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MODELLING AND SIMULATION OF PRODUCTION FLOW IN JOB-SHOP PRODUCTION SYSTEM WITH ENTERPRISE DYNAMICS SOFTWARE

Abstract

The paper presents capabilities of Enterprise Dynamics software in modelling and simulation of production process in job-shop conditions. The modelled production process was conducted on the total of 8 machine tools representing 5 different types. The conducted simulation represented production of three types of parts in an alternating sequence of jobs according to the technological machine sequence. The production process of the developed model was controlled by means of 4D Script programming language.

1. INTRODUCTON

The challenges of the modern market, such as global competition, demand from an enterprise constant effort towards increasing the effectiveness of production processes. There is an ongoing pressure on both established and newly designed production systems to reconcile highly flexible production of a wide range of goods and simultaneously ensure optimised engagement of the stock of machine tools (Esmaeilian, Behdad & Wang, 2016).

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Because of the great variety of existing manufacturing system structures as well as different assumptions and limitations concerned with manufacturing orders, it is very difficult to find the optimal solution using mathematical models. Most of the combinatorial optimization problems are NP-hard. Therefore, implementation of computer simulation methods to analyze the behaviour of individual systems enables obtaining interesting results over a relatively short period of time (Kłos & Trebuna, 2017).

Modelling and simulation is one of the most proper ways to deal with solutions based on the experience from the real-world complex systems (Longo, 2010). Many scientific papers include the application of computer simulation in the general design of manufacturing systems in the analysis of operational, production planning and scheduling systems (Negahban & Smith, 2014). Jahangirian *et al.* report the results of a review of the applications of simulations, published in peer-reviewed literature between 1997 and 2006 and the analysis of the role of simulation techniques within manufacturing and business (Jahangirian, Eldabi, Nasser, Stergioulas & Young, 2010). Jagstam and Klingstam use discrete event simulation as an aid to conceptual design and the pre-study of manufacturing systems through developing a virtual factory and identify the problems associated with integration of discrete event simulation into the design and manufacturing systems (Jagstam & Klingstam, 2002). Jithavech and Krishnan present a simulation-based method in order to develop and efficient layout design facility with uncertainty as to the demand of the product (Jithavech & Krishnan, 2010). Yang *et al.* propose the use of simulation and a digital factory to construct a virtual plant environment in order to implement integration between process planning and manufacturing (Yang, Zhang, Chen & Li, 2008). Joseph and Sridharan made an evaluation of the routing flexibility of an FMS with the dynamic arrival part types for processing (Joseph & Sridharan, 2011) while Gola *et al.* used the computer simulation method to analyze economic effectiveness of manufacturing system configurations (Danilczuk, Gola & Cechowicz, 2014; Gola & Świć, 2014).

In general, computer simulation methods are mostly used in maximisation of the throughput of production lines. The problem of maximizing the throughput of production lines by changing buffer sizes or locations using simulation methods was studied by Vidalis *et al.* (Vidalis, Papadopoulos & Heavy, 2005). Stanley and Kim presented the results of simulation experiments carried out for buffer allocations in closed, series-production lines (Stanley & Kim, 2012). The overview of the critical literature in the area of buffer allocation and production and production line performance was done by Demir, Tunali and Eliiyi (Demir, Tunali & Eliiyi, 2014). Finally a lot of research in the field of throughput analysis and optimization of serial and automatic production lines were done by Kłos *et al*. (Kłos & Patalas-Maliszewska, 2015; Kłos, Patalas-Maliszewska & Trebuna, 2016; Kłos & Trebuna, 2015).

In this article, computer simulation methods are used to analyze production flow in a job-shop manufacturing system. The research was performed on a production system including 8 CNC machine tools representing 5 different types. The conducted simulation represented production of three types of parts in an alternating sequence of jobs. The material flow was directed to individual machines following established technological machine sequence. The production process of the developed model was controlled by means of 4DScript programming language.

2. A SIMULATION MODEL OF A JOB-SHOP PRODUCTION SYSTEM

The model of the production system was prepared on the basis of an existing example of a manufacturing system, dedicated to the production of casing parts for the machine building sector. The model and simulation experiments were implemented using Enterprise Dynamics Software (version 7.0.0). The following constraints of the model were introduced:

– The analysed production system consists of 5 types of CNC machine tools, the total number of which is shown in Table 1 below.

Tab. 1. The number of machine tools

Machine tool name	The number of machine tools in the system
MACHINE TOOL_1	1
MACHINE TOOL_2	2
MACHINE TOOL_3	1
MACHINE TOOL_4	1
MACHINE TOOL_5	3

– The system produces three different casing parts, the average annual demand for which is show in Table 2.

Tab. 2. Average annual demand for body parts products in the system

Part	Average annual demand
PRODUCT_1	2030 pcs
PRODUCT_2	2420 pcs
PRODUCT_3	1750 pcs

– The machining is realised according to the technological machine sequence, at the time specified by the ratefixer technologist and shown in Fig. 1.

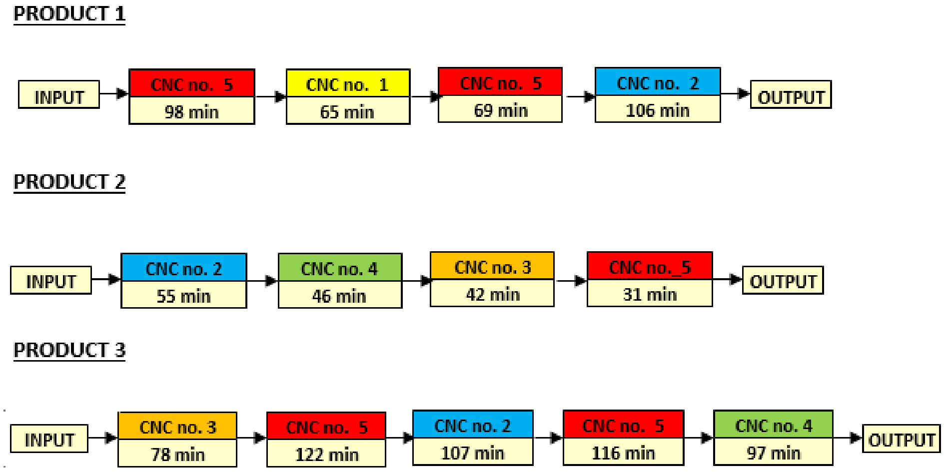

Fig. 1. Technological processes of parts processed in the system

- Input of products corresponds to the time-varying demand and is random both at the input time and the output of the system.
- Machining is carried out according to FIFO principle. In the case of identical machine tools, the product is randomly assigned to a free machine tool.
- The simulation time was specified at 8094 h, which corresponds to effective annual time of system operation.
- To enable simulation of job queue the work-in-progress stores were defined for each machine tool individually, and the storage space was constricted to 20 pcs.
- According to the study assumptions, the layout of machine tools is random, and the works transport is set to zero, as both these issues fall out of the scope of the study.

The developed production system models are shown in Fig. 2 (a basic model), and Fig. 3 (a model with channels connecting objects indicated). Products – workpieces were marked with dots of three different colours. Also implemented into the model were *Lock atoms*, which allow only a pre-defined number of products through (according to the demand) to be processed.

To represent the random character of processing products arrival times the *Uniform* function was employed. The function specifies the random *Inter-arrival time* for particular products as: Product_1: *Uniform(Mins(0), Mins(470))*, Product_2: *Uniform(Mins(0), Mins(390))*, Product_3: *Uniform(Mins(0), Mins(540))*. The average product arrival time was dictated by the effectiveness of the system operation time and the production programme, at the constraint that the last product must not arrive after the 5 days until the end of the year.

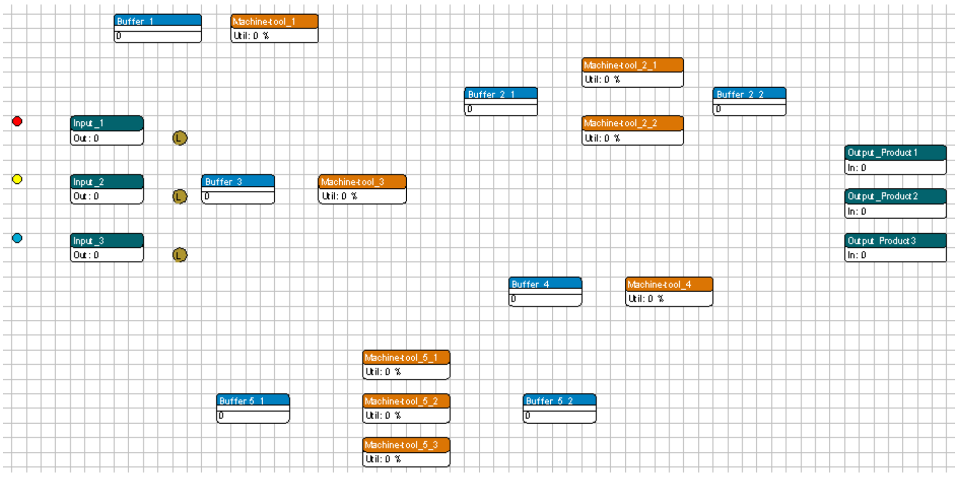

Fig. 2. Basic job-shop system modelled with Entreprise Dynamics system

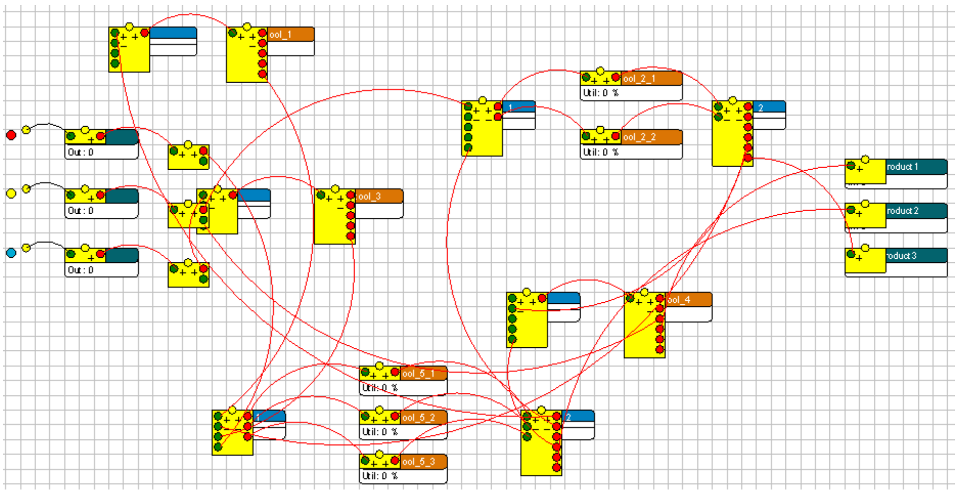

Fig. 3. The job-shop system modelled Enterprise Dynamics software including channels between objects

Since each product is characterised by different processing times on different machine tools and machine routes (governed by the technological process), 4DScript syntax was employed to define times and machine routes. The code created to control the process was developed, whose structure is shown in Tab. 3.

Tab. 3. The structure of scripts controlling the production process in the model

Type of object	Script
PRODUCT (an example of Product_1)	Trigger on exit: `Do (SetLabel([Time1],Mins(98),i), SetLabel([Time2],Mins(65),i), SetLabel([Time3],Mins(69),i), SetLabel([Time4],Mins(106),i), SetLabel([Machine2],1,i), SetLabel([Machine3],5,i), SetLabel([Machine4],2,i),SetLabel([Machine5],6,i), SetLabel([Canal],5,i), SetLabel([Step],1,i))`
BUFFER (an example of Buffer 3)	Trigger on exit: `Do (SetLabel([Canal], Case(Label([Step],i), Label([Machine2],i), Label([Machine3],i), Label([Machine4],i), Label([Machine5],i), Label([Machine6],i)),i))`

MACHINE TOOL (an example of Machine_3)	Cycletime:
	`Case(Label([Step],i),Label([Time1],i), Label([Time2],i), Label([Time3],i), Label([Time4],i), Label([Time5],i))`
	Trigger on exit:
	`Do (SetLabel([Step],Label([Step],i)+1,i))`

3. RESULTS OF SIMULATION AND DISCUSSION

The production model analysed in this paper is nondeterministic, therefore having specified the parameters and constraints, 20 simulations of the model were carried out. The results from the simulations are presented in tables 4–6.

Tab. 4. Numbers of input and output products in the system

Simulation No.	Input products			Output products			Production finished?
	PR_1	PR_2	PR_3	PR_1	PR_2	PR_3	
1.	2030	2420	1750	2030	2420	1750	YES
2.	2027	2420	1750	2026	2420	1750	NO
3.	2030	2420	1750	2030	2420	1750	YES
4.	2030	2420	1750	2030	2420	1750	YES
5.	2030	2420	1750	2030	2420	1750	YES
6.	2030	2420	1750	2030	2420	1750	YES
7.	2030	2420	1750	2030	2420	1750	YES
8.	2030	2420	1750	2030	2420	1750	YES
9.	2030	2420	1750	2030	2420	1750	YES
10.	2025	2420	1750	2023	2420	1750	NO
11.	2030	2420	1750	2030	2420	1750	YES
12.	2030	2420	1750	2030	2420	1750	YES
13.	2030	2420	1750	2030	2420	1750	YES
14.	2002	2420	1750	2000	2420	1750	NO
15.	2030	2420	1750	2030	2420	1750	YES
16.	2030	2420	1747	2030	2420	1745	NO
17.	2030	2420	1750	2030	2420	1750	YES
18.	2030	2420	1750	2030	2420	1750	YES
19.	2030	2420	1750	2030	2420	1750	YES
20.	2030	2420	1750	2030	2420	1750	YES

Tab. 5. Average machining times in the simulated process

Simulation No.	Average machining times							
	MT_1	MT_2_1	MT_2_2	MT_3	MT_4	MT_5_1	MT_5_2	MT_5_3
1.	27.2	55.1	55.1	49.0	57.9	57.5	56.8	56.8
2.	27.1	55.0	55.2	49.0	57.9	57.0	56.8	57.2
3.	27.2	55.2	55.1	49.0	57.9	56.5	57.1	57.4
4.	27.2	55.2	55.0	49.0	57.9	57.1	56.8	57.1
5.	27.2	55.1	55.2	49.0	57.9	56.9	57.0	57.1
6.	27.2	55.0	55.3	49.0	57.9	57.5	56.2	57.4
7.	27.2	55.2	55.1	49.0	57.9	56.9	56.8	57.3
8.	27.2	55.5	54.8	49.0	57.9	57.1	56.9	56.9
9.	27.2	55.4	54.9	49.0	57.9	56.0	57.5	57.5
10.	27.1	55.0	55.1	49.0	57.9	56.9	56.8	56.8
11.	27.2	56.0	54.3	49.0	57.9	57.2	56.9	56.9
12.	27.2	55.3	55.0	49.0	57.9	56.5	56.9	57.6
13.	27.2	55.6	54.7	49.0	57.9	57.0	57.0	57.0
14.	26.8	55.2	54.4	49.0	57.9	56.8	56.8	56.7
15.	27.2	55.1	55.2	49.0	57.9	57.2	56.9	57.0
16.	27.2	54.5	55.7	49.0	57.8	57.4	56.5	56.9
17.	27.2	54.6	55.7	49.0	57.9	57.3	57.2	56.6
18.	27.2	55.4	54.9	49.0	57.9	57.1	57.0	57.0
19.	27.2	55.7	54.6	49.0	57.9	57.0	57.1	56.9
20.	27.2	55.3	54.9	49.0	57.9	57.0	56.9	57.1

Tab. 5. Maximum number of products and average waiting times in subsequent simulations

Simulation No.	Number of products in storage (pcs.)					Average waiting time (seconds)				
	B_1	B_2	B_3	B_4	B_5	B_1	B_2	B_3	B_4	B_5
1.	2	5	5	5	6	289.0	573.3	951.9	1381.6	310.6
2.	2	4	4	5	5	263.9	538.2	961.8	1355.0	278.5
3.	2	5	4	5	6	268.9	522.3	959.1	1428.4	281.0
4.	2	4	3	4	6	299.3	565.6	1014.6	1444.9	321.8
5.	2	5	4	4	7	281.2	562.0	955.1	1385.3	319.4
6.	2	5	5	5	6	233.2	554.8	1040.9	1520.3	306.4
7.	2	4	4	5	7	289.2	545.4	975.1	1444.2	332.2
8.	2	4	4	5	5	231.2	533.3	982.4	1374.8	267.0
9.	2	5	5	5	6	243.8	540.7	1030.5	1487.8	326.2
10.	2	6	4	5	6	247.3	583.7	984.5	1543.2	301.0
11.	2	4	4	4	5	227.4	523.8	988.3	1435.4	284.7
12.	2	5	4	5	5	285.5	562.5	955.1	1476.9	304.9
13.	3	4	4	4	7	319.5	575.9	914.3	1446.6	337.3
14.	2	6	4	5	6	246.8	526.0	977.2	1442.6	260.8
15.	2	5	4	5	7	314.9	536.8	922.5	1493.1	322.7
16.	2	4	3	4	6	267.1	567.8	885.9	1380.7	292.2
17.	2	5	6	5	6	303.3	554.7	1040.9	1491.1	325.4
18.	2	5	4	5	5	296.1	576.7	980.2	1506.6	297.2
19.	2	5	3	4	7	276.5	572.7	948.6	1402.6	327.1
20.	2	5	4	5	5	239.3	592.1	1005.6	1419.6	320.0

The report contains such data as: the number of products entering the production process, the number of products manufactured in simulation (tab. 4), average workload of machine tools in simulation (tab. 5) and the maximum number of products in buffers between operations and average waiting time for processing (tab. 6)

The simulation of the process shows that the job-shop system is suitable for the performance of the defined task. This is proved by both the behaviour of the system in operation as well as the workload on each of the machine tools and buffers between operations.

The analysis of production process models leads to several main conclusions:

– the analysed system is capable of providing a relatively smooth performance of scheduled production jobs, which are random time- and number-wise. In all models the system processed the specified number of input products. Failure to carry out the annual plan (observed in simulations 2, 10 and 16) resulted from not entering all the products into production in the specified time (simulation time), which was a consequence of the defined randomness of product input. In each of the three cases, the system managed to make up for the delay in another period (year),
– bottlenecks, connected with overloading machine tools and/or exceeding work-in-progress store space, were not observed in any of the simulations,
– short queue at work-in-progress storage (Figs. 4-8) and relatively short waiting time between processing jobs (Tab. 5) confirm good production flow in the system,

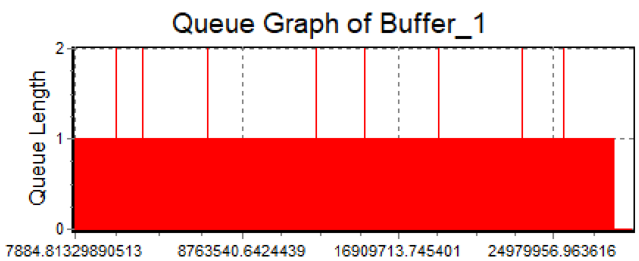

Fig. 4. Queue graph of BUFFER_1 over production process simulation

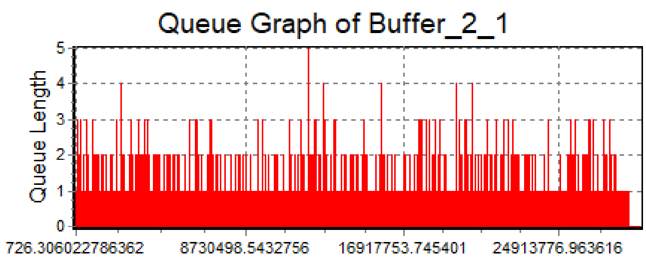

Fig. 5. Queue graph of BUFFER_2_1 over production process simulation

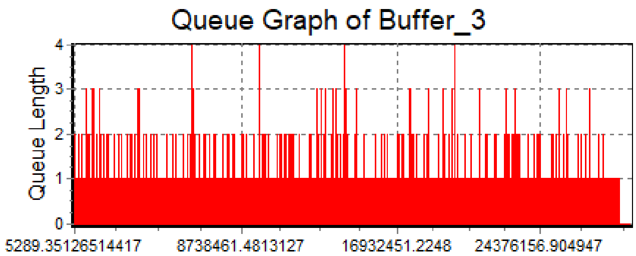

Fig. 6. Queue graph of BUFFER_3 over production process simulation

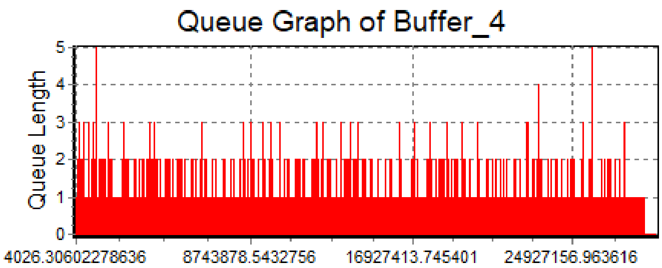

Fig. 7. Queue graph of BUFFER_4 over production process simulation

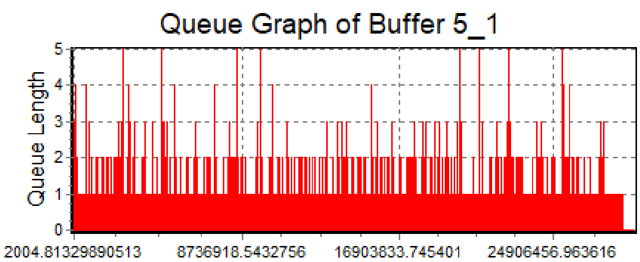

Fig. 8. Queue graph of BUFFER_1 BUFFER_5_1 over production process simulation

- despite stochastic character of the process, its high stability is confirmed by little variation of machining time results and of buffer queue indicators.

4. SUMMARY AND CONCLUSIONS

Designing a production system is a highly complicated process, partly due to the fact that there may occur certain contradictory optimisation objectives, such as flexible production of a range of products and maximisation of the set of machine tools engagement. Job-shop is a specific representative of production systems which combines crossing routes and repeated processing of jobs on machine tools. These constraints of a job-shop model cause that the typical discrete process modelling software is unsuitable for this purpose.

This paper showed methods of modelling and workflow analysis in the job-shop environment consisting of 8 machine tools, which process 3 types of products requiring different technological processes. The system was modelled by means of Enterprise Dynamics software. Given the character of the modern market it was resolved that one-piece-flow production system should be subjected to analysis. The jobs entering the system in question do so at random order.

Despite the constraints imposed on the model the conducted analyses appear to indicate that by employing computer simulation it is possible to carry out optimisation works in job-shop environment, through identification of bottle-necks and constant analysis of machine tool engagement. The results infer that optimisation of production flow in a production system may often require developing and implementing diverse manufacturing technologies, along with dive-sifying the size of batches. These problems will be further analysed in future works.

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