# THE APPLICATION OF VIRTUAL REALITY TOOLS FOR VERIFYING THE DYNAMIC CHANGES IN PRODUCTION PROCESSES

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**Abstract**

The tools of the virtual reality are becoming more frequently used in planning, implementation as well as analysis of production processes. The simulation programmes which offer the possibilities of probable threats of negative impact on the production process allow the application of various corrective actions, which are about to improve the effectiveness of chosen systems and to implement priorities which are individually defined by a particular organisational entity. The article presents the analysis of the influence of the production growth on manufactural capacity of an enterprise as well as the level of generated costs.

**Keywords:** Computer simulation, production systems efficiency, production process

## 1. INTRODUCTION

Computer simulation, in other words the mathematical-logical computer record based on simulation models, which objective is to reflect the real form of the analysed object under simulation. The mathematical-logical record covers the description of relations which aim is to define the object under simulation (the real object including its surrounding) in such a way that is allows its evaluation by the input signals and basic model's parameters change or modification [1]. The complex structure of relations between the following parts of the manufacturing process as well as quite a big quantity of totally dependent parameters (that characterise the process capacities) make the proper production control and prediction of results difficult. The cause - effect results directly influence the effect of particular stages of the analysed manufacturing process [1,2]. The virtual tools for production processes planning and their verifying are used in a situation when the functioning of the linked relations system under analysis is of high percent of uncertainty and when working out the solution with analytical methods is too complicated or not possible [3]. Production enterprises tend to apply the tools of virtual simulation more frequently to plan new production systems or to verify the existing ones. Large popularity of computer simulation and dense competition of companies offering software contribute to wide choice of virtual planning tools on the market, beginning with the simplest based on the mathematical models finishing with the very advanced ones including stochastic system [1].

## 2. DESIGNING SIMULATION MODELS

During production processes the input raw materials change into a final object that is characterised by individual features defined at its designing level. Planning the production process is about defining methods used to manufacture a particular detail as well as designing and describing (in a form of technological documents) the performed operations. It is difficult to predict unambiguously the flow of production process due to great complexity of production processes and randomness of events. One of the methods that allows predicting theoretical results and reflects the real state of the existing production processes is the computer simulation and connected experiments carried out on simulation models [4].

The basic cause that determines the need to carry out the experiment is the necessity of getting to know the behaviour of a chosen system (e.g. manufacture) or as well the structure of algorithms allowing its management and controlling. The term of simulation modelling concerns direct description of objects under simulation (on which the experiments are carried out). One of the main feature that characterises models is the existence of similarities in structure of the defined object and the one being created. Each of the elements taking part in the process is assigned an analogical element of the model responsible for same function performed in the virtual image of the real production process. Therefore, in order to present the analysed process properly, it is necessary to design and build the model which will act as a simulator. The simulator is the outcome of many activities connected with differentiation of unique qualities of the system, their formulation as well as characterising the relations between them [1, 5].

On the basis of the designed and built models describing the flow of particular manufacture processes it becomes possible to match characteristic volumes that determine the way how the whole system functions and its particular elements. While modelling the production processes structures it is necessary to reflect their dynamic character, which requires defining duration of technological actions, size of production stocks and logistic links that determine flow of the analysed manufacture process. The proper model designing and building is a factor that determines the effectiveness of simulation and precision of gathered data [5, 6]. The obtained (as a result of the conducted simulation) results constitute a foundation to conduct further research or may be directly applied on the real physical object. The possible margin of error in the existing misreading between the generated results (in the reality and virtual process mirroring) must be as small as possible. Underestimation ratio level of the assumed parameters may cause a high level of losses incurred by the production plant, and in critical situations, may prevent the effective work of the plant [1, 5].

## 3. VERIFICATION OF THE PRODUCTION CAPACITY OF THE MANUFACTURING SYSTEM UNDER VARIABLE PRODUCTION LOAD CONDITIONS

Production capacity of the selected manufacturing system describes the number of elements produced in a given period of time. The value of the production capacity depends, first of all, on the production capacity of a given devices, availability of the required accessories which are crucial for production, possessed financial measures, workforce as well as appropriate quantities of reserves. Determination of the production capacity volume under hypothetical, constant process conditions is not complex. However, large number of chance events causing disturbances during the production process prevent precise determination of the real production capacity of the system. The most frequent disturbances, preventing the execution of theoretically assumed production volume, include: failures of the production devices, absence of production employees, failure to maintain time frames during the execution of technological operations and delays in supplying raw materials. Emerging problems with regard to disturbances in the production cycle and theoretical possibilities of their aggregation leads to underestimation of the production capacity which is directly connected to the acquisition of orders including reduced number of elements.

Short time to decide on the acceptance of the order does not make it possible to determine the corrected duration of the production process which decides on the possibility to accept the order as well as costs volume and production profitability, if it is necessary to apply additional stations or production personnel. Computer simulation is one of the tools used for analyzing plant production capacity and visual mirroring of costs of manufacturing process under dynamic variability of process factors (input data and production capacity).

The article analyzes the production process of rotary-symmetrical part X. The manufacturing process of the produced part covers seven technological operations. The volume of the production of X constitutes 1150 items per one month (30 days) and the percentage of the lack of production oscilates at the level 2%. The following stations take part in the execution of the production process: saw, lathe, winch, metal station, grinder for holes, surface grinders and quality control station. This process is executed in single-shift system. **Table 1** presents the cycle times ($t_j$) and preparation-completion times ($t_{pz}$) determined by the technologist during the preparation of technological documentation.

**Table 1** Time for the execution of part X

| **Operation** | **10** | **20** | **30** | **40** | **50** | **60** | **70** |
|---|---|---|---|---|---|---|---|
| **$t_{pz}$ [h]** | 0.15 | 0.3 | 0.3 | 0.1 | 0.43 | 0.17 | 0.1 |
| **$t_j$ [h]** | 0.013 | 0.25 | 0.012 | 0.13 | 0.248 | 0.12 | 0.09 |

For the execution of the assumed goal, namely the production of 1150 items of X, it is necessary to apply 20 work stations and engage 23 employees executing defined technological operations. As a result of sudden increase in demand for parts produced in the plant, it was appropriate to increase the production level to level of 1700 items maintaining single-shift system (**Table 2**).

**Table 2** Data and assumptions regarding new production plan

| **DATA AND ASSUMPTIONS** | |
|---|---|
| Monthly production plan (30 days) | 1700 items |
| Percentage share of the lack of production | 2% |
| Number of work shifts | One shift |
| Used means of transport | Forklifts |
| Material reserves | 30 days |
| Number of shifts | 1 |

In order to verify the production capacity of the plant it was necessary to use the simulation model enabling determination of the costs generated by the new production plan assuming the increase in the production size. Created virtual models present the algorithm for placing all production stations, the way of flaw of semi-finished products and organization of the flow of production for assumed volume of produced parts.

In order to assume the necessary number of production stations and operators enabling the execution of the assumed (increased) production plan, the calculation of station consumption for n-details ($S_n$), unit station consumption ($S_j$) and operational station consumption ($S_o$) of particular stations.

**Assumptions:**

$t_{pz}$ = preparation-completion time (**Table 2**)

$t_j$ = cycle time (**Table 2**)

n = 2 (volume of the production batch)

$i_p$ =12 (constant)

$F_n$ = 176 [production hours] (station-related labour fund)

$F_p$ = 160 [man-hour] (employee-related labour fund)

- Station consumption for n-details, $S_n$:

$$S_n = t_{pz} + n * t_j \quad (1)$$

- Unit station consumption, $S_j$:

$$S_j = \frac{t_{pz}}{n} + t_j \quad (2)$$

- Product station consumption, $S_p$:

$$S_p = (t_{pz} + t_j * n) * i_p \tag{3}$$

- Operational station consumption, $S_o$:

$$S_o = S_p * 100 \tag{4}$$

- Total station consumption, $S_c$:

$$S_c = (\sum tj * n + \sum tpz) * ip * 100 \tag{5}$$

- Required number of stations, $L_s$:

$$L_s = \frac{S_c}{F_n} \tag{6}$$

- Required number of employees, $L_p$:

$$L_p = \frac{S_c}{F_p} \tag{7}$$

As a result of the executed necessary calculations (on the basis of possessed input data) results were acquired enabling the identification whether to produce the assumed number of items (1700 items) it is necessary to have: 26 production stations and 28 employees.  In comparison with the production of 1150 items it was necessary to launch 6 additional production stations and engage 5 additional employees. Change in the number of stations and employees concerned the following operations: 20, 40, 50, 60, 70 (**Table 3**).

**Table 3** Results determining the number of stations and employees

| Operation no. | $S_n$ | $S_j$ | $S_p$ | $S_o$ | $L_s$ | Number of stations | $L_p$ | Number of employees |
|---|---|---|---|---|---|---|---|---|
| **10** | 0.18 | 0.09 | 2.11 | 211.2 | 1.2 | 2 | 1.32 | 2 |
| **20** | 0.8 | 0.4 | 9.6 | 960 | 5.5 | 6 | 6 | 6 |
| **30** | 0.32 | 0.16 | 3.88 | 388 | 2.2 | 3 | 2.43 | 3 |
| **40** | 0.36 | 0.18 | 4.32 | 432 | 2.5 | 3 | 2.7 | 8 |
| **50** | 0.93 | 0.46 | 11.1 | 1111 | 6.3 | 7 | 6.94 | 7 |
| **60** | 0.41 | 0.21 | 4.92 | 492 | 2.8 | 3 | 3.08 | 4 |
| **70** | 0.28 | 0.14 | 3.36 | 336 | 1.9 | 2 | 2.1 | 3 |
| **Total number of necessary production stations and employees for the execution of the assumed production goal = 1700 items** | | | | | | **26** | | **28** |

Once the number of employees and production stations have been calculated (enabling the execution of the production of 1700 items) the algorithm of placing particular objects which take an active part in the manufacturing process were built and individual, characteristic (describing their work) volumes were assigned. All stations which take part in the manufacturing process have been divided into organizational cells and were separated with the intermediate storage facility. Once all elements have been placed on the simulation program' operating plate, connections between objects were defined - characterizing the direction of the executed flow of semi-finished products and the line for the executed production works.

In order to obtain results regarding the volume of costs generated by the process which executes constant production plan (1150 items) and increased (1700), each production station was assigned with the assumed cost of work. The volume of the cost of work was calculated on the basis of the analysis of expenditures:

faculty, general management board, theoretical costs resulting from the assumed selling price of the produced element and purchase price of raw materials (**Table 4**).

**Table 4** Costs of work per station

| Operation no. / production station | Cost of work per station [j/h] |
|---|---|
| Operation: 10 / station: saw | 45 |
| Operation: 20 / station: lathe | 60 |
| Operation: 30 / station: winch | 60 |
| Operation: 40 / station: metal station | 30 |
| Operation: 50 / station: grinder for holes | 55 |
| Operation: 60 / station: surface grinder | 55 |
| Operation: 70 / station: quality control | 30 |

Data on the level of costs were entered to FlexSim simulation program and then the simulation of the manufacturing process was executed (**Figure 1**).

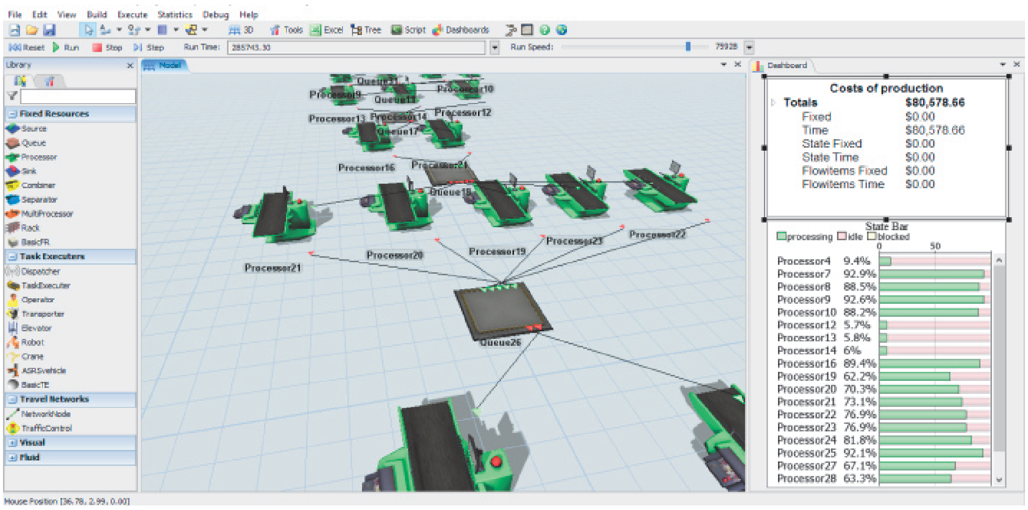


**Figure 1** Sample simulation for cost verification

## 4. COMPUTER SIMULATION AND DATA ANALYSIS

During the first phase, the analysis covered the production process of 1700 items without the changing the structure of the plant (with the use of 20 production stations and 23 operators). These lead to the results on the basis of which it was was not possible to execute the assumed production plan owing to too high (exceeding the standard) level of the use of particular production stations (**Table 5**). The next phase covered the simulation for two production volumes with the use of existing and future system for placing production stations and including the increased number of operators (26 stations and 28 operators).

**Table 5** The load of production stations when producing 1700 items (20 stations / 23 operators)

| Operation no. | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|---|
| Load | 13% | 99% | 10% | 96% | 80% | 90% | 67% |

On the basis of the conducted simulation the results presenting total level of production costs ($K_c$), real production costs ($K_p$) (generated during the operation of the station) for two analyzed production volumes and the level of load for the selected technical devices were obtained. In order to calculate the real time of engagement of particular stations, in the executed production process the percentage share with regard to the total time of the manufacturing process was calculated (**Table 6**).

**Table 6** Production process costs for two production options

| Number of items | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | ∑ |
|---|---|---|---|---|---|---|---|---|---|
| **1150** | **$K_c$ [j]** | 7144 | 19107 | 14289 | 4760 | 21830 | 8732 | 4760 | **80578** |
| | **$K_p$ [j]** | 621 | 18632 | 1321 | 4236 | 17027 | 7858 | 3094 | **52780** |
| **1700** | **$K_c$ [j]** | 9238 | 24648 | 18480 | 6156 | 28233 | 11293 | 6157 | **104208** |
| | **$K_p$ [j]** | 845 | 23145 | 1756 | 5432 | 22645 | 10451 | 4115 | **68389** |

The total cost of the production process ($K_c$) when executing 1150 items and engagement of 20 production stations and 23 operators constituted 80578 j, while producing 1700 items and the use of additional number of stations and production personnel constituted 104208 j. Owing to direct impact of the duration of the process on the level of costs when producing 1700 items, the costs of station operation are higher than when producing 1150 items (**Figure 2**).

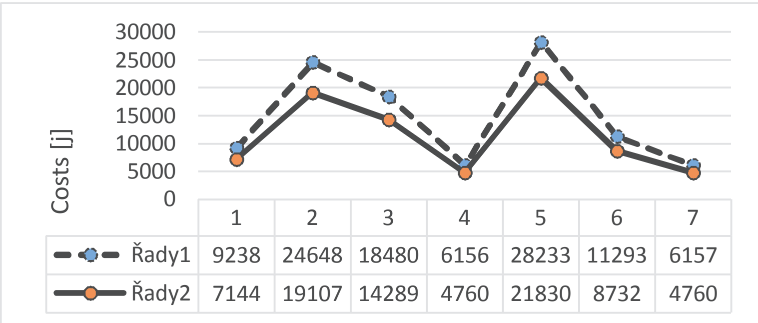


**Figure 2** Costs generated by selected production stations

## 5. CONCLUSION

Dynamically changing conditions for business activities executed by production companies, intensity of the competence and the development of new technologies resulted in the fact that companies must seek solutions which make it possible to plan and assess the course of the executed process [8]. Virtual tools for planning the production process make it possible to execute complex calculations which enable to analyze given problems with a certain, not defined level of uncertainty. The possibility to verify organizational-process solutions make it possible to predict the results of their application and implement various corrective measures increasing the production capacity of the analyzed manufacturing systems.

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