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IMPROVING MANUFACTURING PROCESSES USING SIMULATION METHODS

Abstract

The paper presents the results of simulation research on buffer space allocated in a flow line and operation times influence on the throughput of a manufacturing system. The production line in the study consists of four stages and is based on a real machining manufacturing system of a small production enterprise. Using Tecnomatix Plant Simulation software, a simulation model of the system was created and set of experiments was planned. Simulation experiments were prepared for different capacities of intermediate buffers located between manufacturing resources and operation times as input parameters, and the throughput per hour and average life span of products as the output.

1. INTRODUCTION

Computer simulation is a powerful method for designing and analyzing manufacturing processes in industry. Today, within a relatively short period of time, it is possible to design or redesign a manufacturing system to implement new production processes using simulation software. On the basis of the layout of a plant and a description of the technology in use, manufacturing resources can be allocated and the performance of the system can be estimated. A simulation model enables us to analyze various alternatives of the manufacturing system configuration and gauge the influence of the different parameters on the efficiency of different manufacturing processes. Advanced tools of computer simulation enable the analysis of the general performance of manufacturing systems, scheduling methods, support of facility layouts, automated material handling,

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automated guided vehicle systems design, etc. By doing this, we can reduce manufacturing costs and improve the system's throughput. Typically, however, the building of a simulation model of a manufacturing system is time-consuming and only enables the solution of individual problems. Therefore, it is often the case that a generalization of the results of simulation research is difficult. A very important advantage of a computer simulation is the possibility to create a model of a manufacturing system whose behavior could be very close to the real system. Modelling the processes of a manufacturing system and production processes is time-consuming and needs expert knowledge which increases the costs of the simulation method. To reduce the modelling time, often some simplifications of a manufacturing system are introduced which do not significantly affect the behavior of the system. Especially for companies which implement multi-assortment, repetitive production; it is very important to design and organize the production system effectively. Each new project requires the design of a technological process. To analyze the efficiency of a new production process, a model should be created that includes operation and setup times, the number of workers, the capacity of intermediate storage buffers, the availability of machines and tools, etc.

1.1. Literature overview

Simulation has been successfully implemented in a lot of research related to manufacturing system design and operation. Computer simulation offers very effective tools for visualizing, understating, and analyzing the dynamics of manufacturing systems (Seleima et al., 2012). Due to its complexity and importance, the buffer allocation problem has been studied widely and numerous publications are available in the literature. Stanley and Kim (2012) presented results of simulation experiments made for buffer allocations in closed serial-production lines. For the line, a single buffer space is the room and the associated material handling equipment that is needed to store a single job that is a work-in-process, and buffer allocation is the specific placement of a limited number of buffer spaces in a production line. The authors demonstrated a buffer allocation decomposition result for closed production lines, and also provided evidence that optimal buffer allocations in closed lines are less sensitive to bottleneck severity than in open production lines. The placement of buffers in a production line is an old and well-studied problem in industrial engineering research. Vergara and Kim (2009) proposed a new buffer placement method for serial production lines. The method is very efficient and uses information generated in a production line simulation whose conceptual representation of job flow and workstation interaction can be described with a network which aims to place buffers in order to maximize throughput. They compared the results of the new method against a method for buffer placement based on a genetic algorithm. Yamashita and Altiok (1998) proposed an algorithm for minimizing the total buffer allocation for a desired throughput in production lines with phase-type processing times.

They implemented a dynamic programming algorithm that uses a decomposition method to approximate the system throughput at every stage. Gurkan (2000) used a simulation-based optimization method to find optimal buffer allocations in tandem production lines where machines are subject to random breakdowns and repairs, and the product is fluid-type. He explored some of the functional properties of the throughput of such systems and derived recursive expressions to compute one-sided directional derivatives of throughput, from a single simulation run. Shi and Gershwin (2009) presented an effective algorithm for maximizing profits through buffer size optimization for production lines. They considered both buffer space cost and average inventory cost with distinct cost coefficients for different buffers. To solve the problem, a corresponding unconstrained problem was introduced and a nonlinear programming approach was adopted. Abu Qudeiri et al. (2008) used a genetic algorithm for studying the design of serial - parallel production line. They tried to find the nearest optimal design of a serial parallel production line that maximized production efficiency by optimizing buffer size between each pair of work stations, machine numbers in each of the work stations and machine types. Nahas et al. (2009) formulated a new optimal design problem of a parallel production line, where parallel machines and in-process buffers are included to achieve a greater production rate. The main objective was to maximize the production rate subject to a total cost constraint. Nourelfath et al. (2005) formulated a new problem of the optimal design of a series production line system, and developed an efficient heuristic approach to solve it. The problem was solved by developing and demonstrating a problem-specific system algorithm. Fernandes and Carmo-Silva (2011) presented a simulation study of the role of sequence-dependent set-up times in decision making at the order release level of a workload controlled make-to-order flow-shop. They indicated that the local strategy, which has been traditionally adopted in practice and in most of the studies dealing with sequence-dependent set-up times, does not always give the best results. Matta (2008) presented mathematical programming representations for the simulation-based optimization of buffer allocation in flow lines.

1.2. Problem specification

In this paper, a simulation method is used to analyze the impact of intermediate buffer capacities and lot sizes on the throughput of a production line. The buffer allocation problem is an NP-hard combinatorial optimization problem which deals with finding optimal buffer sizes to be allocated into buffer areas in a production line (Smith & Cruz, 2005; Huang, Chang & Chou, 2002). In general, the buffer allocation problem is classified into three categories according to its objective function (Demir et al., 2013; Krenczyk & Skolud, 2014):

1. Maximize the throughput rate of the production line with fixed amount of buffer sizes.
2. Minimize the total buffer size to achieve the desired throughput rate of the production line.
3. Minimize the average amount of work-in-process in the production line.

The presented paper takes into account the combination of the first two problems. The main problem considered in the paper can be formulated as follows: *Given a production line with a determined number of manufacturing resources, operation times and set-up times. How does an intermediate buffer capacity and sequence of operation times affect the throughput of the production line?* Using a simulation method, the best relation between allocated buffer capacity and throughput for several variants of operation times is examined. On the basis of the proposed simulation experiments, the principles by which solutions are reached can be analyzed and evaluated. In the next chapter, the simulation model of the production system is described and assumptions for simulation experiments are formulated. The third chapter contains the results of the simulation research and an analysis of the behaviour of the manufacturing system. In the last chapter, conclusions and directions for further study are presented.

2. SIMULATION MODEL OF THE MANUFACTURING SYSTEM

The model of the automated production line was prepared on the basis of a real example of a manufacturing system dedicated to metal tooling in an automotive company. The model and simulation experiments are implemented using Tecnomatix PLM simulation software. The studied manufacturing system includes four technological operations: cutting, turning, milling and grinding. The manufacturing process is divided into four stages by technology and between each two stages an intermediate buffer is allocated (Diering et al., 2015). Every stage of the manufacturing system encompasses a determined number of manufacturing resources (three CNC machines in every stage). The simulation model of the manufacturing system was prepared with Tecnomatic Plant Simulation Software version 11.0.0 and is presented in Fig. 1.

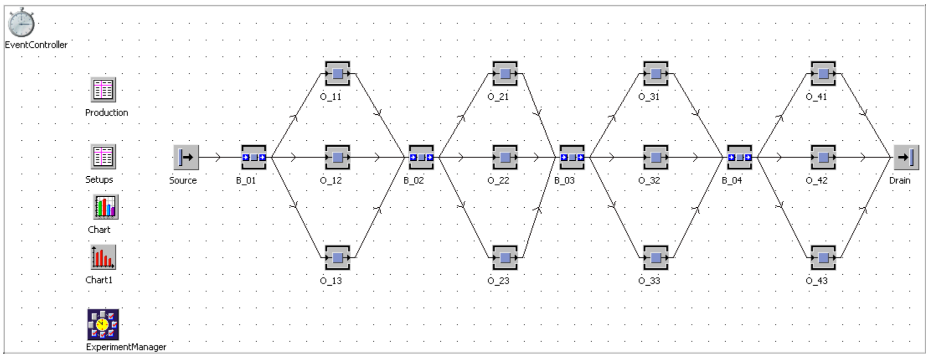

Fig. 1. Simulation model of the manufacturing system (own study)

The production is divided into four batch sizes of products (A, B, C, D) and realized cyclically. It was assumed that the efficiency of manufacturing resources is approximately 95%. The model of the production system was prepared on the basis of a real manufacturing company. The operation times are based on a lognormal distribution. A lognormal distribution is a continuous distribution in which a random number has a natural logarithm that corresponds to a normal distribution. The realizations are non-negative real numbers. The density of the lognormal distribution Lognor(σ,μ) is calculated as follows (Tecnomatix, 2011):

$$f(x) = \frac{1}{\sigma_0 x\sqrt{2\pi}} \cdot \exp\left[\frac{-\ln(x-\mu_0)^2}{2\sigma_0^2}\right] \tag{1}$$

where σ and μ are respectively mean and standard deviations and are defined as follows:

$$\mu = \exp\left[\mu_0 + \frac{\sigma_0}{2}\right] \tag{2}$$

$$\sigma^2 = \exp(2\mu_0 + \sigma_0^2) \cdot (\exp(\sigma_0^2) - 1) \tag{3}$$

The maximum of the density function is defined as:

$$\exp(\mu_0 - \sigma_0^2) \tag{4}$$

The example of the density function of lognormal distribution Lognormal(3,2) is presented in the Fig. 2 (Tecnomatix, 2011).

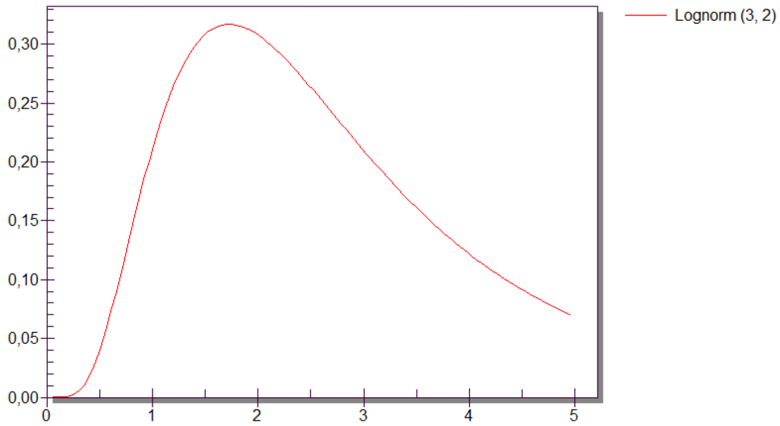

Fig. 2. Density function of lognormal distribution – lognor(3, 2) (own study)

The variants of operation times are presented in the table 1.

Tab. 1. The matrix of variants of operation times (own study)

Technological operations	Variant 1	Variant 2	Variant 3	Variant 4
O_11;O_12;O_13;	Lognor(5;0.5)	Lognor(5;0.5)	Lognor(2;0.5)	Lognor(5;0.5)
O_21; O_22; O_23;	Lognor(5;0.5)	Lognor(4;0.5)	Lognor(3;0.5)	Lognor(3;0.5)
O_31; O_32; O_33;	Lognor(5;0.5)	Lognor(3;0.5)	Lognor(4;0.5)	Lognor(3;0.5)
O_41; O_42; O_43;	Lognor(5;0.5)	Lognor(2;0.5)	Lognor(5;0.5)	Lognor(5;0.5)

The set-up times are defined in a set-up matrix (see Table 2). The numbers presented in the set-up matrix refer to the set-up time of changing the production batch (for example a batch change from product A to product B takes 15 minutes of set-up time).

Tab. 2. The matrix of setup times (own study)

	Product A	**Product B**	**Product C**	**Product D**
	10:00.0000	10:00.0000	10:00.0000	10:00.0000
Product A	10:00.0000	15:00.0000	10:00.0000	10:00.0000
Product B	15:00.0000	10:00.0000	20:00.0000	10:00.0000
Product C	20:00.0000	15:00.0000	10:00.0000	15:00.0000
Product D	10:00.0000	20:00.0000	20:00.0000	10:00.0000

The sequence of lot size is presented in the Table 3.

Tab. 3. The lot size matrix (own study)

	Lot size
Product A	20
Product B	25
Product C	15
Product D	10

The main variable in the simulation experiments was the intermediate buffer capacity. The proposed values of different combinations of intermediate buffers capacities that define the simulation experiments are presented in Table 4. The combination of the buffer capacities was chosen arbitrarily on the basis of author's experiences.

Tab. 4. The matrix of intermediate buffer capacities (own study)

Experiment	B_01	B_02	B_03	B_04
Exp 01	1	1	1	1
Exp 02	3	3	3	3
Exp 03	5	5	5	5
Exp 04	1	5	10	15
Exp 05	15	10	5	1
Exp 06	1	10	10	1
Exp 07	10	1	1	10
Exp 08	10	1	10	10
Exp 09	10	10	1	10
Exp 10	1	2	3	4
Exp 11	4	3	2	1
Exp 12	10	10	10	10
Exp 13	20	20	20	20
Exp 14	30	30	30	30
Exp 15	50	50	50	50

In addition to the system throughput per hour, the average life span of products in the manufacturing system was analyzed. The average life span shows us how long the products stay in the system and enables us to identify the level of work-in-process. In the next chapter, the results of the simulation experiments are presented.

3. THE OUTCOMES OF COMPUTER SIMULATION EXPERIMENTS

On the basis of the described simulation model, a set of simulation experiments for four variants of operation times, as presented in Table 1, were performed. The results of the simulation research show that, generally, the throughput of the system increases with increasing buffer capacities, but together with an associated increase in the average life span of products (work-in-process). To find the best compromise between throughput and average life span; flow index θ is proposed. To calculate the index, the value of the throughput of the system is divided by the average life span.

$$\theta = \frac{\mathrm{T}}{\Lambda} \tag{5}$$

where T and Λ are throughput and average life span, respectively.

The results for the experiments are presented in table 5. In the table the best two results for each variants are shown.

Tab. 5. The values of flow index (own study)

	Variant 1	Variant 2	Variant 3	Variant 4
Exp 01	292.72	406.41	331.13	325.94
Exp 02	274.34	381.21	306.11	307.76
Exp 03	285.29	408.47	309.32	319.48
Exp 04	**376.26**	**523.72**	**349.84**	**403.30**
Exp 05	152.47	219.94	166.36	176.27
Exp 06	237.57	394.16	244.18	270.17
Exp 07	210.33	270.68	259.81	244.23
Exp 08	254.46	317.09	310.49	283.30
Exp 09	215.25	293.25	258.38	271.26
Exp 10	**321.87**	**450.00**	**364.99**	**360.03**
Exp 11	239.01	331.22	266.83	267.57
Exp 12	281.30	388.26	259.62	290.60
Exp 13	214.48	299.08	145.01	226.58
Exp 14	175.32	241.21	99.99	191.72
Exp 15	136.87	174.05	62.30	146.69

The greater the value of the index, the better the compromise between the throughput and average life span that can be found. The best values of the flow indexes were obtained in Variant 2 of the operation times. For experiments 4 and 10, the best values of the index are obtained. The chart presented in Fig. 3 show the values of the flow indexes for all variants of operation times.

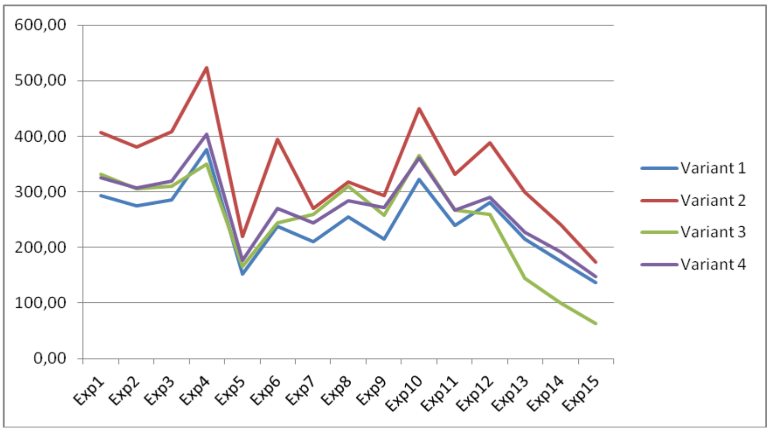

Fig. 3. The values of flow indexes for the different variants of operation times (own study)

The increase in the intermediate buffer capacities results in an increased average life span and work-in-process. The buffer capacity costs money (place, work-in-process, etc.). To comply with the capacity of the intermediate buffers in the analysis of the efficiency of the investigated manufacturing system, the total buffer productivity index ω is proposed.

$$\omega = \frac{T}{B} \tag{6}$$

where T and B are throughput and total buffer capacity, respectively.

In Fig. 4, the total buffer productivity indexes for all variants are presented. There are no significant differences among the values of buffer productivity indexes measured for the various variants. The greatest value in the index was obtained in experiment 1, and it resulted from the small value of the total buffer capacity (single capacity of intermediate buffers). The next best relation between the throughput and buffer capacity for all variants was obtained in experiments 10 and 11.

4. CONCLUSIONS

An analysis of the data collected during the simulation experiments shows us that for each variant of the operation times, in the last four experiments (12, 13, 14 and 15) in which all buffer capacities are equal or greater than 10, the throughput of the manufacturing systems achieved the best results (more than 22 products per hour). For the smallest total capacity of intermediate buffers, the greatest value of throughput was reached in experiments 4, 6, 8 and 9. For flow index, experiments 4, 6 and 10 provided very good results, and for buffer productivity index: experiments 1, 10 and 11. For the manufacturing system, which was investigated in this study, the following general conclusions can be formulated:

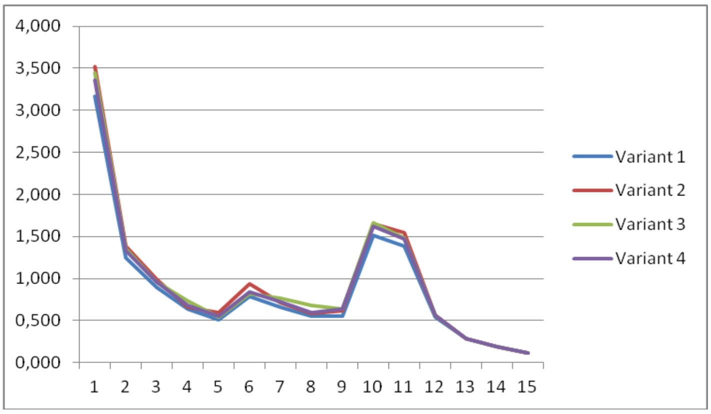

Fig. 4. The values of total buffer productivity indexes for the different variants of operation times (own study)

- The intermediate buffer capacity has a significant impact on the throughput and average life span of the system.
- The proper allocation of buffer capacities provides better values of throughput or average life span of the system.
- It is possible to find a satisfactory compromise between the throughput and average life span of the system, maximizing the proposed flow index.
- It is possible to find a satisfactory compromise between the throughput and costs of buffer capacities, maximizing the proposed total buffer productivity index.

Further research will encompass other structures of the manufacturing system and the impact of employees on the throughput of the manufacturing system.

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