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Modelling of production processes with the use of witness simulator

Modelowanie procesów produkcji z wykorzystaniem symulatora witness

Abstract

Customization of final products forces the so-called "make-to-order" production. In the article, there is a presentation of influence of EPEI changes (Every Part Every Interval indicator) on the efficiency and effectiveness of complex production system. The use of Witness System Simulation Modeling helped to create the model of real object which has been validated in the real work parameters. All of the times of the realized processes have been simulated as random variables with certain density of probability distribution

Keywords: scheduling of the tasks, multi-objective optimization

Streszczenie

Customizacja wyrobów finalnych wymusza produkcję na zasadach make - to - order. W artykule przedstawiono wpływ zmiany wskaźnika EPEI na zmiany wydajności i efektywności złożonego systemu produkcyjnego. Z wykorzystaniem programu Witness System Simulation Modeling opracowano model obiektu rzeczywistego, który następnie został poddany walidacji w zbieżnych z rzeczywistością parametrów pracy. Wszystkie czasy realizowanych procesów zostały w programie Witness zasymulowane jako zmienne losowe o właściwych dla siebie gęstościach rozkładu prawdopodobieństwa.

Słowa kluczowe: harmonogramowanie zadań, optymalizacja wielokryterialna

1. Introduction

Optimization of production processes is one of the most important problems in terms of production. In the production systems, there are multi-criterial and multi-dimensional optimizations. Optimization functions and certain restrictive criteria often vary in some slots (nests) of production stream. In many cases it is a problem of NP – hard [1]. The level of difficulty is caused by the dynamics of changes in statuses of production system, and also by the complexity of particular production system. Dynamics of changes is strictly dependent and connected with changeable environment of the system (like for example: competitors, changes of clients' needs, changes of deliverers, changes of global law regulations). The complexity of production system is affected by the number of active processes, amount of production positions, quality requirements of the process and/or product and also materials which have been used. In changeable conditions, success of the enterprise is caused by its elastics and ability of adapting to a new situation quickly [2, 3]. Frequent changes of statues in the production system impose usage of methods which enable available solutions (which are not always optimal). The use of heuristic algorithms sometimes helps to indicate solutions which are "good enough".

In the article, there is a presentation of results of the practical use of Witness System Simulation Modelling IT tool from Lanner Group Ltd. The first phase of the model was to identify flow streams and random variables of the times of the process realization in the real object and analyze the similarities between model's parameters. Due to the dependency of many random variables, in the next phase there was multiple validation of the real model executed to reveal representative measurements. There was an interval of trustfulness of 80% set for the results. The achieved results have been named as parameters of the current status and their average values for chosen machines have been presented in Table 1. Based on the analysis of differences of orders there was EPEI set – it was the main parameter of changes for creating extension of efficiency. Table 2 presents average values of parameters of work for chosen machines with EPEI multiplied by two. The results were achieved for the upcoming state of variety of stochastic processes. Analyses of all work's model variants are meeting requirements of stability of processes and "lack of memory". In case of the analysis of the flows – there is a need to meet the requirement of stream singularity (variant of $\Delta t \rightarrow 0$ has been excluded) in one device.

2. Definition of models and stream flows

To maximize the flexibility of production system in comparison to variables of client's orders – the processes in a considered system should be optimized with the use of the function of minimizing the time which is needed to complete the order. The amount of time which is needed to complete the order is the so called entire lead time of the order (LTO). It is possible to achieve minimal amount of the entire lead time of the order (LTO) through effective scheduling of the tasks [4]. The analyzed example is a convergent structure of serial-parallel production system. In this type of system – optimization of tasks depends on a few different parameters, such as process, resources (machines and people), materials which empower the system, position of the process in the value stream in comparison to the "narrow throat" and shipment (end of the process) [5, 6]. Moreover, optimization of complex production system depends on the quality of the process, quality of production and also quality of input materials [7]. In such a complex structure, production system has been divided into a group of sub-systems, according to the general theory of complex systems [8, 9]. After that, certain optimization function has been created for all of the extracted sub-systems (to minimize the final time of operations in those extracted sub-systems).

The function of density of realization time probability for consecutive operations has been formulated as a sum of individual times (τ) for the extracted process on certain levels. Optimization in hierarchic production structure is about shaping certain indicators which characterize certain level (sub-system). Complex optimization of the production system should be done based on a weighted mean of particular indicators in a designated sub-system (with an adjustment of certain meaning of particular parameter for the functions of the whole system) [10]. That is why the function of density of realization time probability of consecutive operations is as follows:

$$T_j = \sum_{i=1}^{n} a_i t_{j,i} \quad \forall \quad j = 1,2,\ldots,m \wedge i = 1,2,\ldots,n \tag{1}$$

where T_j is a random variable which describes the whole amount of time for the realization of the processes for j – stream of the value; a_i – weight of the influence of the realization process for the whole time of change, where in every single path of change; n – amount of necessary operations in j – value stream; $t_{j,i}$ – random variable which sets the realization time for the data set necessary to execute all the tasks. Moreover, $t_{j,i} \sim$ Erlanga $(k, \lambda_{j,i})$, where k=2,3,.., l for $2 \leq l \leq 20$, k – is a parameter which sets a digit from the same semi-product; $\lambda_{j,i}$ is a parameter of exponential assignment which is caused by the independent time of realization of i production process for single semi-product; $t_{j,i}$ – time of realization of k operations in i process. Random variable t_i has been assigned based on formula (2):

$$t_{j,i} = \tau_{j,i,1} + \tau_{j,i,2} + \ldots + \tau_{j,i,k} \tag{2}$$

where: $\tau_{j,i,1}, \tau_{j,i,2}, \ldots, \tau_{j,i,k}$, – random variables which asset the time of realization for a single task, which is caused by the k of orders [11]. Moreover, $\tau_{j,i,k} \sim$ Exp ($\lambda_{j,i}$). So the density of random variable $t_{j,i}$ is as follows:

$$f_{t_{j,i}}(\tau) = \sum_{k=2}^{l} \frac{\left(\lambda_{i,j}\right)^k \cdot \left(\tau_{i,j,k}\right)^{k-1} \cdot e^{-\lambda \cdot \tau_{i,j,k}}}{(k-1)!} \tag{3}$$

In the article, there was great dynamics of changes of the systems' statues established. It is caused by differences in client's orders $t_{j,i} \sim$ Erlang $(k, \lambda_{j,i})$ for k=1, has been skipped, because there will be a different result due to the fact of Erlang's distribution: $t_{j,i} \sim$ Exp ($\lambda_{j,i}$) [12, 13]. Then, random variable T_j which defines the whole amount of time for realizing the order will be a sum of independent random variables with different $\lambda_{j,i}$ parameters [16].

The complexity of the scheduling process is affected by the amount of machine resources with the same attributes. The term "machine's attribute" means its ability to execute certain production task. In the analyzed production system there are two different tasks: 1) dividable and 2) undivided with priority of operation. In both there are different criteria of optimization [3].

Elementary criterion of optimization for dividable alignment is minimal time of ending of the process for the necessary system for the tasks [3].

$$t_{j,i} = \sum_{k=2}^{l} \tau_{j,i,k} \rightarrow \min \quad \forall \quad 2 \leq l \leq 20 \tag{4}$$

where: $t_{j,i}$ ~ Erlanga $(k, \lambda_{j,i})$ – set random variable of the time of realization of the system necessary to execute k tasks in i – process of j stream, $\tau_{j,i,k}$ ~ Exp $(\lambda_{j,i})$ – random variable of single k – task in i – process of j – stream.

In the case of undivided alignment, the criterion for optimization is aligning the tasks to achieve minimal value of the weighted mean of the flow time [3].

$$\overline{t^*} = \sum_{i=1}^{n^*} b_i \cdot t_{j,i} \rightarrow \min \tag{5}$$

where: – weighted mean of the change's time of i^* processes with indivisible tasks for j – production stream.

In processes or production sockets of the realization time which is lower than maximal time which is available for value stream – there is a possibility to use aligned algorithms of random limits of the order. In this case, there is a need of meeting the criteria for the stream not to be critical (which do not determine the lead time of order LTO). Moreover, in the case of randomization of the alignment there is a need of the following situation:

$$\tilde{T}_j < T_{\max} \tag{6}$$

where $\tilde{T}_j$ – random variable which defines the time of change of j path of the random alignment of the tasks; T_{max} – random variable which defines maximal time of change which is a critical path for the data set which is necessary for executing the tasks.

3. Modelling with the use of Witness Simulator

Effective and efficient use of the procedure of scheduling of complex system tasks has to be supported by IT tools. Verification of ideas and proposals of improvements of the complex production system on the real object is risky and often ineffective [14]. That is why a lot of actions are first validated with the use of simulators. Results achieved after the use of IT tools have an impact on decision of implementation of the verified solution. Often simulators help with decision making process in current tasks.

The convergent production system aforementioned in the article was produced in a Witness System Simulation Modeling simulator (from Lanner Group Ltd.). Due to the individual character of the production, the system is not a deterministic model. All the times of the processes are presented with the use of exponential alignment. For each and every time, real data was gathered and then optimal λ_i was assigned. A critical path was analyzed. It determines the time of realization of customer's orders. Picture 1 presents a print screen of the production system which was created in Witness software.

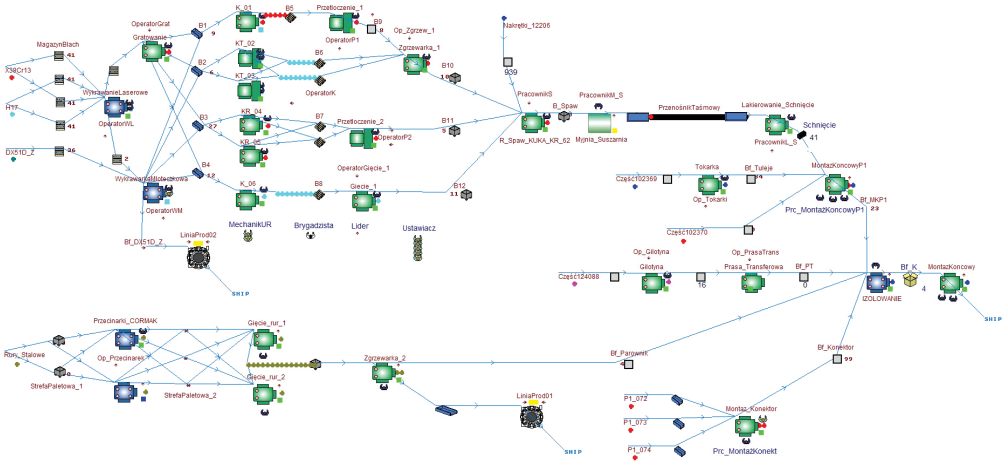

Fig. 1. Layout of the modelled production system

To conduct proper validation of this production system and assign acceptable parameters of work and possible areas of development, there is a need to model the system in IT environment which is the most realistic. Whilst modelling convergent system, it is important to concentrate on proper elaboration of the relation between the objects (machines). Then, parameters of shaping of the intensity of flow stream between the objects were set and also priorities of elementary tasks were presented. The final step was about conducting validation of work of the modelled system. Based on the results, solutions were presented. The final result of the project was to estimate attractiveness of potential implementation of improvements to achieve effectiveness for the future status.

4. Results of the modelled object's simulation

Analysis of the modelled production system was done for the simulation time (t_{sym}) which was equal to two weeks of work in the mode of two changes: t_{sym} = 9600 minutes. In this time two tasks of time around 22.500 of workhours for each production socket were executed. After taking into consideration losses after lack of quality, the number of final products were set.The amount of created products for different groups was around 390. Taking into consideration variability of need, the EPEI (Every Path Every Interval) indicator was set (around

1.78 stock). For the aforementioned parameters, a model of validation was conducted. Table 1 presents results of chosen machines of the modelled system before adding adjustments. For the parameters of the actual system, some adjustments were set, which were simulated as upcoming state. Then, a comparison of the results from the current and upcoming states was conducted.

Table 1. Results of the modelled object simulation – current state

Name	$M_{1,1}$	$M_{1,2}$	$M_{2,1}$	$M_{2,3}$	$M_{2,5}$	$M_{2,6}$	M_5	M_6
Idle time %	0	0	35,5	12,9	0,8	3,8	10,1	11,3
Work time %	95,2	24,3	43,6	72,4	84,2	85,6	81,6	86,8
Blocking time %	0	0	0	3,6	9,5	1,5	1,9	0
Wait for worker %	0,2	3,8	0	0	0	0	0	0
Set up %	4,1	70,6	19,4	10,3	4,9	6,8	6,2	1,9
Breakdown %	0,5	1,3	1,5	0,8	0,6	2,3	0	0
Repair–wait for worker %	0	0,3	1,2	0,1	0,3	0,4	0	0
Number operations	11,877	2457	5834	6032	5936	4731	15,793	6769

The assumption of the changes was to shorten the whole time of realization of a single order (LTO) in the enterprise. The target was to be achieved by minimizing the sum of time which do not add the value of NVAT (Non Value Added Time). Those changes extended EPEI – Every Part Every Interval twice to the value of 3.6 stock and effectiveness in aspect of time sorting of the order of the executed tasks in critical stream. All of the semi-products of the critical path which were extracted by the PERT method were assigned with highest priorities. Table 2 presents the results after adding adjustments.

Table 2. Results of the modelled object simulation – upcoming state

Name	$M_{1,1}$	$M_{1,2}$	$M_{2,1}$	$M_{2,3}$	$M_{2,5}$	$M_{2,6}$	M_5	M_6
Idle time %	0	0	27,2	11,3	0,3	3,2	0,2	9,9
Work time %	96,8	37,8	56,1	75,5	88,4	88,7	90,4	88,7
Blocking time %	0	0	0,1	4,2	7,8	0,1	2,7	0
Wait for warker %	0	2,7	0	0	0	0	0	0
Set up %	2,9	57,4	15,7	7,8	3,2	6,3	6,7	1,4
Breakdown %	0,3	2,1	0,9	1,2	0,3	1,7	0	0
Repear–wait for warker %	0	0,5	0,1	0	0	0,1	0	0
Number operations	12,144	3789	7497	6307	6237	4897	16,132	6923

Devices $M_{1,1}$ and $M_{1,2}$ execute processes of cutting 1 – laser and 2 – hammer; $M_{2,1}$, $M_{2,3}$, $M_{2,5}$, $M_{2,6}$ – the group of edge press of the same attributes but different parameters. It realizes the process of curving with dividable sorting; M_5 and M_6 realize processes of varnishing and isolating in which appears coupled, undividable sorting of tasks and flows of random order of semi-product creation.

5. Conclusion

Optimization of complex production systems which carry certain tasks is a difficult process. In this kind of system (with overwhelmed sub-systems and with underload of the other systems), improvement of efficiency and productivity is possible only with the use of IT tools. Without special software it is impossible to achieve acceptable parameters of work. In the production process there are about 600 different kinds of final products. Production process is customized and dedicated to only one client at the same time. Due to a great variety of final products, there is no "stockroom" production. There are about 450 to 650 different subsystems which make one final product. About 15% of these are components delivered by the suppliers. The components are not processed in the production process. These are only edited in certain steps of the production process. The rest of 85% are the elements which are produced whilst analyzing system of stocks.

In the article, there is an attempt of real modelling of convergent production system with the use of Witness Simulation. Assumptions in the modelled system were about maximization of the executed tasks with the minimization of stoppages of machines. The production part was extended to maximize EPEI – Every Part Every Interval indicator. Extension of the indicator led to the extension of the usage of devices and extension of executed tasks. It is important to remember that the simulated solution led to the shortening of LTO time from the enterprise's position. However, with the extended production part in the MTO structure – "make-to-order" is the average time of waiting for the finalization of the order. If there are a few criteria for the same system, it is impossible to assign the optimal solution which will meet the criteria of a few different functions of the final aim. Heuristic approach enables assigning methods and principles in elaborating parameters of the work.

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