Applied Computer Science, vol. 13, no. 2, pp. 72–81
doi: 10.23743/acs-2017-15

Submitted: 2017-04-10
Revised: 2017-05-04
Accepted: 2017-06-01

computer model, simulation experiment, multi-criteria assessment

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A SIMULATION EXPERIMENT AND MULTI-CRITERIA ASSESSMENT OF MANUFACTURING PROCESS FLOW VARIANTS TESTED ON A COMPUTER MODEL

Summary

The article presents issues relating to designing and improvement of manufacturing processes based on a modelling and simulation method. The 3D model of a production line has been designed and simulation experiment, conducted on the Arena model prepared in a versatile package for modelling and simulation of manufacturing systems and representing functioning of the system, has been carried out. The results obtained from the experiment and analyses of time and ergonomics of work at a work station were subject to multi-criteria assessment based on a point-by-point method of assessment according to Yager.

1. INTRODUCTION

In the face of heavy competition and faster and faster changes in the labour market, companies strive to achieve the shortest possible time to commence sale of products that suit exact customer requirements. Shortening the production cycle, while maintaining the minimum time and cost, proper quality, safety and ergonomics of work, as well as environmental guidelines, has caused the necessity of introducing changes in designing and management of processes. Functioning on the concept of lean manufacturing, the enterprise assumes the use of a number of tools for continuous improvement. They can be applied

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as an aid to research the causes of problems, analysis of processes, creating improvement ideas and determining their impact on functioning of the manufacturing systems (Dennis, 2016; Manas, 2015).

Development of information systems has become an opportunity to optimize preparation of production, among others, through the use of modelling and simulation tools.

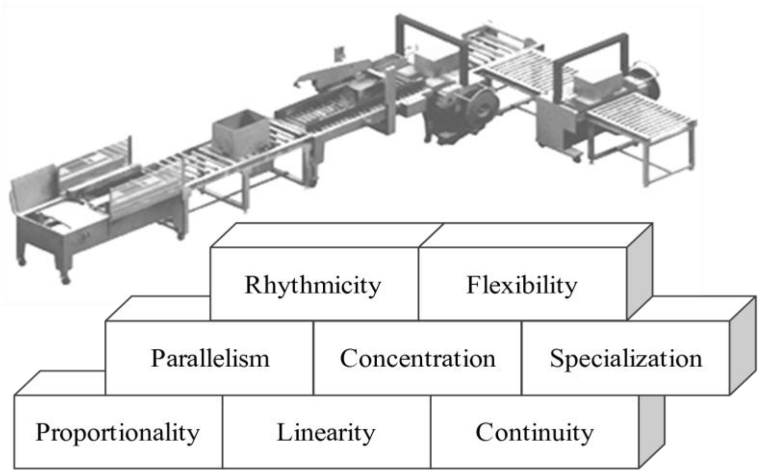

Fig. 1. The principles of organizing production cells
(own study based on Pisz, Sęk & Zielecki, 2013)

There are various principles being guidelines at organization and improvement of production cells (Fig. 1):

– the principle of proportionality that points to the necessity of distribution of production tasks in such a way that all work stations, production cells and operation performed on them were adjusted to one another in terms of production capacity, as well as to prevent internal distributions,
– the principle of linearity that emphasises unidirectionality of the process flow during realization of a part of the production process, i.e. flow paths of the subjects of labour between successive operations should be as short as possible,
– the principle of continuity that recommends eliminating all gaps of the manufacturing process which can have a negative influence on shaping economic as well as production and organizational parameters,
– the principle of parallelism: it is based on manufacturing different products at the same time in order to shorten the production cycle,
– the principle of concentration: it recommends focusing production factors in a particular production area which results in a higher level of their use,
– the principle of specialisation that assumes reducing the diversity of production tasks and range of products to facilitate planning and

organization of the manufacturing process, as well as to increase the performance,
– the principle of rhythmicity relating to the problem of production in a specific rhythm resulting in regular occurrence of the same phenomena in a time interval,
– the principle of flexibility that puts emphasis on such designing of the manufacturing process, as to easily adapt it to new conditions (Pisz, Sęk & Zielecki, 2013; Sobaszek & Gola, 2015).

2. MODELLING AND SIMULATION OF MANUFACTURING SYSTEMS

A model means simplified object whose degree of similarity in comparison with a modelled object causes that the research carried out on it provides significant and useful information in terms of the purpose of research.

Simulation is a technique used to analyse a real system based on a computer model that represents it. Simulation of systems is understood as the action of presenting a real system with the use of a symbolic model, which can be easily operated and provides numeric results (Dima & Man, 2015; Rossetti, 2016). Simulation methods are used more and more often to solve problems in the area of preparation and organization of manufacturing. The use of the modelling and simulation of manufacturing systems method is based on creating a computer model of a real condition, or designing a process and carrying out a number of simulation tests on it (Fig. 2). On the basis of the reports obtained, it is possible to analyse parameters of the systems and create improvement proposals (Kelton, Sadowski & Sturrock, 2007; Kłos, Patalas-Maliszewska &Trebuna, 2016, Maciąg, Piertroń & Kukla, 2013; Rainey & Tolk, 2015).

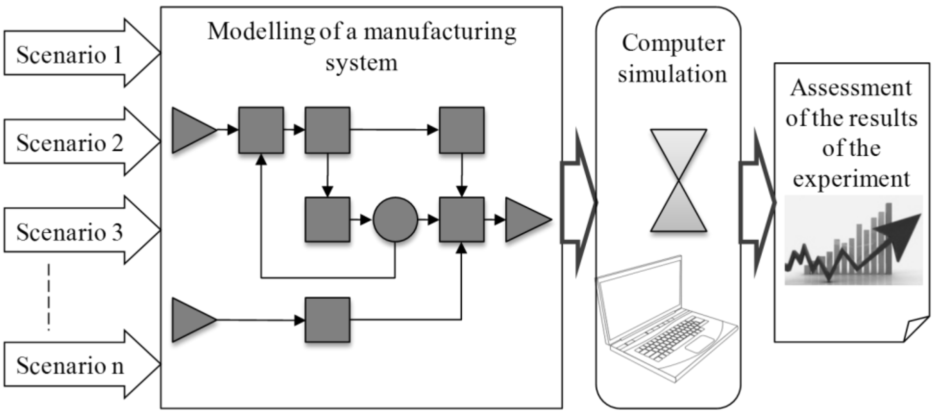

Fig. 2. Modelling and simulation of manufacturing systems

The main objectives of simulation models are as follows:

– supporting manufacturing decisions making,
– presenting features and parameters of the system that has not been known so far.

Using tools for modelling and simulations generates numerous benefits for the enterprise:

– the possibility to observe the course of the processes analysed in changed conditions, such as changes in terms of machinery park, transport organization, cooperation, modified flow of information, etc.,
– examination and assessment of parameters of the systems before launching it in real conditions,
– the possibility to determine the length of the production cycle,
– identifying parameters having significant impact on the economic result of the enterprise,
– determining possible hazards in terms of flow of information, organization of logistics and manufacturing processes,
– determining the risk of different variants in a situation of absence of experience as well as limited knowledge about the process investigated.

however, simulation methods have a lot of vices:

– time consumption of constructing a model,
– no guarantee of finding the optimal solution,
– the need of having wide knowledge of the analysed system by the author of a model,
– the need of fluency in simulation software,
– test results that are difficult to interpret,
– problematic transfer of test results to other tested objects,
– profitability in case of high series and mass production (Maciąg, Piertroń & Kukla, 2013; Plinta, 2015).

3. MULTI-CRITERIA ASSESSMENT OF VARIANTS

As a result of a simulation experiment, the set of reports is obtained. The reports cover the results associated with performance, use of resources, queues, delays, lead time of production tasks, costs, etc. It is difficult to clearly evaluate the results of the experiment, especially when considering several evaluation criteria. Commonly known multi-criteria assessment methods might be helpful (Fig. 3). One of the examples is a multi-criteria point-by-point assessment according to Yager that is based on Saaty's matrices. Selecting one of the variants with the use of Yager's method starts with determining input data including: number of criteria (m), number of variants (n), number of experts (p) and determining the scale of grades and criteria (Kukla, 2014).

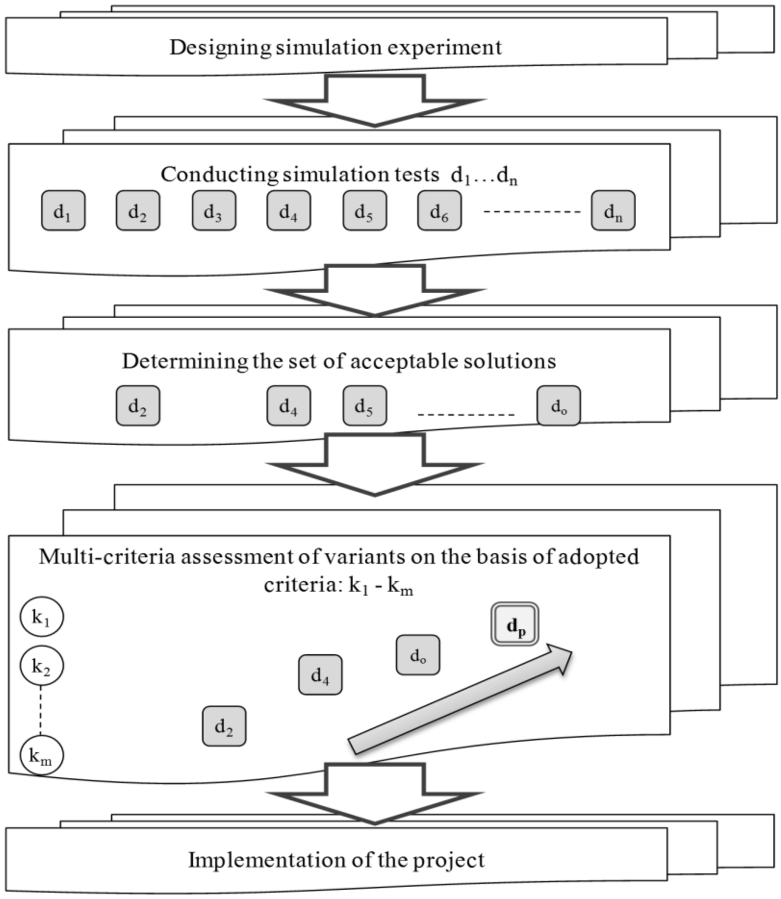

Fig. 3. Simulation experiment and multi-criteria assessment of variants

At the beginning, the criteria are compared in pairs, an overall matrix of assessment is created and weights of criteria are set with the use of the power method. In a further step, based on the results of the experiment and analyses conducted, individual variants of solutions are assessed in relation to each of the criteria and in line with a point-by-point scale adopted. Then, upon summarizing partial grades, normalised grades and overall normalised grades are created on the basis of them by aggregating normalised grades of individual experts for each of the variants, considering evaluation criteria adopted. Normalised decisions are calculated by raising the total normalised values to powers equal to the weights of criteria. For each of the variants, the lowest grade, among all the obtained, for subsequent criteria is selected. A variant, to which the highest grade corresponds (a component of optimum decision) is the most advantageous variant in the light of adopted assessment criteria (Kukla, 2014; Kukla, 2016).

4. A DESCRIPTION OF THE RESULTS OBTAINED

The object of research in the study was the production line associated with the food industry. The purpose of the research was to design a new line based on machinery and equipment of the line already functioning in the plant.

The 3D models of the production line were designed with the use of the Autodesk Inventor software. Measurement of available production space and line equipment was taken and a computer model to visualize the work station being designed was created. Then a simulation model of the line was constructed in the Arena package (Fig. 4). Upon testing the model, a simulation experiment was designed for three variants of solutions.

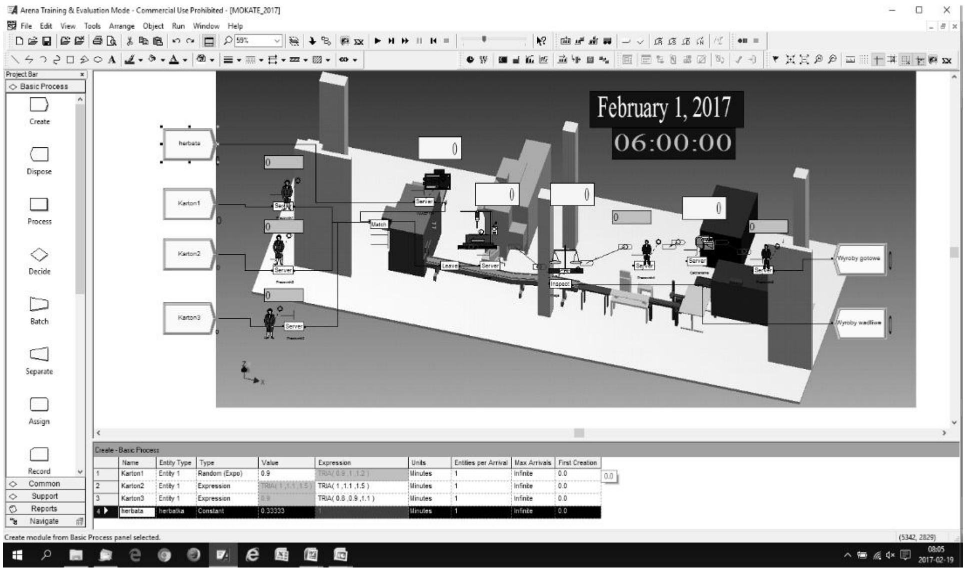

Fig. 4. Simulation model in the Arena software

Thanks to visualisation of work at the work station and observation of working conditions at similar work stations in the plant, an ergonomic analysis of work at given work stands was carried out. The ergonomic analysis was carried out with the use of the point-by-point method, while hand machining was divided into procedures. The aim was to improve the work station in order to eliminate actions that are unnecessary and uncomfortable for an employee.

The assessment of ergonomics of work on the line was carried out on the basis of the chart of ergonomic positions, taking into account 9 situations at the work station (Falzon, 2015; Kukla, 2016). Number grades were assigned to each action and position at work, which correspond to three zones of a three-stage scale (Fig. 5).

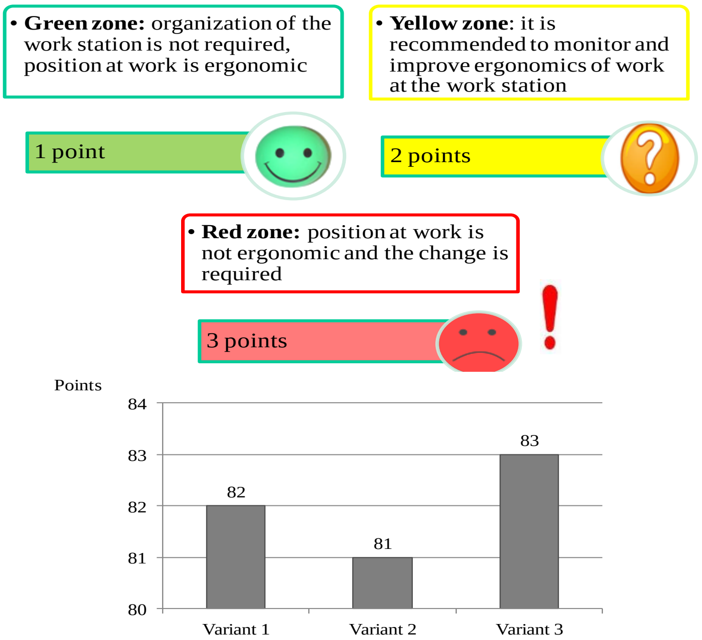

Fig. 5. Point-by-point assessment of ergonomics of work at a work station

On the basis of the 3D model, distance covered by the products on the production line was specified (Fig. 6). Performance and use of individual resources was assessed on the basis of reports from simulation (Fig. 7). Subsequently, line retool times were estimated and their impact on performance and organization of work on the line (Fig. 8).

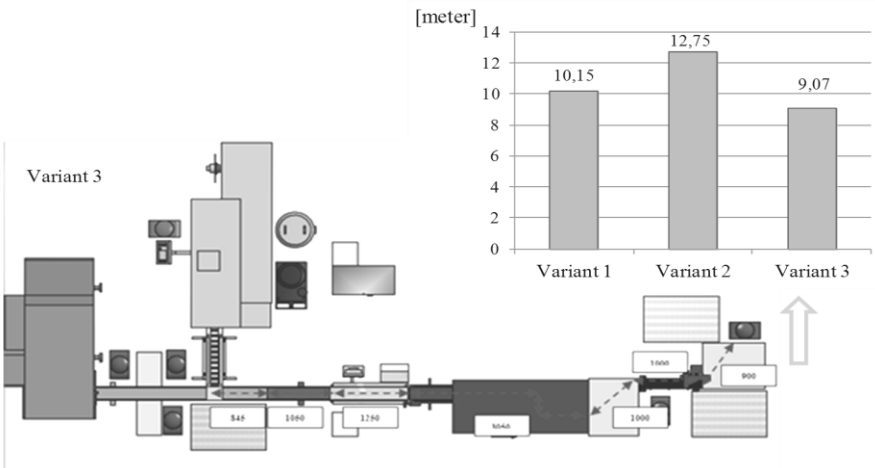

Fig. 6. Distance covered by a product on a line

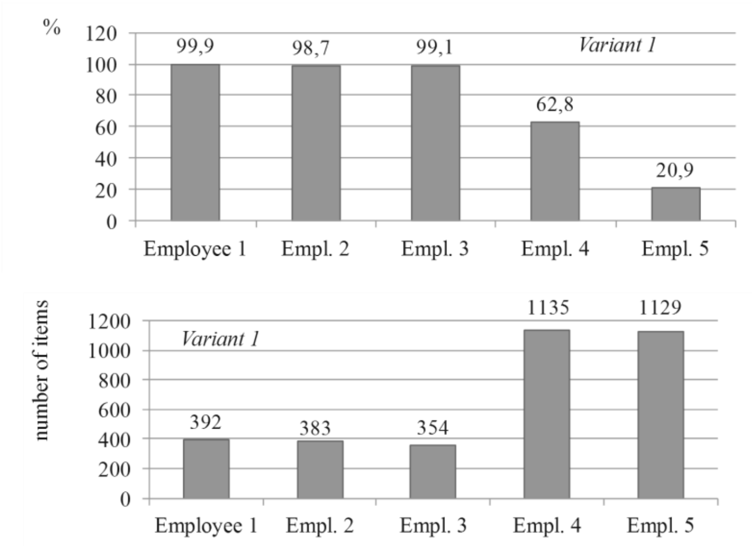

Fig. 7. Performance and use of individual resources: for variant 1

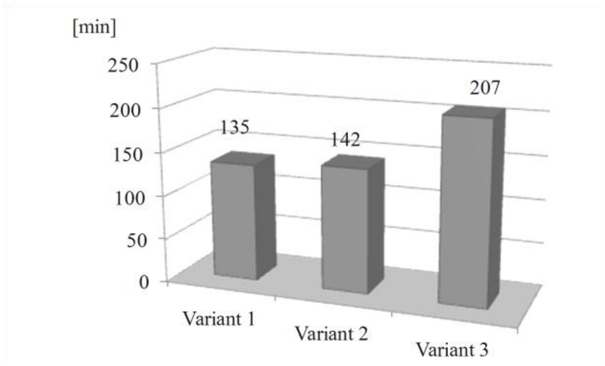

Fig. 8. Line retool time

Variants of solutions were assessed in terms of four criteria, the significance of which was assessed according to the Saaty's method (Fig. 9):

– k_1: performance,
– k_2: ergonomics and safety at a work station,
– k_3: line retool time,
– k_4: distance covered by a product on a line.

Figure 10 presents number grades of variants for each of the criteria prepared by three decision makers that were brought to normalised grades in the range (0.1).

Next, average grades of variants and indicators for normalised decisions were created, which were obtained by raising components of subsequent normalised grades to a power equal to the appropriate weight (Fig. 11).

E_1	k_1	k_2	k_3	k_4
k_1	1	2	1	2
k_2	0,5	1	0,333	0,5
k_3	1	3	1	4
k_4	0,5	2	0,25	1

E_2	k_1	k_2	k_3	k_4
k_1	1	3	1	3
k_2	0,333	1	2	2
k_3	1	0,5	1	1
k_4	0,333	0,5	1	1

E_3	k_1	k_2	k_3	k_4
k_1	1	1	1	2
k_2	1	1	2	4
k_3	1	0,5	1	2
k_4	0,5	0,25	0,5	1

Overall matrix of criteria significance:

	k_1	k_2	k_3	k_4
k_1	1	2,000	1,000	2,333
k_2	0,500	1	1,444	2,167
k_3	1,000	0,692	1	2,333
k_4	0,429	0,462	0,429	1

Fig. 9. Criteria significance assessment using the Saaty's method for three experts and an overall matrix of criteria significance

Criteria	Experts	Variants			Sj(e)
		W_1	W_2	W_3	
k_1	E_1	4	3	3	10
	E_2	5	3	3	11
	E_3	4	3	3	10
k_2	E_1	3	4	2	9
	E_2	2	4	2	8
	E_3	3	4	2	9
k_3	E_1	4	3	1	8
	E_2	3	3	2	8
	E_3	4	4	2	10
k_4	E_1	5	4	4	13
	E_2	4	3	5	12
	E_3	3	3	4	10

Criteria	Experts	Process flow variants		
		W_1	W_2	W_3
k_1	E_1	0,400	0,300	0,300
	E_2	0,455	0,273	0,273
	E_3	0,400	0,300	0,300
k_2	E_1	0,333	0,444	0,222
	E_2	0,250	0,500	0,250
	E_3	0,333	0,444	0,222
k_3	E_1	0,500	0,375	0,125
	E_2	0,375	0,375	0,250
	E_3	0,400	0,400	0,200
k_4	E_1	0,385	0,308	0,308
	E_2	0,333	0,250	0,417
	E_3	0,300	0,300	0,400

Fig. 10. Bringing number grades of variants to normalised grades

As a result of the presented procedure, the best variant among those indicated in the analysis of the area of acceptable solutions was selected. It turned to be the solution marked as W1.

Kryteria	Warianty		
	W_1	W_2	W_3
k_1	0,3256	**0,2041**	0,2041
k_2	**0,2445**	0,4006	0,1758
k_3	0,3728	0,3310	**0,1488**
k_4	0,6690	0,6277	0,6942

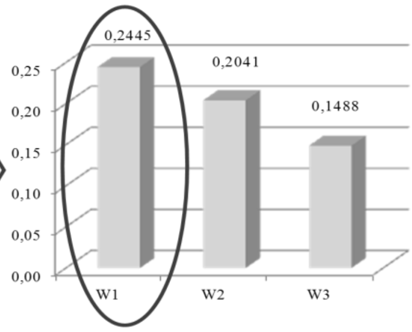

Fig. 11. Bringing number grades of variants to normalised grades

5. CONCLUSIONS

The use of simulation tools requires detailed knowledge of manufacturing process flow and interrelationship of individual cells in an enterprise. Although constructing a model is a time-consuming process, the prepared model can be used for fast verification of various scenarios of solutions relating to functioning of current manufacturing system or manufacturing system being designed.

Generated simulation reports are an important source of information about the analysed system. They enable assessment of system parameters without the need to experiment on a real object.

Thanks to the use of a multi-criteria assessment, it is possible to consider a larger number of criteria, with various significance, by assessing variants verified by a simulation as well as finding a compromise.

Prefer solution is Variant 1 with maximum value in decision function 0,2445.

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