LOGISTIC MODELLING OF ORDER REALIZATION IN THE COMPLEX PARALLEL MANUFACTURING SYSTEM

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ABSTRACT

The paper highlights the problem of mathematical modeling of the highly complex manufacturing system in which work stations are arranged serially within each production plant. Production plants are located in a parallel way. The specification details and the model resulting from them led to creating the simulator to be employed to solve the problem of realizing customers' orders. Equations of state are given to illustrate the state of the system at each stage. The complex system is controlled by implementing heuristic algorithms. The criteria to be met are defined. The study case is based on randomly generated data and solved by means of the dedicated information tool. The search for the satisfactory solution is carried out either by an increased number of simulation runs or comparing the pairs or combinations of order and plant choosing algorithms. The main goal remains to meet the stated criterion.

INTRODUCTION

The growth of markets towards globalization results in materialization of automated industries with high performance of manufacturing systems. Traditional manufacturing systems are no longer able to satisfy these requirements. In the global market there is an increasing trend toward achieving a higher level of integration between designed and manufacturing functions in industries to make the operations more efficient and productive (Modrak and Pandian 2012).
Effective organization and management of materials, processes and human resources of a company is a prerequisite in today's highly competitive industrial landscape. Key goals are to improve planning and scheduling of processes, increase productivity, minimize inventory level, improve responsiveness to changes in demand, improve quality, and lower operation cost.
These problems are solvable with the use of modelling and simulation of such production systems. One of the most useful tools in the arsenal of an operations research (industrial engineering) management science analyst consists in computer simulation. In this case it is necessary to put attention to the benefits resulting from combining both spheres, the one of formalized algorithms and the other one of the human instinct (Neumann 2011).
The use of simulation, as a support tool to the operational decision making process, allows us to analyze, from a statistical point of view, the behavior of a production or logistic system that is subject generally to either controllable and or not controllable factors. Through computer simulation it is possible to select those operational decisions that maximize an objective function or a system performance parameter, and to evaluate effects of these decisions without controllable factors variability. An approach to implement efficiently and effectively simulation models in manufacturing systems is deployed in (Chramcov et al. 2011). Currently, a wide range of commercial products which use graphic interfaces (e.g. Arena, Witness, MapleSim 4, AutoMod, Quest, PlantSimulation, etc.) offer an extremely wide spectrum of possibilities for modelling and simulation of manufacturing, logistic and other queuing systems (Rizzoli 2009). Nevertheless, the general language C# has been adopted for creation of our production system simulator because the programming logic cannot be easily expressed in GUI-based systems (Babich and Bylev 1991).
The initial specification and consequent modelling of the discussed manufacturing system is described in detail in (Bucki et al. 2012a). This paper is later expanded to the simulation form enabling us to carry out a simple simulation process (Bucki et al. 2012b). The simulation process shows that one of the suggested heuristics minimizes the total order realization time. However, the need to search for the solution to tasks carried out in the complex manufacturing system with buffer stores leads to extending specification details and the subsequent model which finally forms the basics for the simulation process (Bucki 2012). The simulation process is carried out by means of the simulation tool built on the basis of these specification details and the subsequent model (Marusza 2013).

GENERAL SYSTEM FORMULATION

Let us propose the information system imitating the continuous production process carried out in J work

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stations arranged in a series. We assume that there is a machine in each work station which can perform I operations. However, we assume that only one tool can be determined to perform the operation on the order unit in each work station. We assume there are buffer stores between the work stations. The capacity of each buffer store is limited. Operations are performed in the work stations in sequence. Further, we assume there are more than one identical production systems available. Let us assume that A manufacturing plants are arranged in parallel. This system requires K stages to realize the order elements. The matrix of orders at the k-th stage is considered in the form (1), where $z^k_{m,n}$ is the number of conventional units of the n-th order of the m-th customer at the k-th stage. The stage k, k=1,…,K is the moment of making the production decision.

$$Z^k = \left[z^k_{m,n}\right] ,m=1,...,M;\ n=1,...,N;\ k=1,...,K \tag{1}$$

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

$$z^k_{m,n} = \begin{cases} z^{k-1}_{m,n} - x^k_{m,n} & \text{if the number of units } x^k_{m,n} \\ & \text{is realized at the } k-\text{th stage,} \\ z^{k-1}_{m,n} & \text{otherwise.} \end{cases} \tag{2}$$

Some of the charge materials are used for manufacturing products of the specific order. The assignment matrix of ordered products to charges takes the form (3), where $\omega_{m,n}$ is the number of charge material assigned to the order $z_{m,n}$

$$\Omega = \left[\omega_{m,n}\right] ,\ m=1,...,M;\ n=1,...,N \tag{3}$$

Elements of the assignment matrix take values according to (4).

$$\omega_{m,n} = \begin{cases} l & \text{if the order } z_{m,n} \text{ is realized} \\ & \text{from the } l-\text{th charge,} \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

We also assume that used charge matrix elements are immediately supplemented, which means that we treat them as the constant source of charge material. However, for simplicity reasons, we assume that each n-th order of the m-th customer is made from the universal charge which enables realization of the given element of the order from any l-th charge.

Let h, $(h=1,...,H)$ be the allowable number of regeneration procedures of the tool. If $h=0$, then the i-th tool is subject to replacement. Otherwise, the i-th tool can be regenerated h times.

General structure of the system

Let us introduce the general structure (assignment matrix) in the form (5) for realizing the order $z_{m,n}$ in each manufacturing plant, where the elements of this structure $e_{m,n}(i,j)$ take values according to (6).

$$E_{m,n} = \left[e_{m,n}(i,j)\right] \tag{5}$$

$$e_{m,n}(i,j) = \begin{cases} 1 & \text{if the } i\text{-th tool is able to be used} \\ & \text{in the } j\text{-th workstation in order} \\ & \text{to realize the order } z_{m,n}, \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

Let us define the route vector of orders in the form (7) where $d_{m,n}(j)$ is the number of the tool in the j-th work station to realize the order $z_{m,n}$.

$$D_{m,n} = \left[d_{m,n}(j)\right] \tag{7}$$

If the order $z_{m,n}$ is not realized in the j-th work station then $d_{m,n}(j) = 0$.

Life of the tool

The base life vector of the complex system for a new brand set of tools used to manufacture elements of the order matrix takes the form (8), where $g(i)$ is the base number of units which can be manufactured by the i-th tool before the tool in this station is completely worn out and requires immediate replacement (should there be no active work station, then $g(i)$=-1).

$$G = \left[g(i)\right] ;\ i=1,...,I \tag{8}$$

Let $\Psi(i) = \left[\psi_{m,n}(i)\right]$ be the matrix of conversion factors determining how many units of the order $z_{m,n}$ can be realized with the use of the i-th tool in each work station, $\psi_{m,n}(i) > 0$. If the order $z_{m,n}$ is not realized by the i-th tool at all, then $\psi_{m,n}(i) = -1$.

Let us now define the life matrix for realizing the order $z_{m,n}$ in the form (9), where the life matrix element $g_{m,n}(i)$ is the base number of the order $z_{m,n}$ conventional units which can be realized by means of the i-th tool before the tool is completely worn out. This element takes the values according to (10).

$$G(i) = \left[g_{m,n}(i)\right] \tag{9}$$

$$g_{m,n}(i) = \psi_{m,n}(i) \cdot g(i) \tag{10}$$

Buffers

Let $b_{j,\alpha}$ be the buffer store between the j-th workstation and the workstation $(j+1)$, $(j=1,...,J-1)$ in the α-th manufacturing plant. The capacity of each buffer store is calculated in the number of the ordered semi-products $z_{m,n}$.

Let us introduce now the base capacity matrix of buffer stores in the complex manufacturing system in the form (11), where $gb(j,\alpha)$ is the base capacity of the j-th buffer store in the α-th manufacturing plant

$$Gb = [gb(j,\alpha)] \tag{11}$$

STATE OF THE SYSTEM

The state of the complex system consisting of parallel manufacturing plants (state of their tools) changes after every decision about production of the element $z_{m,n}$ in the α-th manufacturing plant. The state of the i-th tool in the j-th work station in case of the order $z_{m,n}$ manufacturing changes according to (12) where $s^k_{m,n}(i,j,\alpha)$ is the number of conventional units of the order $z_{m,n}$ already realized by the i-th tool in the j-th work station in the α-th manufacturing plant. This element takes the value according to (13) where $x^k_{m,n}(i,j,\alpha)$ is the number of the order $z_{m,n}$ units realized by the i-th tool in the j-th work station in the α-th manufacturing plant at the k-th stage.

$$s^0_{m,n}(i,j,\alpha) \to ... \to s^k_{m,n}(i,j,\alpha) \to ... \to s^K_{m,n}(i,j,\alpha) \tag{12}$$

$$s^k_{m,n}(i,j,\alpha) = \begin{cases} s^{k-1}_{m,n}(i,j,\alpha) - \text{if the order } z_{m,n} \\ \text{is not realized by the } i-\text{th tool} \\ \text{in the } j-\text{th workstation of the } \alpha-\text{th} \\ \text{plant at the } k-\text{th stage} \\ \\ s^{k-1}_{m,n}(i,j,\alpha) + x^k_{m,n}(i,j,\alpha) \quad \text{otherwise} \end{cases} \tag{13}$$

The base state of the i-th tool in the j-th workstation in the α-th manufacturing plant is calculated according to (14).

$$s^k(i,j,\alpha) = \frac{s^k_{m,n}(i,j,\alpha)}{\psi_{m,n}(i)} \tag{14}$$

If in case of another unit of the order $z_{m,n}$ the state of the station is exceeded, it is marked as $s^k_{m,n}(i,j,\alpha) = -1$. It means no unit of any order can be realized in the manufacturing plant and it triggers the need to carry out the replacement process to resume the production in the discussed work station. If the i-th tool has to be replaced with a new one, the state of this tool changes to zero after carrying out the replacement procedure.

If the i-th tool in the j-th work station in the α-th manufacturing plant is not used at the k-th stage, then $s^k_{m,n}(i,j,\alpha) = -1$.

Flow capacity of the system

Let $P^k_{m,n}(\alpha) = [p^k_{m,n}(i,j,\alpha)]$ be the matrix of the flow capacity of the α-th manufacturing plant for the order $z_{m,n}$ realization at the k-th stage where $p^k_{m,n}(i,j,\alpha)$ is the number of conventional units of the order $z_{m,n}$ which still can be realized with the use of the i-th tool in the j-th work station of the α-th manufacturing plant. If the flow capacity of the work station does not allow to realize at least one conventional unit of the order $z_{m,n}$ then $p^k_{m,n}(i,j,\alpha) = -1$. If there is remaining flow capacity in the i-th tool of the j-th work station but the subsequent unit of the order $z_{m,n}$ cannot be realized fully in this station, then the replacement process in this station is carried out automatically.

On the basis of the above assumptions the flow capacity of the i-th tool in the j-th work station of the α-th manufacturing plant for the order $z_{m,n}$ can be determined in the form (15).

$$p^k_{m,n}(i,j,\alpha) = g_{m,n}(i) - s^k_{m,n}(i,j,\alpha) \tag{15}$$

The base flow capacity of the i-th tool in the j-th workstation in the α-th manufacturing plant is calculated according to the form (16).

$$p^k(i,j,\alpha) = \frac{p^k_{m,n}(i,j,\alpha)}{\psi_{m,n}(i)} \tag{16}$$

It is then possible to calculate the total base flow capacity of the α-th manufacturing plant at the k-th stage according to the formula (17).

$$P^k(\alpha) = \sum_{i=1}^{I} \sum_{j=1}^{J} p^k(i,j,\alpha) \tag{17}$$

PRODUCTION TIME

It is possible to define the matrix of production times in the form (18) where $\tau^{pr}_{m,n}(i,j)$ is the time of realization one conventional unit of the order $z_{m,n}$ with the use of the i-th tool in the j-th work station.

$$T^{pr}_{m,n} = [\tau^{pr}_{m,n}(i,j)] \tag{18}$$

If the order $z_{m,n}$ is not realized in the j-th work station with the use of the i-th tool, then $\tau^{pr}_{m,n}(i,j) = -1$.

Throughout the manufacturing process tools get worn out and require replacement. The manufacturing process is brought to a standstill in the work station in which the tool cannot realize any order and, as a consequence, leads to stopping production activities in preceding work stations. For this reason, the replacement is to be carried out as fast as possible.

Let us define the vector of replacement times for the tools in the form (19) where $\tau^{repl}(i)$ represents the replacement time of the *i*-th tool.

$$T^{repl} = \left[\tau^{repl}(i)\right] \tag{19}$$

If the *i*-th tool is not implemented in the production process, then $\tau^{repl}(i) = -1$.

The total manufacturing time of all orders is calculated in accordance with the formula (20) where ΔT is the time during which elements are manufactured simultaneously.

$$\begin{aligned} T = & \sum_{\alpha=1}^{A}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{j=1}^{J} y'(i,j,\alpha)^k \cdot \tau_{m,n}^{pr}(i,j) + \\ & + \sum_{\alpha=1}^{A}\sum_{k=0}^{K}\sum_{i=1}^{I}\sum_{j=1}^{J} y''(i,j,\alpha)^k \cdot \tau^{repl}(i) - \Delta T \end{aligned} \tag{20}$$

The variable $y'(i,j,\alpha)^k$ represents the value indicating realizing one conventional unit of the product $z_{m,n}$ with the use of the *i*-th tool in the *j*-th work station in the *α*-th manufacturing plant at the *k*-th stage and $y''(i,j,\alpha)^k$ represents the value indicating replacement of the *i*-th tool in the *j*-th work station in the *α*-th manufacturing plant at *k*-th stage. Moreover, the variables mentioned above take their values according to the form (21) or (22).

$$y'(i,j,\alpha)^k = \begin{cases} 1 & \text{if realizing the order } z_{m,n} \text{ with the use of the } i\text{-th tool in the } j\text{-th workstation in the } \alpha\text{-th manufacturing plant at the k-th stage is carried out,} \\ 0 & \text{otherwise.} \end{cases} \tag{21}$$

$$y''(i,j,\alpha)^k = \begin{cases} 1 & \text{if the replacement procedure of the } i\text{-th tool in the } j\text{-th work station in the } \alpha\text{-th manufacturing plant at the } k\text{-th stage is carried out,} \\ 0 & \text{otherwise.} \end{cases} \tag{22}$$

CONTROL OF THE SYSTEM

The control of the complex of manufacturing systems consists in implementing heuristic algorithms which choose:

- a manufacturing plant from the set of plants to place the order to be realized
- an order from the matrix of orders Z^k for manufacturing.

There are some heuristic algorithms which can be put forward. The control algorithm of either the maximal or minimal orders and the algorithm of either maximal and minimal flow capacity.

The algorithm of the maximal flow capacity of the production plant

This algorithm chooses the *α*-th manufacturing plant for order realization on condition that it is characterized by the maximal coefficient $\xi^k(\alpha) = \sum_{i=1}^{I}\sum_{j=1}^{J} p_{m,n}^k(i,j,\alpha)$. To determine the *λ*-th manufacturing plan, where $1 \le \lambda \le A$, the condition (23) must be met, where $\xi^k(\lambda) = \xi^k(\alpha)$.

$$\left[q_{\max}^k(\alpha) = \xi^k(\lambda)\right] \Leftrightarrow \left[\xi^k(\lambda) = \max_{1\le\alpha\le A} \xi^k(\alpha)\right] \tag{23}$$

The algorithm of the minimal flow capacity of the production plant

This algorithm chooses the *α*-th manufacturing plant for order realization on condition that it is characterized by the maximal coefficient $\xi^k(\alpha) = \sum_{i=1}^{I}\sum_{j=1}^{J} p_{m,n}^k(i,j,\alpha)$. To determine the *λ*-th plant for order realization, where $1 \le \lambda \le A$, the condition (24) must be met, where $\xi^k(\lambda) = \xi^k(\alpha)$.

$$\left[q_{\min}^k(\alpha) = \xi^k(\lambda)\right] \Leftrightarrow \left[\xi^k(\lambda) = \min_{1\le\alpha\le A} \xi^k(\alpha)\right] \tag{24}$$

The algorithm of the maximal order

This algorithm chooses the order matrix element characterized by the maximal value $\gamma_{m,n}^k$. To produce the order $z_{\mu,\eta}^k$, $1 \le \mu \le M$, $1 \le \eta \le N$ the condition in the form (25) must be met, where $\gamma_{m,n}^k = z_{m,n}^k$.

$$(q_{z_{\max}}^k = z_{\mu,\eta}^k) \Leftrightarrow \left[\gamma_{\mu,\eta}^k = \max_{\substack{1\le m\le M \\ 1\le n\le N}} \gamma_{m,n}^k\right] \tag{25}$$

The algorithm of the minimal order

This algorithm chooses the order matrix element characterized by the minimal value $\gamma^k_{m,n}$. To produce the order $z^k_{\mu,\eta}$, $1 \le \mu \le M$, $1 \le \eta \le N$ the condition in the form (26) must be met, where $\gamma^k_{m,n} = z^k_{m,n}$.

$$(q^k_{z_{\max}} = z^k_{\mu,\eta}) \Leftrightarrow \left[\gamma^k_{\mu,\eta} = \min_{\substack{1\le m\le M \\ 1\le n\le N}} \gamma^k_{m,n} \right] \qquad (26)$$

It is possible to use some manufacturing criteria for evaluation of used control algorithms. In this case, the total order realization time, the lost capacity due to the unavoidable replacement, the remaining capacity at the K-th stage and the total tool replacement time criterion are put forward.

CASE STUDY WITH THE USE OF THE SIMULATOR

The simulator of the general manufacturing system was created on the basis of the assumptions described above. The discussed simulator was created with the use of C# environment and it is used for simulating of the dedicated production system.

The simulator is the synthetic representation of the potential real system so the data must be given on condition they match the real ones. During the simulation process operations are analogous to the ones which are carried out in the real system. It is possible due to the fact that special methods were elaborated. These methods are responsible for moving elements between work stations, replacement of tools and carrying out production operations on semi-products. There are also methods responsible for directing orders to manufacturing plants. These methods use either heuristic algorithms or a random choice of orders. The whole process is carried out in a loop as long as all order matrix elements are completely realized and moved to the store of ready products.

Results and a production timescale in a graphic form for all manufacturing plants are presented after completing the simulation process. Simulation results are consequently used for the evaluation of used heuristic control algorithms.

Definition of the specific production system

The case study assumes that the complex production system consists of 3 identical manufacturing plants arranged in parallel. Each plant consists of 5 work stations arranged in a series. There are 5 tools that can perform dedicated operations in each work station. The tools cannot be regenerated. Four customers set orders to be realized by the production system. The number of conventional units of the orders for each specific customer is specified in the matrix (27).

$$Z^0 = \begin{bmatrix} 240 & 2900 & 0 & 170 \\ 380 & 0 & 150 & 740 \\ 0 & 810 & 0 & 210 \end{bmatrix} \qquad (27)$$

We assume that the charge is universal and each buffer store is inactive for this set of data. The orders are realized in accordance with the route vectors presented in the form (28).

$$D = \begin{bmatrix} \{1,2,4,3,5\} & \{2,1,3,5,4\} & \{0,0,0,0,0\} & \{2,4,1,3,5\} \\ \{3,2,1,5,4\} & \{0,0,0,0,0\} & \{4,2,1,3,5\} & \{2,1,4,5,3\} \\ \{0,0,0,0,0\} & \{5,2,1,3,4\} & \{0,0,0,0,0\} & \{2,4,1,5,3\} \end{bmatrix} \qquad (28)$$

The base life vector for a new brand set of tools is given in the form (29) and the matrixes of conversion factors for all tools are specified according to (30).

$$G = [120,80,50,40,30] \qquad (29)$$

$$\Psi(i) = \begin{bmatrix} 1 & 2 & -1 & 3 \\ 2 & -1 & 1 & 1 \\ -1 & 2 & -1 & 5 \end{bmatrix}, \quad i = 1,\dots,5 \qquad (30)$$

The times of realization of one conventional unit of the order $z_{m,n}$ in each j-th workstation with the use of determined tools (according to the route matrix) are defined in the vectors (31).

$$\begin{aligned} &T^{pr}_{1,1} = [23,54,10,15,21], T^{pr}_{1,2} = [23,37,42,26,33], \\ &T^{pr}_{1,4} = [18,23,31,34,42], T^{pr}_{2,1} = [39,41,45,16,49], \\ &T^{pr}_{2,3} = [16,19,21,11,27], T^{pr}_{2,4} = [11,12,20,17,13], \\ &T^{pr}_{3,2} = [10,16,15,22,30], T^{pr}_{3,4} = [14,27,20,35,40], \end{aligned} \qquad (31)$$

The vector of replacement times of tools is defined in the form (32).

$$T^{repl} = [15,13,9,5,26] \qquad (32)$$

Results of the simulation

The simulation is to be run for some initial values of state of tools and for the discussed control algorithms. Firstly, a random choice of orders and manufacturing plants was used. The random choice was carried out 1000 times. The best results are shown for 10, 100 and 1000 simulations. Consequently, the orders were realized by means of 4 pairs of heuristic control algorithms.

The following control algorithms are implemented:

– the control algorithm of the maximal order [$\hbar$(max)],
– the algorithm of the minimal order [$\hbar$(min)],

– the algorithm of the maximal flow capacity of the production plant [ƛ (max)],
– the algorithm of the minimal flow capacity of the production plant [ƛ (max)].

Some manufacturing criteria are used for evaluation of the implemented control algorithms The results of the simulation for these manufacturing criteria are shown in the following tables. Table 1 presents the results of the total order realization time; the values of the lost capacity due to the unavoidable replacement are shown in Table 2. The values of the left capacity at the *K*-th stage are presented in Table 3. Table 4 shows the values of the total tool replacement time. The minimal or maximal values for each initial value of the state of tools are highlighted.

Table 1: The values of the total order realization time for used control algorithms

Control algorithm		Initial value of tool wear			
		0%	20%	40%	60%
Random choice (number of simuations)	1	137965	139948	134170	148617
	10	122570	122780	122780	122780
	100	122570	122780	122780	122780
	1000	122570	122780	122780	122780
ħ(max) & ƛ (max)		122570	122780	122780	122780
ħ(min) & ƛ (max)		146665	146703	146733	146631
ħ(max) & ƛ (min)		122570	122780	122780	122780
ħ(min) & ƛ (min)		146665	146703	146733	146631

Table 2: The values of the lost capacity due to the unavoidable replacement for used control algorithms

Control algorithm		Initial value of tool wear			
		0%	20%	40%	60%
Random choice (number of simuations)	1	0,00	0,67	1,33	0,67
	10	0,00	0,33	0,33	0,33
	100	0,00	0,00	0,00	0,00
	1000	0,00	0,00	0,00	0,00
ħ(max) & ƛ (max)		0,00	0,00	0,00	0,00
ħ(min) & ƛ (max)		0,33	0,33	0,33	0,33
ħ(max) & ƛ (min)		0,00	0,00	0,00	0,00
ħ(min) & ƛ (min)		0,33	0,33	0,33	0,33

Table 3: The values of the remaining capacity at the *K*-th stage for used control algorithms

Control algorithm		Initial value of tool wear			
		0%	20%	40%	60%
Random choice (number of simuations)	1	1981,67	1829,00	1596,33	1235,00
	10	2141,67	1919,33	1627,33	1205,33
	100	2141,67	2039,67	1677,67	1285,67
	1000	2181,67	2039,67	1677,67	1355,67
ħ(max) & ƛ (max)		2111,67	1919,67	1677,67	1205,67
ħ(min) & ƛ (max)		1981,33	1879,33	1677,33	1205,33
ħ(max) & ƛ (min)		2111,67	1919,67	1677,67	1205,67
ħ(min) & ƛ (min)		1981,33	1879,33	1677,33	1205,33

Table 4: The values of the total tool replacement time for used control algorithms

Control algorithm		Initial value of tool wear			
		0%	20%	40%	60%
Random choice (number of simuations)	1	4698	4886	4996	5042
	10	4796	4952	5028	5017
	100	4793	4969	4844	5030
	1000	4745	4835	4814	4965
ħ(max) & ƛ (max)		4786	4869	4864	4941
ħ(min) & ƛ (max)		4704	4850	4833	4918
ħ(max) & ƛ (min)		4786	4869	4864	4941
ħ(min) & ƛ (min)		4704	4850	4833	4918

The results show that the defined manufacturing system should be controlled by means of the algorithm of the maximal order. If the minimal value of the total tool replacement time is to be prioritized, it is possible to use the algorithm of the minimal order.

On the other hand, the use of the control algorithm of either maximal or minimal flow capacity does not have any impact on the final results. The results also show that to find a good solution, it is advisable to use the method of the random choice of orders and manufacturing plant. Better results were achieved already in 100 simulation runs than in case of implementing pairs of heuristic algorithms.

CONCLUSION

The specification and the subsequent model of the complex manufacturing system were verified by the goals formulated in the case study. In case of the time minimizing criterion as well as the lost capacity due to the unavoidable replacement, the simulation approach (random choice) does not show any improvements. The simulator returns other data for the lost capacity, the remaining capacity at the *K*-th state and the total tool replacement time. However, if there is one big order, in our case $z_{1,2}^{0} = 2900$, then it is very unlikely to obtain a better result in terms of meeting the criterion of time minimizing, so carrying out a bigger number of simulations does not seem reasonable. Generally, as seen in the tables with results, there is a need to carry out simulation runs because in this way it is possible to find better results in accordance with the stated criterion. In our case, better results were achieved for the remaining pass capacity at the *K*-th stage and the total tool replacement time than in case of realizing orders by means of pairs of heuristic algorithms. Nevertheless, if the order matrix is modified, simulation runs should be carried out again in order to seek for the satisfactory solution, better than in case of implementing pairs of heuristic algorithms.

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