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SIMULATION OF CAPACITY EXPANSION FOR PRODUCTION PROCESS OF ELECTROMOTORS

Abstract: The paper recommends the methodology of simulation, possible advantages from its utilisation, type of simulation, and computer support of simulation experiments for a verification of planned investment activities in the area of increase of capacity and efficiency of manufacturing operations. Expansion of disposable capacity of the manufacturing operation for production of electromotors was chosen as an example.

Keywords: modelling, simulation, production process, logistics.

1. Simulation

Simulation models combine the "trial-and-error method" with a mathematical model for the purposes of description and evaluation of a real system behaviour. Simulations relatively cheaply and quickly provide ideas about systems' behaviour under various conditions and give basic data necessary for the selection of the best variant. Simulation experiments can be repeated and their results can be processed and interpreted statistically.

Simulation is a descriptive rather than a normative tool; there is no automatic search for an optimal solution. Instead, a simulation describes or predicts the characteristics of a given system under different circumstances. Once these characteristics are known, the best policy can be selected.

For the actual use of simulation in logistics processes it is necessary to determine:

– the methodology of simulation, i.e. the procedure of designing and conducting experiments;
– possible advantages from its utilisation;
– type of simulation;
– computer support of simulation experiments.

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1.1. The methodology of simulation

Simulation involves setting up a model of a real system and conducting repetitive experiments on it. The methodology consists of a number of steps (Turban, Meredith 1993):

1. **Problem definition** – the real-world problem is examined and classified. We should specify why simulation is necessary. The system's boundaries and other such aspects of problem clarification are attended to here.
2. **Construction of the simulation model** – this step involves gathering the necessary data. In numerous cases, a flowchart is used to describe the process.
3. **Testing and validating the model** – the simulation model must properly imitate the system under study. This requires validation.
4. **Design of the experiment** – once the model has been proven valid, the experiment is designed. Included in this step is determining how long to run the simulation and whether to consider all the data or to ignore the transient start-up data. Thus this step deals with two important and contradictory objectives: accuracy and cost.
5. **Conducting the experiments** – there are several types of simulation different from one another at this step is different.
6. **Evaluating the results** – the final step, prior to implementation, is the evaluation of the results. At this stage, we may even change the model and repeat the experiment.
7. **Implementation** – the implementation of simulation results involves the same issues as any other implementation. However, the chances of implementation are better, since the manager is usually more involved in the simulation process than with analytical models and these simulation models are closer to reality.

1.2. Advantages of simulation

Simulation belongs to methods whose practical application in logistics management has been growing in importance:

- simulation theory is relatively straightforward;
- the simulation model is the aggregate of many elementary relationships and interdependencies;
- simulation supports asking what-if type questions, experimenting with various policies and searching a suitable solution;
- the model is built from the practice perspective and corresponds with real-life decision making process;
- simulation is a universal tool, which can handle a wide range of problems;
- simulation enables the inclusion of the real-life complexities of problems; simplifications are not necessary;
- due to the nature of simulation, a great amount of time compression can be attained, which enables the long-term effects of various policies to be found out in a matter of minutes;

– the experimentation is done with a model rather than by interfering with the system, which makes it possible to search for a solution at a relatively low cost;
– the massive development of IT support for conducting the simulation experiments.

1.3. Type of simulation

There are several various types of simulation approaches. In practice, probabilistic simulation is used most often for the analysis and evaluation of logistics processes. This type of simulation is designed to study and solve complex dynamic problems where one or more of the independent variables is probabilistic.

The simulation results in a statistical estimation of monitored parameters and its exactness increases with a number of repeated trials. Therefore, it is usually necessary to carry out the trials on a computer in order to obtain representative results. Probabilistic simulation is conducted with the aid of a technique called the Monte Carlo method. Its main principle can be found for example in Jablonský (2004).

1.4. Computer support of simulation experiments

Realisation of simulation experiments in real life must involve the use of computers. In principle, one of the following three options can be used in order to execute experiments on a model using computers (Bazala *et al.* 2008):

– classic programming or special simulation language,
– spreadsheet program,
– special simulation software.

The spreadsheet programs and simulation software are the most important options for a common user without any deeper knowledge of programming.

The spreadsheet program can be recommended in situations when a relatively easy application, which does not require any demanding program and development means, needs to be put together.

MS Excel spreadsheet program is most commonly used, its main advantages being:

– Nowadays, MS Excel is a common, user friendly software tool, and basic knowledge of functions and spreadsheet tools is sufficient to draw a computer model.
– Experiments on a model are not time consuming, even in the case of a relatively high number of simulation cycles.
– MS Excel supports automatic generation of pseudorandom numbers or the actual random quantity values, both discrete and continuous distributions – it has two basic tools for such purposes. The user can use a special function or a complex tool which is called pseudorandom numbers generator.

If complex problems in the scope of production logistics management are solved, the user can use some of the specialised simulation programs which can provide them with other unquestionable advantages:

– User's comfort thanks to easy control, user friendly operation, the possibility to present the results, etc. The cutting-edge products are based on modular hierarchic structure featuring well arranged operations with the simulated model.
– Visualisation and animation, which provide the possibility to display the computer results of various managerial decisions in a graphic form. The user can follow the simulation of the given problem in time and can take part in the creation and validation of the real system model. The user finds himself/herself in a position in which he/she can utilise his/her knowledge and experience to affect the model enabling him/her to examine alternative strategies. The classic simulation does not enables the experimentator to "see" how the solution of a complex problem evolves in time, and it provides a static view of a sequence of individual experiments only.
– Communication and integration with other software products and company information systems. Most often, it involves cooperation with presentation software, spreadsheet programs and database systems. The analysis simplifies the integration of statistical tools, optimisation or planning software.

A number of specialist companies from all over the world offer simulation software nowadays. Lanner Group Ltd.'s WITNESS simulation tool is the most common instrument in logistic management. It is leading software used for interactive process simulation. WITNESS supports the visual creation of understandable simulation models of complicated company processes, as well as analysis and optimisation thereof.

2. Simulation of production process of electromotors

2.1. Problem definition

The aim of the simulation was to verify the newly proposed solution for an expansion of disposable capacity of the manufacturing operation for production of electromotors.

The verified solution included processes of assembly, store management, surface treatment, packaging and dispatch:

– three assembly lines,
– stores and necessary manipulation for lines,
– four lines for surface treatment,
– three packaging lines,
– department of expedition.

Schematic representation of material flow within the frame of the monitored operation is shown in Figure 1.

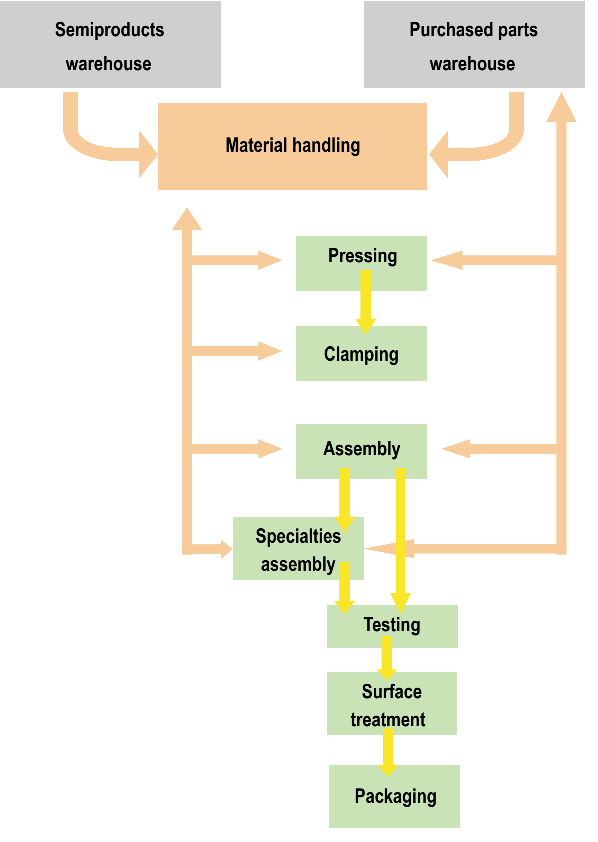

Fig. 1. *Scheme of material flow in the monitored operation*

Both the identification of bottlenecks and the suggestions for their removal, as well as the indication and elimination of idle capacities, if any, in the individual processes (increasing the production process efficiency) were supposed to be the outcomes of the simulation.

2.2. Construction of the simulation model

The following resources of information on operation processes were used:

– system of check back indication,
– order plan for the month,
– technological descriptions of operations and workplaces,
– time studies of individual operations.

For the purpose of the model creation, data on orders from one month was processed. A file of about 3,500 orders was selected as a primary sample. The following material flows of the existing operation were analysed – handling in individual stores, pallet transfers among production lines and stores, activity of manufacturing lines, handling at packaging and dispatch departments – and duration of individual operations for the representatives of the individual product groups.

As the next step, the model of the existing operation and the model of proposed solution for the capacity increase were designed in the environment of the Witness simulation software (Fig. 2).

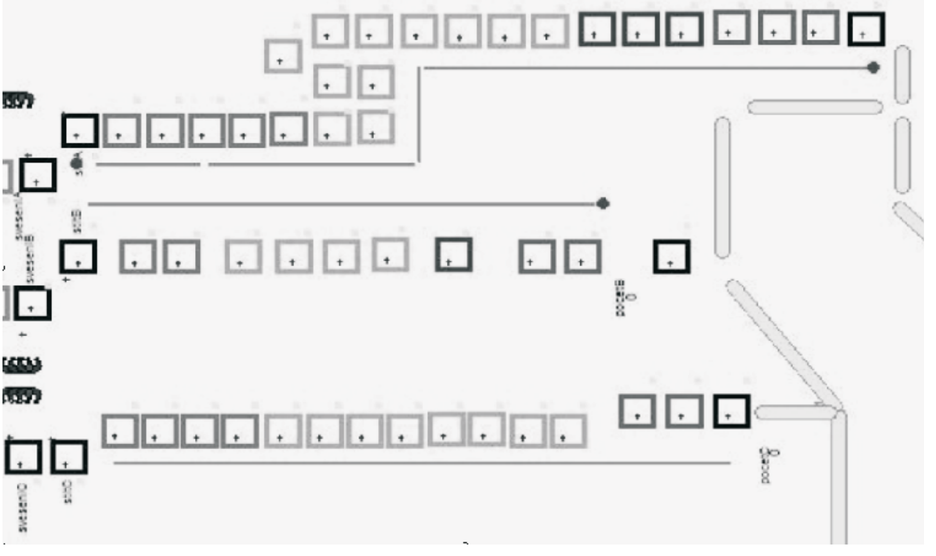

Fig. 2. *Example – part of the model of the examined plant created in the Witness program*

2.3. Testing and validating the model

The designed model was verified Formby means of simulation of the existing production operation with the quantity and structure of orders corresponding to the reviewed period. That verification evidenced sufficient conformity of the model to the real system.

Percentage representation of various types of electromotor packages put out by the packing line section (see Tab. 1) can be deemed an example of model verification outcome.

Table 1. *Percentage share of the individual electromotor package types*

Package type	Reality	Model
Box	15.1	16.2
Special	17.6	17.0
Pallet	67.3	66.8

2.4. Design of the experiment

The created model of newly proposed solution for manufacturing of electromotors was used for a verification of three production volumes:

Variant 1 (V1) – simulation of existing production volume (in the given month).
Variant 2 (V2) – simulation with the 15-percent production increase.
Variant 3 (V3) – simulation with the 30-percent production increase.

From the point of view of allocation of individual product groups to production lines, these basic variants were further divided into three partial options A–C (see Tab. 2). A total of nine options have been created altogether as a result. Take option V1.A as an example. It expresses a simulation of existing production volume and of the assumed allocation of product groups P1, P2 and P3 to line No. 1, P5 and P6 to line No. 2, and P4 and P5 to line No. 3.

Table 2. *Allocation options of product groups to production lines*

Assembly line	Product groups allocation options		
	A	**B**	**C**
1	P1, P2, P3	P1, P2, P3	P1, P2
2	P5, P6	P4, P5, P6	P5, P6
3	P4, P5	P3, P4, P5	P3, P4

2.5. Conducting the experiments

During the experiments, several scale factors of the operational efficiency were considered and measurements were taken to ensure the achievement of the requested production volume and, at the same time, to reduce operational and investment costs of the planned production capacity expansion.

The following scale factors of the operational efficiency were considered:

- number of products produced in the one month reviewed;
- utilisation of workers on individual workplaces along the assembly lines;
- ratio of product waits for a worker on individual workplaces of the manufacturing lines (it is the stage when a motor is moved to a next workplace where it must wait for the worker to complete his work on previous products);
- utilisation of manipulation techniques and workers in the store and related activities while the lines are being supplied with necessary components;
- number of pallets prepared for assembly;
- number of pallets on individual assembly workplaces and the time of their stay there;
- utilisation of surface treatment lines;
- utilisation of workers at the packaging department;
- utilisation of high-lift trucks in the dispatch department.

As an example of the model outputs it is possible to introduce the utilisation of workers at assembly lines for variant V1 (Tab. 3) or the utilisation of high-lift trucks at the dispatch department for each of the variants reviewed (Tab. 4).

Table 3. *Percentage utilisation of workers at assembly lines in variant 1*

Variant	Assembly line	Workplace of assembly line						
		A	B	C	D	E	F	G
V1.A	1	81.1	84.4	66.4	86.5	87.1	70.6	80.5
	2	63.0	57.4	45.8	51.8	57.3	73.6	53.7
	3	43.4	50.8	29.3	59.5	61.7	66.4	75.6
V1.B	1	58.2	60.5	49.0	62.1	62.8	72.2	83.3
	2	74.5	73.8	80.1	69.6	75.3	76.5	71.7
	3	55.8	63.2	39.3	66.1	68.4	72.7	65.2
V1.C	1	50.0	52.0	42.8	53.5	54.2	72.0	57.0
	2	75.3	68.2	56.8	63.1	69.8	77.1	78.0
	3	61.8	78.3	45.8	81.1	83.4	72.7	68.5

Table 4. *Percentage utilisation of high-lift trucks for dispatch for the variants reviewed*

High-lift truck	Variant								
	V1.A	V1.B	V1.C	V2.A	V2.B	V2.C	V3.A	V3.B	V3.C
X	51.6	55.2	56.9	55.2	57.2	54.0	56.9	71.2	64.8
Y	51.6	55.1	56.6	55.1	57.2	54.0	56.6	71.1	64.8
Z	51.5	55.1	56.9	55.1	57.0	54.0	56.9	71.0	64.8

2.6. Evaluating the results

The whole simulation process consisted of tracking and specifying the necessary data, carrying out additional measurements and removing the identified bottlenecks, identified in repeated simulations. A coherent database for simulation models could be defined using this method, and it was possible to perform a detailed analysis of the options considered.

The executed experiments made it possible to evaluate the suggested solutions for expanding the available production capacity in all material flow segments, including the subsequent main conclusions and recommendations:

1. **Assembly lines**
   - The suggested solution is sufficient for achieving the required operation capacity increase for each of the options considered.
   - From the point of view of allocating the product groups to individual production lines, option A may be deemed most suitable – unlike the other options, it also offers even utilisation of all production lines and the shortest continuous production time.

2. **Stores and necessary handling for assembly lines**
   - The correctness of the suggested number of handling machinery and employees at individual warehouses can be confirmed.
   - The capacity problems in this area may occur exclusively with the highest performance of the production lines, and when an unexpected failure of the handling machinery occurs. The reduction of forklift trucks working load in the warehouses can be achieved by introducing a system of material stocking according to its selling time (the fast selling material should be stored close to the delivering windows).
3. **Lines for surface treatment**
   - Reduction of the number of lines for surface treatment from four to three and changes in the technology setting.
   - Proposal of new layout of the conveyer between the test room and the surface treatment line. This solution introduced storage space for products waiting to be surface treated, which led to an increase in the whole operation permeability.
   - Withdrawal of a production branch serving for special painting from one of the lines for surface treatment. The new proposal enabled to save about EUR 150,000 in capital expenditure.
4. **Packaging lines**
   - The packing line capacity corresponds to a production line in the case of packing carried out on pallets. The more time consuming packing in boxes would cause a decrease in packing lines permeability, and thus a creation of a bottleneck, which would threaten the performance of the whole plant. Accordingly, such packing should be carried out in the area away from the packing line.
5. **Department of expedition**
   - In terms of production increase, the existing transport capacity for the final products transferred to the distribution warehouse will be insufficient. Accordingly, it is necessary to take into account an increase in the number of trucks carrying out this transport.

3. Conclusion

The executed simulation experiments enabled us to check the suggested solution for the increase of available capacity of the electromotor production plant from the point of view of its permeability. The bottlenecks were gradually identified, and optional ways of the removal thereof were suggested. On the other hand, superfluous capacity was identified for certain equipment, and the recommendations for efficiency increase of the whole process were suggested.

The presented example proved advantages of simulation application to a verification of planned investment activities in the area of increase of capacity and efficiency of manufacturing operations. In particular, it enabled the verification of the relatively wide range of measurements which can be a source of significant savings in operating costs and capital expenditure.

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