. However, only one operation can be performed in each work stand at one time. Required specification is shown in order to model the expected system. The presented system requires the strategy on the basis of which the whole logistic process is run. Moreover, there is the need to implement the adequate criterion to obtain the expected results. The heuristic approach determines the order vector element to be realized. A sample case study is analyzed.

***Keywords*—** Discrete event simulation, heuristic algorithm, manufacturing strategies, mathematical modeling, production system.

I. Introduction

Manufacturing companies are currently facing very strong pressures in terms of cost, quality, flexibility, customization and time to market. Manufacturing or production systems that transform raw materials into high quality and highly reliable products are being developed and improved to address these needs. The manufacturing system is defined as being the ensemble of machining systems which are used for realization of a certain product. Each of these machining systems is made up of machine-tool/tools, apparatus, parts, an operator and it executes one of the manufacturing operations [1]. Manufacturing is performed on the basis of customer orders and each order can be unique. Naturally, the through put times of the components may differ from one another. The production systems have to be flexible and able to react to changing production capacity requirements. All this planning and management of production networks a complex task. Manufacturing process design and scheduling process are critical areas. They are primarily focused on how to improve line efficiency. Manufacturing system design involves a number of interrelated subjects, e.g. the tooling strategy, allocation of buffer storage structures with certain capacities between stations, material-handling system, system size, process flow configuration, flexibility needed for future engineering changes or capacity adjustment and space strategy [2]. Production scheduling has long been a hot research direction in these fields such as automation, industrial engineering, management engineering and so on. The production scheduling problem is related to the constraints of resources and processes [3].

One of the most useful tools in the arsenal of an operations research (industrial engineering) management science analyst consists in computer simulation. Frequently, simulation is considered to be synonymous with Discrete Event Simulation (DES). A simulation is simply an imitation of the operation of a real-world system for purposes of evaluating that system [4]. Simulation involves creating a model which imitates the behaviors of interest; experimenting with the model to generate observations of these behaviors; and attempting to understand, summarize, and generalize these behaviors. In many applications, simulation also involves testing and comparing alternative designs and validating, explaining, and supporting simulation outcomes and study recommendations [5]. Simulation is a powerful tool for the evaluation and analysis of a new system designs, modifications to existing systems, and proposed changes to control systems and operating rules [6]. Many approaches provide an introduction to simulation and modeling and the main concepts underlying simulation. The paper [7] discusses a number of key issues regarding a simulation team, how to conduct a simulation study, the skills required and the steps involved. It also provides project management guidelines and outlines pitfalls to avoid. There is also a more in-depth look at simulation concepts and worldviews [8], [9]. Simulation has been used to study such wide ranging topics as urban systems, social systems, transportation systems, health care delivery systems, logistic systems, production systems e-commerce systems [10] and many more. Simulations are often used to analyze systems which are too complicated to attack via analytic methods such as calculus, standard probability and statistics, or queuing theory. Moreover, simulation is the most widely-used management science and operation research technique employed by industry and government. References to papers by areas of application are presented subsequently in the paper.

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Manufacturing is one of the earliest simulation application areas [11], and today it remains one of the most popular application areas. Over the past four decades a large amount of research has been devoted to the analysis and modeling of manufacturing systems. The tutorial [12] introduces manufacturing applications of simulation through three illustrative example applications. These examples illustrate the additional understanding of system behavior gained by the use of simulation models. Discrete-event simulation can be used in the design, operation and continuous improvement of complex manufacturing and logistical systems [13]. A combination of simulation with systems engineering methodology and the horizontal and vertical extension of simulation models in an enterprise are described in detail. Many articles and many software programs focus on manufacturing scheduling problems. Manufacturing scheduling systems are available on all platforms at many levels of complexity. Simulation-based planning and scheduling systems have proven to be very successful in this area. A hands-on approach letting us understand how simulation can be used as a planning and scheduling tool is emphasized in [14]. Additionally, it describes how to build a simulation model that can be used for planning and scheduling, and how to use that model to manually produce multiple schedules using simulation. The power and flexibility of using simulation as a tactical tool is exhibited. The work [15] provides a review of the recent achievement and discusses the agent internal structure, multi-agent scheduling model and agent negotiation mechanism which are key issues in implementing manufacturing processes. Besides, the methods and strategies of rescheduling with multiagent technique in manufacturing process are also analyzed and described. Development of scheduling algorithm is a fundamental and important problem for realizing flexible manufacturing systems. It is a problem of combinatorial optimization and includes difficulties such as complicated constraints and many locally optimal solutions. In many manufacturing processes the schedule of production is determined in a heuristic way by an expert operator. He solves the scheduling problem in such a way that the solution is feasible but not necessarily optimal. In recent complicated processes, however, even a feasible solution is difficult to obtain. Several approaches have been investigated to overcome the difficulties. The papers [16] and [17] direct the attention to a genetic algorithm (GA) which aims at obtaining a suboptimal solution by a skilful combination of random search with heuristic method. In these papers, various methods of individual description are presented to improve the performance of GA for scheduling problems in manufacturing processes. Computer aided scheduling with use of genetic algorithms and a visual discrete event simulation model is also solved in [18]. This article describes the method of upgrading conventional scheduling with the use of problem decomposition and genetic algorithms combined with a visual discrete simulation model.

The design of production systems, and also management of annual production targets, requires determining optimal buffer storage allocation on the line. Analysis and synthesis of systems with optimal buffer stocks is thus of both theoretical and considerable practical interest. For example, the paper [19] solves modeling of the logistic system with shared interoperation buffer stores or a simulation model which was proposed in [20] defines the optimal dimension of the buffer with regard to the maintenance policy. A generalized meta-model is developed in the work [21]. It incorporates simulation and neural network modeling 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 available. It is also possible to use the Markovian production system model with a bottleneck [22].

In discrete manufacturing processes such as stamping, assembly, or machining processes, product quality, often defined in terms of the dimensional integrity of work pieces, is jointly affected by multiple process variables. During the production phase, the states of tooling components, which are measured by adjustable process variables, are subject to possible random continuous drifts in their means and variances. These drifts of component states may significantly deteriorate product quality during the production process. Therefore, maintenance of the tooling components with consideration of both their continuous state drifts as well as catastrophic failures is crucial in assuring desired product quality and productivity. In contrast to traditional maintenance models where product quality has not been well addressed, especially for discrete manufacturing processes, a general quality oriented maintenance methodology is proposed to minimize the overall production costs [23]. In this research, the total production cost includes product quality loss due to process drifts, productivity loss due to catastrophic failures, and maintenance costs.

One of the most important issues for managers of manufacturing companies to decide on is what production control system would be the most appropriate for their companies. The choice is a matter of research and investigation but choosing the right system is a very important competitive advantage for the manufacturing companies. Comparing 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 is presented in [24]. The study is inspired by a production scheduling problem in a large aluminum rolling and processing factory in Istanbul. The problem of optimal control of pull manufacturing systems is analyzed thoroughly in [25]. The objective is to determine the optimal control for the production rate at each machine in the system. Optimal control of a substitutable inventory system, structured assemble to order systems and the impact of advance demand information on various production inventory control mechanisms are the key factors which must be taken into account while planning order realization procedures [26]. Deterministic systems used for these purposes do not involve any randomness in the development of subsequent states of the logistic system. Therefore, such a model will always produce the same output from a given initial state. Stochastic ordering is a fundamental guide for decision making under uncertainty. It is also an essential tool in the study of structural properties of complex stochastic systems [27]. Developing solutions with heuristic tools offers two major advantages: shortened development time and more robust systems [28]. Evolutionary design of intelligent systems is gaining much popularity due to its capabilities in handling several real world problems involving optimization, complexity, noisy and non-stationary environment, imprecision, uncertainty and vagueness [29].

One feature of simulation is that one can change the parameters of a simulation model easily and try to observe the system performance under different sets of parameters. Therefore, it is natural to try to find the set of parameters which optimizes the system performance and is understood as optimization via simulation or simulation optimization [30]. Because simulation optimization requires simulating the system for multiple replications at multiple, possibly a very large number of parameter settings, abundant computing power is necessary. Due to the rapid growth of computing power, simulation optimization has become popular in recent years. Simulation optimization is an extremely valuable technique for investigating the behavior of many business processes. The high abstraction level of the concept of discrete event simulation means that its application potential is extremely wide-ranging. Some common application areas of discrete event simulation or simulation optimization are service stations such as airports [31], call centers and supermarkets; road and rail traffic; industrial production lines [32] or technological process [33] and logistical operations like warehousing and distribution [34], [35]. 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 emphasized in the work [36].

DES and simulation optimization are highly complex fields of research that have the potential of having a considerable impact on the practice - and particularly, when computers become significantly faster. In general, increased computational power has enabled development of detailed „high-fidelity“ models of systems to aid in design and operation. Therefore, at present, a wide range of commercial products are available on the market which are intended for the Windows and UNIX platforms, and which offer an extremely wide spectrum of possibilities for the modeling and simulation of manufacturing, logistical and other queuing systems [37],[38]. Currently, nearly every commercial discrete event simulation software contains a module which performs some sort of “optimization” rather than just pure statistical estimation. The goal of an “optimization” package is to orchestrate the simulation of a sequence of system configurations so that a system configuration is eventually obtained providing an optimal or near optimal solution. The work [39] surveys the most prominent simulation optimization software packages (either plug-ins or integrated) currently available and their vendors and the simulation software product which they support. There is a big emphasis on the search techniques used in it.

II. General assumptions

Let us assume that the discussed manufacturing system consists of I production stands equipped with the machines used to manufacture the elements of the order vector Z. The order vector consists of N elements. Each work stand is equipped with exactly the same machine. There is only one machine in each work stand. Each machine has some of the M tools. Each tool performs a defined operation. At one moment only one operation can be carried out in each work stand. This system requires K stages to realize the order vector elements. The vector of orders at the kth stage is considered in the form (1), where z_n^k the number of units of the nth order at the kth stage awaiting for realization. The stage k, $k=1,\dots,K$ is the moment at which the manufacturing process at any production stand begins.

$$Z^k = \left[z_n^k\right] \ , \ n = 1,\dots,N \ , \ k = 1,\dots,K \tag{1}$$

The order vector is modified after every decision about production in accordance with the specification (2).

$$z_n^k = \begin{cases} z_n^{k-1} - x_n^k & \text{if the number of units } x_n^k \text{ of the } n\text{th order is realized at the } k \text{ stage,} \\ z_n^{k-1} & \text{otherwise.} \end{cases} \tag{2}$$

Let us introduce the matrix of structure for realizing the nth product of the serial manufacturing system in the form (3).

$$E = \left[e_{n,i}\right] \ , \ n = 1,\dots,N \ , \ i = 1,\dots,I \tag{3}$$

The elements of this matrix take the values shown in the form (4).

$$e_{n,i} = \begin{cases} 1 & \text{if there are required operations on the } n\text{th element in the } i\text{th stand,} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Let us now assume that charge materials are represented by the vector of charges in the form (5) where: ω_w is the wth charge material.

$$\Omega = \left[\omega_w\right] \ , w = 1,\dots,W \tag{5}$$

Now we can introduce the matrix of charge material allocation to products in the form (6), where $\theta_{w,n}$ is the *w*th charge material allocation to the product of the *n*th order. Its elements take the values as in (7).

$$\Theta = \left[\theta_{w,n}\right],\ w = 1,...,W,\ n = 1,...,N \tag{6}$$

$$\theta_{w,n} = \begin{cases} 1 & \text{if the product of the } n\text{th order is made from the } w\text{th charge,} \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

In each *i*th work stand the machine includes tools which get worn out and are subject to replacement or regeneration. In such cases the machine must be stopped for the defined period of time and either the replacement or regeneration process is carried out. It is assumed that the regeneration process can be carried out only a certain number of times and after exceeding this number the used up tool has to be excluded from the manufacturing process.

Let the matrix in the form (8) be the matrix of operations performed by tools on the order vector elements. The elements of this matrix take the values pursuant to (9), where $\lambda_{n(i,m)}$ is the operation carried out with the use of the *m*th tool on the product of the *n*th order in the *i*th work stand.

$$\Lambda_n = \left[\lambda_{n(i,m)}\right],\ n=1,...,N;\ i=1,...,I;\ m=1,...,M \tag{8}$$

$$\lambda_{n(i,m)} = \begin{cases} 1 & \text{if the operation is carried out on the } n\text{th order vector element with the use of the } m\text{th tool in the } i\text{th workstand,} \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

Let us introduce the matrix of routes $D = \left[d_{n,i}\right]$, $n=1,...,N;$ $i=1,...,I.$ The elements of this matrix take the values as in (10), where $d_{n,i}$ is the number of the tool in the *i*th stand to realize the *n*th order.

$$d_{n,i} = \begin{cases} m & \text{if the } n\text{th order is realized in the } i\text{th stand by means of the } m\text{th tool} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Let $G_n = \left[g_{n(i,m)}\right]$, $i=1,...,I;$ $m=1,...,M;$ $n=1,...,N;$ be the life matrix of tools in the manufacturing system in case of manufacturing the *n*th product where $g_{n(i,m)}$ is the number of units of the *n*th order vector element which can be realized by the *m*th tool in the *i*th production stand before the need for replacement or regeneration arises.

Let $S_n^k = \left[s_{n(i,m)}^k\right]$, $i=1,...,I;$ $m=1,...,M;$ $n=1,...,N;$ $k=1,...,K;$ be the state matrix of tools in the manufacturing system in case of producing the *n*th product where $s_{n(i,m)}^k$ is the number of units of the *n*th order vector element already realized by the *m*th tool in the *i*th production stand by the *k*th stage.

If the ζ th tool is to be replaced with a new one in the υ th work stand, where $1 \le \upsilon \le I$, $1 \le \zeta \le M$, then the state of tools changes according to (11).

$$s_{n(i,m)}^k = \begin{cases} 0 & \text{if } i = \upsilon \text{ and } m = \zeta \text{ at the stage } k, \\ s_{n(i,m)}^{k-1} & \text{otherwise,} \end{cases} \tag{11}$$

Let $P_n^k = \left[p_{n(i,m)}^k\right]$, $i=1,...,I;$ $m=1,...,M;$ $n=1,...,N;$ $k=1,...,K;$ be the flow capacity matrix of tools in the manufacturing system in case of producing the *n*th product where $p_{n(i,m)}^k$ is the number of units of the *n*th order vector element which still can be realized by the *m*th tool in the *i*th production stand at the *k*th stage.

The number of units of the *n*th order vector element which still can be realized by the *m*th tool in the *i*th production stand at the *k*th stage can be calculated from the equation (12).

$$p_{n(i,m)}^k = g_{n(i,m)} - s_{n(i,m)}^k \tag{12}$$

III. Manufacturing Time

Let $T_n^{pr} = \left[\tau_{n(i,m)}^{pr}\right]$, $n=1,...,N;$ $i=1,...,I;$ $m=1,...,M;$ be the matrix of production times on the *n*th product with the use of *m*th tools in *i*th work stands. If the machine tool is not used for carrying out an operation on the product of *n*th order, then $\tau_{n(i,m)}^{pr} = 0$.

Let $T^{repl} = \left[\tau_m^{repl}\right]$, $n=1,...,N;$ be the vector of replacement times of tools in work stands where τ_m^{repl} is the *m*th tool replacement time.

Let $T^{reg} = \left[\tau_m^{reg}\right]$, $n=1,...,N;$ be the vector of regeneration times of tools in work stands where τ_m^{reg} is the *m*th tool regeneration time. If the machine tool is not subject to regeneration and should be replaced by a new one after exceeding the operating life, then $\tau_m^{reg} = 0$.

The *n*th product manufacturing time in the *i*th working stand is calculated by means of the formula (13), where $\Delta\tau_{n,i}^{reg}$ is the time throughout which the production process of the *n*th order vector element in the *i*th work stand is in a standstill mode. The variable y_{repl}^k takes the values as in (14).

$$T_{n,i} = \sum_{m=1}^{M} \tau_{n(i,m)}^{pr} + \sum_{k=1}^{K}\sum_{m=1}^{M} y_{repl}^k \tau_m^{repl} + \Delta\tau_{n,i}^{reg} \tag{13}$$

$$y_{repl}^{k} = \begin{cases} 1 & \text{if the decision about the replacement is made at the kth stage,} \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

A charge is passed subsequently through work stands and finds its final location meaning realizing the order. Semi-products relocation times are given in the matrix of relocation times in the form (15), where $\tau_{n,i\to i+1}$ is the time of passing the semi-product of the *n*th order to the subsequent work stand.

$$T_{reloc} = \left[\tau_{n,i\to i+1}\right],\ n=1,\dots,N;\ i=0,\dots,I \quad (15)$$

In a specific case, the variable $\tau_{n,0\to i=1}$ represents the time of moving the charge of the *n*th order to the first work stand e_i, and the variable $\tau_{n,I\to I+1}$ represents the time of moving the product of the *n*th order from the last work stand e_i to its proper location.

To calculate the total manufacturing time of the *n*th order realization we need to use the formula (16) where τ_i^k is the time of awaiting for completing the manufacturing process in the *i*th work stand at the *k*th stage.

$$T_n = \sum_{i=1}^{I} T_{n,i} + (I+1)\tau_{n,i\to i+1} + \sum_{k=1}^{K}\sum_{i=1}^{I}\tau_i^k \quad (16)$$

There are no buffer stores in the system so manufacturing process in the stand *i+1* blocks passing order vector elements to it and they remain in the preceding *i*th work stand till the moment when the stand *i+1* is ready to accept it.

IV. System Control

The presented system requires either the strategy on the basis of which the whole logistic process will be run or the criterion which will be responsible for setting the right sequence of products or, finally, the heuristic approach to determine the *n*th order to be realized.

Let us assume that Q_φ, $\varphi = 1,\dots,\Phi$ is the manufacturing criterion, Ξ_β, $\beta = 1,\dots,B$ is the production strategy, H_α, $\alpha = 1,\dots,A$ is the heuristic algorithm responsible for choosing the order vector element for production and Ψ_φ is the simulation result of the simulation process concerning the φth criterion. The sample control solution is proposed in the form of the diagram shown in the Fig. 1.

V. Sample Case Study

The following sample case study is shown in order to illustrate the mathematical model included in the paper. Let us assume that the discussed manufacturing system consists of 2 production stands, $I = 2$. There is only one machine in each work stand. Each machine can use only one of the two available tools $M = 2$. Two different products are ordered. The first order includes 3 elements and the second one 5. The order vector at the beginning of the manufacturing process (*k=0*) takes the form shown by (17).

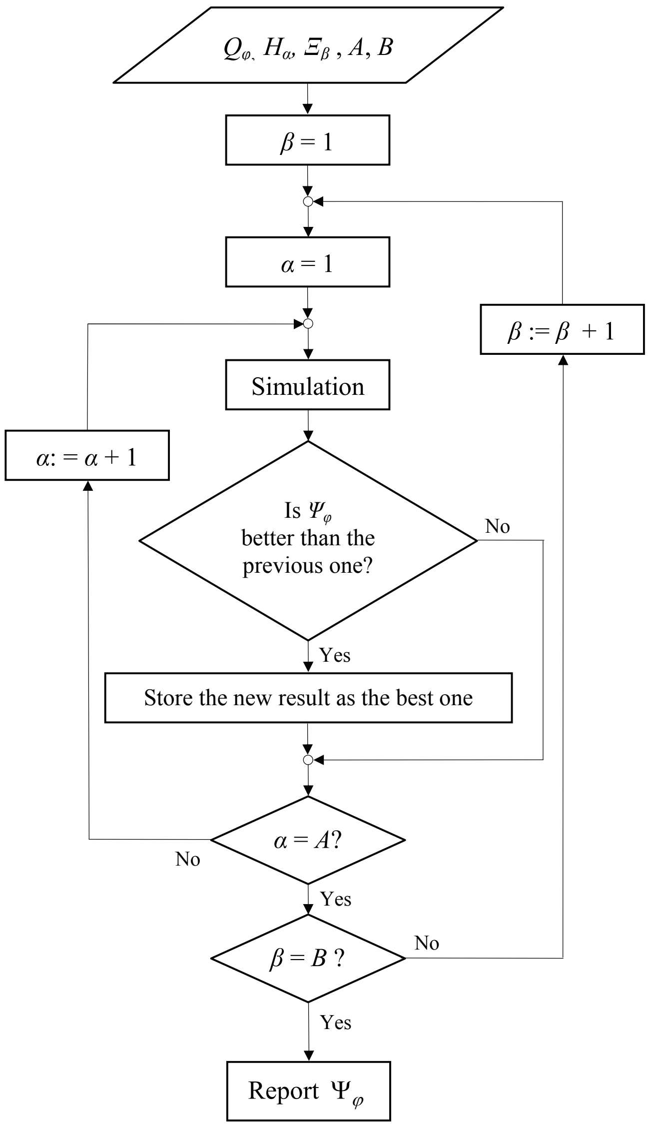

Fig. 1 The control diagram

$$Z^0 = \begin{bmatrix} 3 \\ 5 \end{bmatrix};\ z_1^0 = 3;\ z_2^0 = 5 \quad (17)$$

The structure of the serial manufacturing system for realizing defined orders is given by matrix in the form (18). This matrix indicates that the first order requires operations performed by both work stands and the second order requires an operation only in the second work stand.

$$E = \left[e_{n,i}\right] = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \quad (18)$$

The matrixes in the forms (19) and (20) specify which tools are required to carry out operations on a product of the *n*th order in the first and second work stands. For example, the first matrix indicates that the product of the first order is manufactured in the first work stand with the use of the second tool and later in the second work stand with the use of the first tool and the product of the second order is manufactured in the second work stand with the use of the second tool.

$$\Lambda_{n=1} = \left[\lambda_{1(i,m)}\right] = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \tag{19}$$

$$\Lambda_{n=2} = \left[\lambda_{2(i,m)}\right] = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \tag{20}$$

The life matrixes of tools for manufacturing the products of the first and second orders take the forms (21) and (22).

$$G_{n=1} = \left[g_{n(i,m)}\right] = \begin{bmatrix} 0 & 2 \\ 1 & 0 \end{bmatrix} \tag{21}$$

$$G_{n=2} = \left[g_{n(i,m)}\right] = \begin{bmatrix} 0 & 0 \\ 0 & 2 \end{bmatrix} \tag{22}$$

We assume that 1 unit of any order can be realized by the first tool before the need for replacement arises and 2 units of any orders can be realized by the second tool before the need for replacement arises. This assumption can be simply written by means of vector in the form (23).

$$G^{base} = \left[g_m^{base}\right] = \begin{bmatrix} 1 \\ 2 \end{bmatrix} \tag{23}$$

Moreover, we assume that the tools are brand new which can be written in the form (24).

$$\underset{k=0}{\forall}\ \underset{1\le i\le I}{\forall}\ \underset{1\le m\le M}{\forall}\ \underset{1\le n\le N}{\forall} s^k_{n(i,m)} = 0 \tag{24}$$

The matrixes in the form (25) and (26) specify times to manufacture products of the first and second orders. For example, the matrix (25) indicates that the processing period of the product of the first order is 1 time unit in the first work stand with the use of the second tool and 2 time units in the second work stand with the use of the first tool.

$$T^{pr}_{n=1} = \left[\tau^{pr}_{1(i,m)}\right] = \begin{bmatrix} 0 & 2 \\ 1 & 0 \end{bmatrix} \tag{25}$$

$$T^{pr}_{n=2} = \left[\tau^{pr}_{2(i,m)}\right] = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \tag{26}$$

Replacement times of tools in work stands are given by the vector (27).

$$T^{repl} = \left[\tau^{repl}_m\right] = \begin{bmatrix} 1 \\ 2 \end{bmatrix} \tag{27}$$

The proposed criterion is meant to minimize the total manufacturing time. The strategy remains to realize the elements of the order vector simultaneously if possible.

There are the following algorithms on the basis of which the order vector elements are chosen for realization.

The algorithm of the maximal order chooses the order matrix element characterized by the maximal value γ^k_n. To produce the order z^k_η, $1 \le \eta \le N$ the condition in the form (28) must be met, where $\gamma^k_n = z^k_n$.

$$(q^k_{z_{\max}} = z^k_\eta) \Leftrightarrow \left[\gamma^k_\eta = \max_{1\le n\le N} \gamma^k_n\right] \tag{28}$$

The algorithm of the minimal order chooses the order matrix element characterized by the minimal value γ^k_n. To produce the order z^k_η, $1 \le \eta \le N$ the condition in the form (29) must be met, where $\gamma^k_n = z^k_n$.

$$(q^k_{z_{\min}} = z^k_\eta) \Leftrightarrow \left[\gamma^k_\eta = \min_{1\le n\le N} \gamma^k_n\right] \tag{29}$$

The sequential algorithm chooses products alternately.

Moreover, the following assumptions have to be made:

1) No regeneration process is carried out.
2) Each worn out tool is to be replaced with a new one.
3) There is a sufficient number of tools which are used in the replacement process.
4) $\underset{1\le i\le I}{\forall}\ \underset{1\le n\le N}{\forall} \tau_{n,i\to i+1} = 0$
5) If the whole unit of the order vector cannot be realized fully in the production stand at the *k*th stage with the use of the *m*th tool, then the *m*th tool replacement process is due to be carried out.
6) If possible, operations are carried out simultaneously on condition there are servicing agents to serve each *i*th stand.

The time scaling graphs in the Fig. 2, Fig. 3 and Fig. 4 illustrate how the manufacturing process is carried out with the use of the above algorithms. We assume that the letters represent the discussed times:

a – production process
b – replacement process of the identical *m*th tool
c – exchange of different tools in the *i*th stand

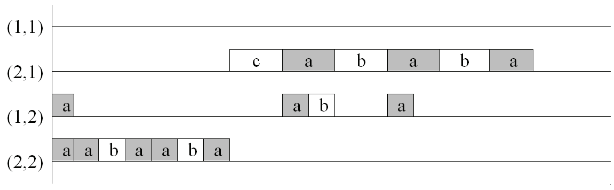

Fig. 2: Time scaling with the use of the algorithm of the maximal order (total manufacturing time T=19)

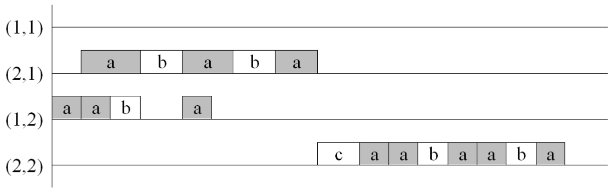

Fig. 3: Time scaling with the use of the algorithm of the minimal order (total manufacturing time T=20)

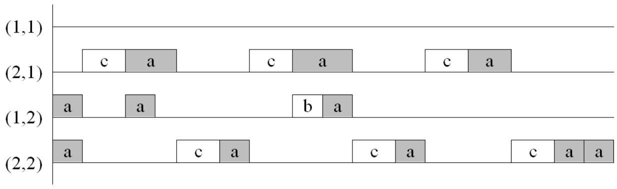

Fig. 4: Time scaling with the use of the sequential algorithm (total manufacturing time T=23)

As seen above, after all necessary calculations, the obtained results prove that for the stated data the total manufacturing time is minimized by the algorithm of the maximal order.

VI. Conclusions

The system presented in the paper hereby shows the general model of the proposed manufacturing structure. It is necessary to make general assumptions which form the base for modeling the synthetic environment representing a highly complex logistic formation. The general model leads to building a specific structure consisting of production stands which are equipped with production tools. To simplify the case we assume that each tool gets worn up throughout the manufacturing process and requires to be replaced immediately. However, a more sophisticated model should be developed to examine replacement as well as regeneration procedures. The use of additional heuristic algorithms may deliver a satisfactory solution. If not, it is possible to implement a combination of algorithms or even draw elements of the order vector for realization. However, this is possible only by means of the simulation method as a big number of simulation experiments should be carried out. The particular advantage of the use of simulated data consists in obtaining a set of data which may deliver the satisfactory solution. The experimental approach, with its emphasis on simulation-based solution seeking, seems to be the only way of finding an acceptable procedure. The proper insight into the nature of the specific problem, the approximations and assumptions, and other relevant modeling and simulation issues may provide the desired simulator. Simulation, and only simulation, takes into account the combined effect of variability, uncertainty, and complex interdependencies between processes. As there are more criteria, it also seems reasonable to verify different two- or more criterion models. Moreover, different criteria are used to evaluate the production process. They can be connected with input or output streams of objects. Appropriate bounds must always associate each criterion. Another aspect worth analyzing is realizing clients' orders continuously, no matter when they appear. This approach seems reasonable as it would lead to avoiding unnecessary delays consisting in waiting for potential customers who would fill the order vector. From the planning point of view it would mean bringing the whole production system to a standstill when the level of orders does not allow for resuming production.

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