Int. j. simul. model. 4 (2005) 4, 173-183
ISSN 1726-4529 Original scientific paper

SIMULATION BASED DESIGN AND RECONFIGURATION OF PRODUCTION SYSTEMS

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Abstract

In the time of constant changes in market demands for certain products and their amounts, time to market period is limited by the increasing competition influence. The global approach allows multinational and trans-national companies, by being present in great many markets, to market their products, which are made as a result of mass production, in smaller amounts at separate markets, leading to price decrease of these products. This conditions the need to find a way for the shortest answer possible for every customer's demand, with respect to their demands. The time for designing a product, working process and production system, procuring necessary material, equipment and tools, production and delivery should not be the reason for a decreased degree of competitiveness. This paper presents the approach in developing a method for designing production systems supported by building simulation model of the system and the working process by specialized software. Results and information acquired by simulation process should make possible the analysis of the proposed variations and making the decision on designing and later on reconfiguration of the production working unit at the moment when the values of the critical number of parameters exceed the limits of allowed deviations.

(Received in May 2005, accepted in October 2005. This paper was with the authors 3 months for 2 revisions.)

Key Words: Production System Reconfiguration, System Designing, Simulation Software, Model, Optimisation

1. INTRODUCTORY NOTES

Contemporary corporative approach marks the activities which are not rarely used by a company to define first the market strategy, including the selection of products and competitive characteristics (amounts and prices), and then to define the integral production system which should fulfil the previously stated demands, as well as financial limitations [1]. The mentioned approach in system formulation leaves very little space to establish an effective production system based on real premises. The opposition to the real situation in the area of developing production systems can be noticed in the observation emphasizing the strategic role of production process in creating business strategy in a company, going all the way as to come to the statement that the competitiveness of a company depends on its production characteristics. Forming an effective production system as a result of the applied principles and methods produces a production program made by a set of products with precisely defined production capacity often presented by the ratio of program structure and amounts connected to certain products p_j/q_j. Products defined in such a way, by the change in time, influence the degree of the system flexibility stipulating too large complexity in material flows in the system. System flexibility, as one of the very significant characteristics, influences all the other designed system properties since it offers the possibility for successful adjustments that appear in uncertain surrounding conditions. A high degree of system efficiency can be achieved by the proper combination (integration of significant

DOI:10.2507/IJSIMM04(4)2.047

characteristics) and the influence of the system flexibility factor on creating marketing and sales strategies. The presented approach expresses the strategic formation of integrated production systems. One of rather simple answers to the stated demands is the introduction of the decision support system which allows testing various scenarios and simpler reaching of the optimal solution. A suitable tool for finding a solution often implies the use of a simulation program for discrete event simulation modelling, since, adjusting certain parameters, the model can easily present the continual, or as often is the case in practice, combined process.

In early phases of system design it is essential to ensure information that speaks in favour of project feasibility. Contemporary design methods, like concurrent engineering, demand a high degree of coordination of the employees' teams for various assignments. The role of a consultant is better and more significant in the area of developing production systems. The experience and knowledge received from him becomes a real value in the period that follows in developing human society. "Knowledge economy" presents a business environment based on knowledge as the fastest and easiest renovated resource that starts production.

Technical development brought progress asking for new procedures for using the given possibilities. Modern machine tools integrated on the principles of CIM now need trained professional workers to manage them, since the rest of the work, determining and defining operations of principle, approach, and process parameters, is already finished working phase done by the machine manufacturer. Usage characteristics define a significant group of operations possible to perform on one machine, which completely changes the appearance of a production plant. Instead of lines for production and assembling that contain over dozens of different machines, now the production process is executed at only few working places. The increasing importance in this case is to define interdependence of working places, which in the mentioned process become complex functions with more variables.

Historically, the ideology of production system design that we consider traditional originates from a period following World War II, the mass production of products was widely used. At the same time, the production system widened its working area, overcoming the production of a larger amount of products. In the stated period, the paper of Skinner [2], who explains how the production system can fulfil the market demands in limited production, was considered a significant one. The bases for system design according to the concept of a factory within the factory can be found in the papers by Hayes and Wheelwright [3]. From the above, taking into account more and more present product invariability and changeable market demands, it is possible to draw the conclusion that one-way approach, whether upwards or downwards, cannot give sufficiently stable foundation for designing production systems according to earlier stated demands. Almost any type of manufacturing system can be modelled as a discrete event system. Discrete event systems are dynamic systems, which evolve in time by the occurrence of events at regular and irregular time intervals; examples are flexible manufacturing systems, production assembly lines and traffic transportation systems [4]. The new type of manufacturing system, which is called the *reconfigurable manufacturing system,* will allow flexibility not only in producing a variety of parts, but also in changing the system itself. Such a system will be created using basic process modules hardware and software that will be rearranged quickly and reliably [5].

2. PROBLEM AND OBJECTIVE OF RESEARCH

If out of all the segments in a supply chain we separate production that encloses period and actions from material input into production space to storage of final products, implying all the processes of elements shaping, material handling, assembling and control during and at the end of the process, then we can determine that there is a range of questions whose answers would lead to fulfilling the set demands at the very beginning, in introductory observation. Forming the effective production system implies placing the foundations for optimal usage of given resources. The given system has to be reconfigurable, which is a consequence of built-in flexibility, in the needed measure in a very short time period, for which it is necessary to ensure designing a new appearance, content and characteristics of the system with relatively certain effects of the presented change.

2.1 Approach in developing production system

The concept of system development is based on the results and observations derived from the analysis of system state and it is made of activities in the order as follows:

- production program development,
- working procedure development,
- system spatial structure development [6].

Intensified synthesis of statements by Mintzberg [7], who claims that the approach from up downwards in setting a process is the past and that it is not suitable in most cases, and statements by Ackoff who says that the strategic planning process is an essential procedure in system formation, can lead to the conclusion that making strategic decisions is in a direct relation to the system designing itself which should ensure certain working processes. The usual manner in designing a working/production system is defined as the process going from up downwards. At the beginning the product and the market are identified, which is followed by system designing that should fulfil certain requirements. This type of approach receives almost full affirmation in the case when the beginning is from the green field, yet the conditions are significantly more complex when one is dealing with an existing system. In behalf of condition complexity one can state uncertain conditions of business environment which demand not only setting the system that can fulfil market demands in a given moment, but also controlling and managing a system in a certain time period. Essentially, the approach in production system designing should provide the answer to the question as to how to set a system that would in a necessary measure be directed (focused) to fulfilling specific demand and at the same time flexible. Synthesizing the approach from up downwards and from down upwards, stated by Mintzberg and Waters [8], and introducing a time variable, it is possible to have an influence on the reduction of times that do not directly contribute to in-building added value of a product.

The influence on the optimization of working process duration from the aspect of technological design conditions can be performed by introducing the following activities:

- eliminating all times that do not build in added value and times in quitting,
- launching working orders in shorter time intervals, so that the working object could spend the shortest time necessary in the system,
- introducing parallel and combined ways to connect operations.

The above given procedure is a manner to increase the level of system readiness for effective answer to market demands. The notion of a manufacturing cell life cycle appears more and more in the systems where the production is shaped according to group technology and spatial order that implies manufacturing cell as a basic unit. It is obvious that the system spatial structure design is performed on the basis of static input figures, not regarding the time dimension.

Manufacturing cell life cycle can be successfully managed so it could be lengthened with as little intervention as possible, while the period until reconfiguration would be postponed. However, the intensity of changes according to the above requires the need for the reconfiguration of the production system or its segments.

Since the intensity of changes in time is increasing, it is necessary to determine the ratio of the time that the system spends in work and the time of system reconfiguration. In connection to it, it is simple to prove that the non-functional time appears more often and presents a significant contribution to inefficiency in work.

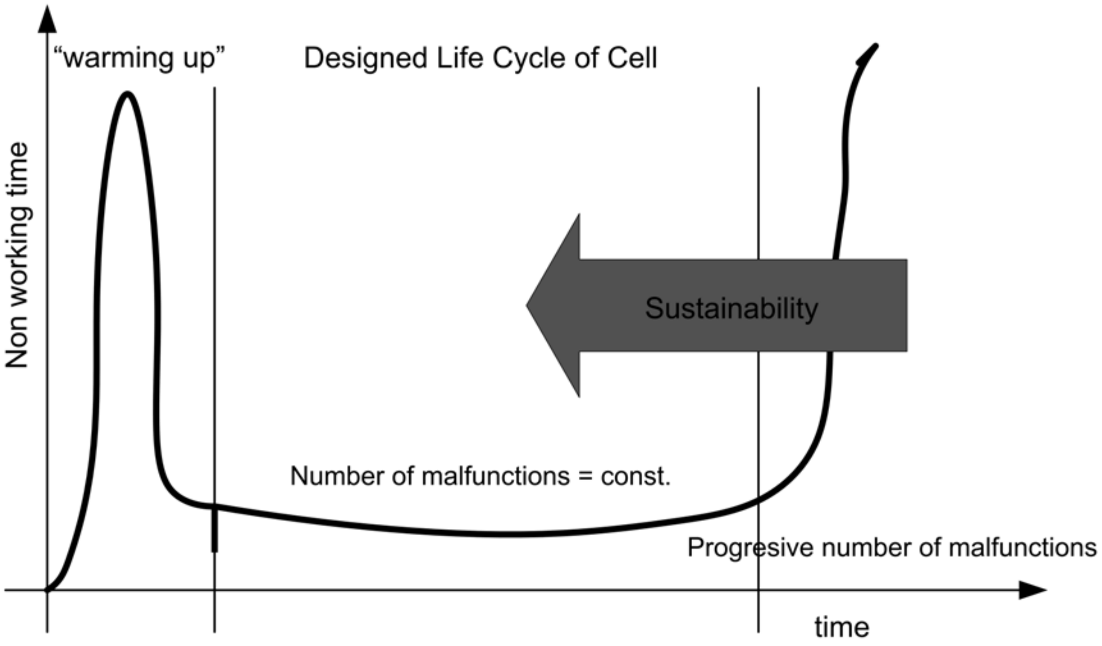

Figure 1: Life cycle of production cell.

Simulation is considered as a very important computer aid to the design process, partly because of the increased complexity of manufacturing systems and partly because of their dynamic and stochastic behavior [9].

2.2 Non-functional time

Non-functional time during the production system life cycle presents the time when the production system is in the state of quits not because of system elements quitting, but because of inability to fulfil market demands. In the given case it is inevitable to perform partial or complete system reconfiguration. Time period of returning the system to the position IN WORK can be divided into two segments, the system reconfiguration time ($_0T_{pr}$) and the time for preparing working places for production (T_{pz}). Reconfiguration time presents the figure which is significantly dependant on system properties built in during the design. In time, the influence of the built-in characteristics weakens, while the need for more effective methods (rapid planning) in system design becomes intensified. Total system working time can be divided to the period when the added value is built into the product (value added time) and the period when the system is prepared for work (non value added time). Applying different methods for determining potential effects by introducing changes into the system, the time is shortened and the possibilities for predicting effects of the system in the subsequent period are increased. Analysing life cycle of a production system or its segments, it is possible to determine that the certain activities lasting for unequally long time period are repeated. Production system design process is a part of the first observed period T_o. That period also contains the processes for work preparation and the production itself which are repeated a certain number of times. Repeating number depends on the relation system-surrounding and built-in starting system flexibility. When, in time, production program and production volume are changed a number of times, there appears the need for system reconfiguration.

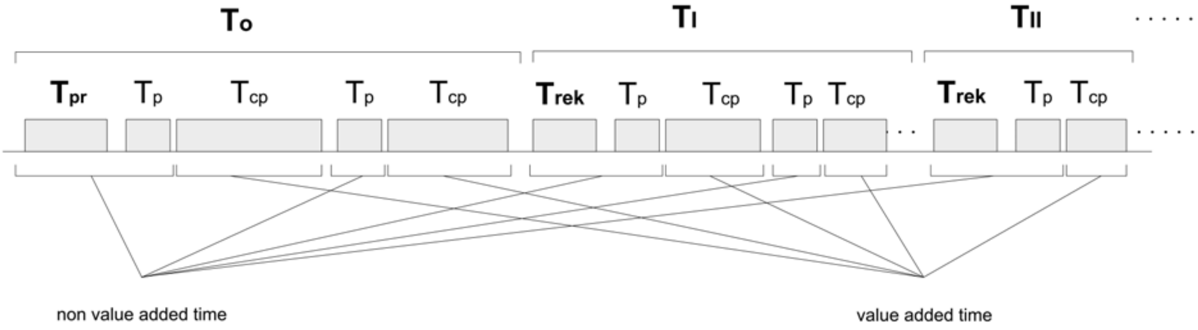

Figure 2: Reconfiguration intervals.

Periods T_I, T_{II}, ...T_n (Fig. 2) present time intervals during which, instead of system design process, there appears a new process of system reconfiguration. It is easy to observe the trend of the decrease of length period under observation, which is also shown by statement (5). The problem is presented in the ratio of the time for building added value into a product and total time for system work which is constantly decreasing. T_{cp}, production cycle duration length, which is proportional to the size of a batch of working objects, reduces with the decrease in production volume.

Therefore, the length of duration of T_o processing period, after the production unit is set for the first time, is determined in the following way:

$$T_o = T_{pr} + \sum_{j=1}^{k} \left(T_p + T_{pc} \right)^{(j)} \tag{1}$$

while each subsequent interval can be defined by expressions as follows:

$$\begin{aligned} T_I &= T_{rek} + \sum_{j=k}^{l} \left(T_p + T_{pc} \right)^{(j)} \\ T_{II} &= T_{rek} + \sum_{j=l}^{m} \left(T_p + T_{pc} \right)^{(j)} \end{aligned} \tag{2}$$

where

k, l, m – numbers of different working objects which can be manufactured during one reconfiguration period T_I, T_{II} etc.

Since the preparation of the working place and technological system requires more profound analysis and since very often the size is designed by the manufacturer of the technological system, it means in the stated observations that: $T_p = const.$ and then:

$$\sum_{j=k}^{l} \left(T_p + T_{pc} \right) = \left(l - k \right) T_p + \sum_{j=k}^{l} T_{pc}{}^{(j)} \tag{3}$$

It is known that:

$$T_{pc} = f\left(q_j \right) = a + t_{ii} q_j \tag{4}$$

while from the hypothesis it can be concluded that:

$q_j^{(i)} < q_j^{(i+1)}$ and $(l-k) > (m-l)$

which means that smaller and smaller number of different working objects can be manufactured during one reconfiguration period. Finally, taking into account all the above mentioned, it follows that:

$$\sum_{j=k}^{l} T_{cp}^{(j)} > \sum_{j=l}^{m} T_{cp}^{(j)} \Rightarrow T_I > T_{II} > T_{III} > \ldots \tag{5}$$

Modified degree of non-functionality presents the relation:

$$\begin{gathered} \eta_n^I = \frac{T_{rek}}{T_I} \\ \eta_n^I > \eta_n^{II} > \eta_n^{III} \ldots \end{gathered} \tag{6}$$

This proves that the degree of system non-functionality increases when the size of batches q_j decreases and during the process it changes the production program, conditioning the possibility of processing smaller and smaller number of various segments during the reconfiguration period.

If T_{rek} which presents the time for designing and repositioning working places of the same or changed functional content decreases, it would directly, according to (6), condition the decrease in system non-functionality degree. The alternative solution presents the increase of reconfiguration period T_I, which presents the very market behaviour and whose change does not depend solely on system behaviour, but it is also conditioned by surrounding elements, competition systems, etc.

2.3 Research objective

Taking into consideration the momentary state in the field of production system design, it is possible with assured certainty to determine working direction towards the improvement in designing conditions through ensuring necessary information at the very beginning and during designing system production structures. One of automation processes for production system design presents the usage of working process simulation results performed on the specially shaped working system model. In the research results of the stated problem it is necessary to formulate design procedures which would enable:

- *the decrease in total time necessary for designing and reconfiguration* of the production system with respect to stated limitations.

3. SIMULATION MODEL DEVELOPMENT

The concept for dynamical modelling of flexible manufacturing systems has been developed with the aim to increase the quality of designed ***effective production systems*** [10]. This effectively is the complex term consisting of the range of indicators such as: flexibility, reliability, quality, efficiency, etc., with parameters that have to be determined. The proposed concept therefore assumes the introduction of simulation as a necessary tool, providing a more realistic picture of the assembly system behaviour during the exploitation period. As a result of the previous research conducted at IIM was developed Simflex simulation language. Simflex software has been developed in C programming language requiring the following input data:

- statically designed alternatives of the assembly systems - detailed layout of the system,
- structure of the production program and the assembly process plans,
- production plans foreseen to simulate.

The simulation is carried out in planning period (shift, week ...) according to the dynamics expected in the exploitation period. It is possible to monitor the changes on the elements of the system as well as the flow of material from the input buffers to the output buffers. After the simulation has been finished following reports can be obtained:

- throughput time of the simulation Tcp,
- up and down time for each of the workplaces Twp,
- utilization of the work places η,
- maximum number of products that can be assembled during the planning period ($Q_{j\,max}$),
- maximum number of product variants that can be assembled during the planning period ($P_{j\,max}$),
- flexibility level of the designed alternatives,
- etc.

The simulation results pointed out the significant distinctions between the required capacity (simulation) and the analytic (static) calculation and provide control of the statically designed variants upon the predefined requirements, finding and eliminating the bottle necks of the system, evaluation of the systems flexibility, determination of the number of workers, etc.

Developing simulation model as a support in design, effective production system is presented on the bases of set theoretic foundations describing the application of specialized software for system simulation (Arena®7.0) which contains subprograms for analysing the work of production system (Factory Analyzer) and optimization of the sizes under observation (OptQuest). The problem observed in this study is presented in setting and formulating material flows in production processes, determining the number of technological systems necessary for performing operations with defining their usage degree, determining the number of necessary workers and spatial order of working places. The problem is marked as adequate, since it provides the necessary foundations and limitations that demand for the application of sophisticated simulation software.

The company's production program, whose model has been developed and simulated, encircles products made of four modules. Modules can be made of braces which can appear in six different shapes, combined with a short or a long pipe. Furthermore, every of the brace shapes can appear in one out of three different colours. The observed production problem is connected to the brace painting operation which can have different preparation period. Time needed for changing the paint container is 10 seconds, while the time needed for tool change is 30 seconds. All the stated leads to four various events during the production process:

1. same working objects painted in the same colour ($t_{pz} = 0$),
2. same working objects painted in the different colours ($t_{pz} = 10$ s),
3. different working objects painted in the same colour ($t_{pz} = 30$ s) and
4. different working objects painted in the different colours ($t_{pz} = 40$ s).

Forming working units, basic holders of production process in accordance with the group technology principles of the stated production system, presents the task with a large number of different solutions. To reduce the cluster of potential solutions it is necessary to find tools that would, in short time period, give information necessary for designing, and later for system reconfiguration. According to that, a production system model for producing flexible pipes has been developed as given in Fig. 3.

Table I presents t_{pz} that varies as given above in dependence on the nature of relation of i and $i+1$ working object.

If we include into observation the model with two working units which would ensure working object classification, we can acquire the solution which is the most suitable. In the same way, if the working objects are divided into several different technological systems belonging to various working units, the most suitable solution could be gained (Table II).

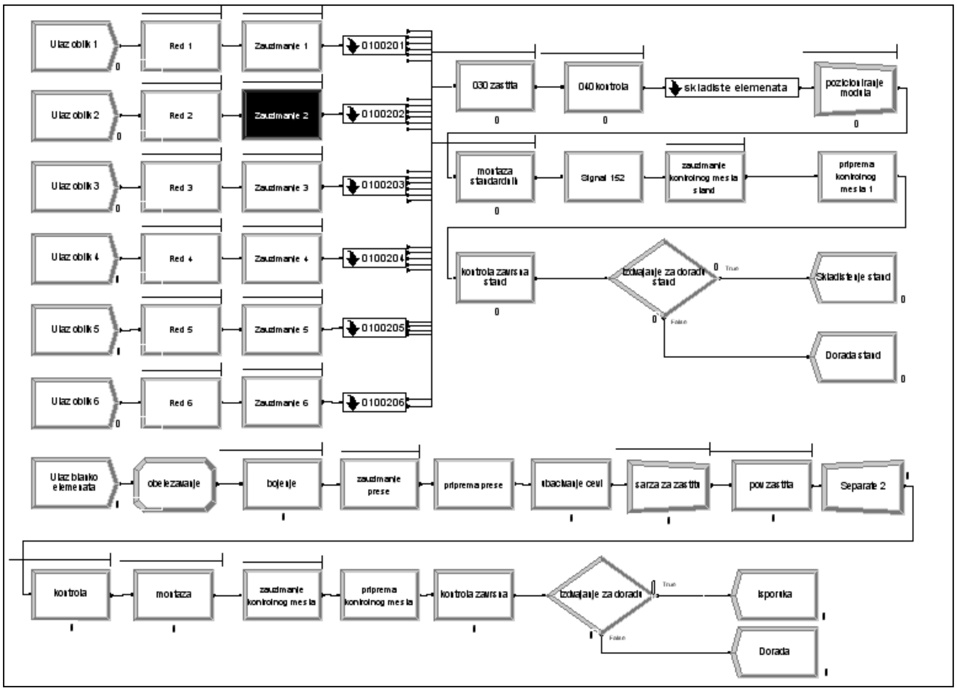

Figure 3: Developed model of VM production system.

Table I: Waiting times in random case (go to idle).

i i+1	1R	1B	1G	2R	2B	2G	3R	3B	3G	4R	4B	4G	5R	5B	5G	6R	6B	6G
1R	10	20	20	40	50	50	40	50	50	40	50	50	40	50	50	40	50	50
1B	20	10	20	50	40	50	50	40	50	50	40	50	50	40	50	50	40	50
1G	20	20	10	50	50	40	50	50	40	50	50	40	50	50	40	50	50	40
2R	40	50	50	10	20	20	40	50	50	40	50	50	40	50	50	40	50	50
2B	50	40	50	20	10	20	50	40	50	50	40	50	50	40	50	50	40	50
2G	50	50	40	20	20	10	50	50	40	50	50	40	50	50	40	50	50	40
3R	40	50	50	40	50	50	10	20	20	40	50	50	40	50	50	40	50	50
3B	50	40	50	50	40	50	20	10	20	50	40	50	50	40	50	50	40	50
3G	50	50	40	50	50	40	20	20	10	50	50	40	50	50	40	50	50	40
4R	40	50	50	40	50	50	40	50	50	10	20	20	40	50	50	40	50	50
4B	50	40	50	50	40	50	50	40	50	20	10	20	50	40	50	50	40	50
4G	50	50	40	50	50	40	50	50	40	20	20	10	50	50	40	50	50	40
5R	40	50	50	40	50	50	40	50	50	40	50	50	10	20	20	40	50	50
5B	50	40	50	50	40	50	50	40	50	50	40	50	20	10	20	50	40	50
5G	50	50	40	50	50	40	50	50	40	50	50	40	20	20	10	50	50	40
6R	40	50	50	40	50	50	40	50	50	40	50	50	40	50	50	10	20	20
6B	50	40	50	50	40	50	50	40	50	50	40	50	50	40	50	20	10	20
6G	50	50	40	50	50	40	50	50	40	50	50	40	50	50	40	20	20	10

Table II: Waiting times in case of separate cells.

i i+1	1R	1B	1G	2R	2B	2G	3R	3B	3G	4R	4B	4G	5R	5B	5G	6R	6B	6G
1R	10	20	20	40	50	50												
1B	20	10	20	50	40	50												
1G	20	20	10	50	50	40												
2R	40	50	50	10	20	20												
2B	50	40	50	20	10	20												
2G	50	50	40	20	20	10												
3R							10	20	20	40	50	50						
3B							20	10	20	50	40	50						
3G							20	20	10	50	50	40						
4R							40	50	50	10	20	20						
4B							50	40	50	20	10	20						
4G							50	50	40	20	20	10						
5R													10	20	20	40	50	50
5B													20	10	20	50	40	50
5G													20	20	10	50	50	40
6R													40	50	50	10	20	20
6B													50	40	50	20	10	20
6G													50	50	40	20	20	10

3.1 Size optimisation in the simulation model

In the process of analysing simulation model it appears essential to determine the combination of input sizes which in the simulation process result provides optimal (minimal, maximal, that is, suitable) key output effects/sizes [11]. The result of the paper presented problem of the need to shorten time for production system design and reconfiguration significantly relies on the results of the application of the offered solution optimization methods.

Applying OptQuest tool program for simulation Arena, with variable starting conditions for optimization, the results presented in the Table III have been gained.

Table III: Distribution of parts on the working cells with different starting conditions (OptQuest process results).

Pre-Conditions (1,1,1,1,1,1)							
Simulation	Min. Time Entity1	shape_1	shape _2	shape _3	shape _4	shape _5	shape _6
1	3.17986	1	1	1	1	1	1
3	3.13542	1	1	1	1	1	2
5	3.09514	1	1	1	1	2	2
9	3.08958	1	1	1	2	2	2
18	3.03264	1	2	1	1	1	1
19	3.02708	1	2	1	1	1	2
20	2.99375	1	2	1	1	2	1
Min: 24	**2.98819**	**1**	**2**	**1**	**2**	**2**	**1**
Time for finding the optimal value: 55 sec							
Pre-Conditions (1,1,1,2,2,2)							
Simulation	Min. Time Entity1	shape_1	shape _2	shape _3	shape _4	shape _5	shape _6
1	3.08958	1	1	1	2	2	2
18	3.03264	1	2	1	1	1	1
19	3.02708	1	2	1	1	1	2
20	2.99375	1	2	1	1	2	1
Min: 21	**2.98819**	**1**	**2**	**1**	**2**	**2**	**1**
Time for finding the optimal value: 45 sec							

Main objective set in the optimization process is:

- minimum time for keeping the working object in the system.

As it can be seen from the table, the best solution with the set conditions presents the classification of working objects into two technological systems according to the following:

PRJ 1 (shape 1, shape 3, shape 6)
PRJ 2 (shape 2, shape 4, shape 5)

Optimization process was repeated twice, but the starting conditions were changed, which led to different duration of optimization process. This presents the importance of previous knowledge of system behaviour as the advantage in system reconfiguration process. Graphic presentation of the optimization process is given in Fig. 4. Insufficiently precise selection of limitations and starting conditions can lead to the error of finding local minimum instead of final suitable solution. It can happen when, by mistake, the optimal solution remains outside the defined limitations. The application of genetic programming can overcome this problem relatively simple.

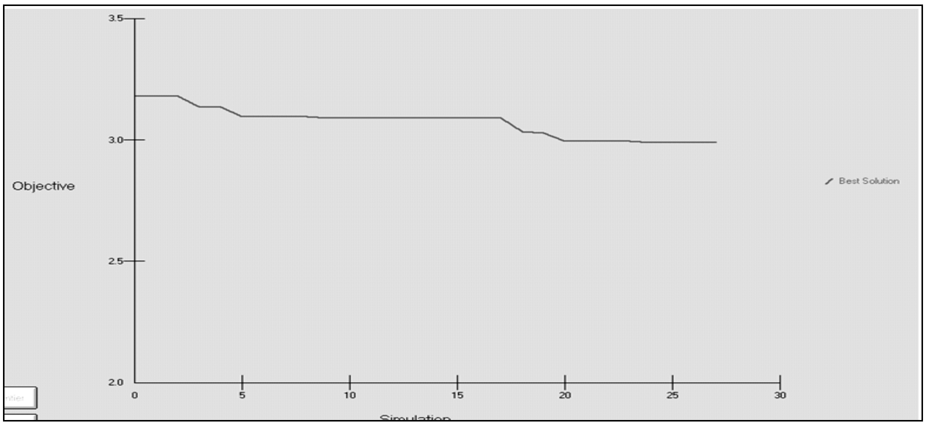

Figure 4: Optimisation of parts distribution.

5. FURTHER RESEARCH DIRECTIONS

Applying group technology (GT) in modelling material flows in the system, significant advantages are achieved, and drawbacks observed while individual design approaches are removed. Group approach in modelling flows influence the solution of oppositeness found in the aspiration that the function is provided with technological systems of higher order which are in the case of wide range of production programs completely unprofitable. Forming modules, then operational groups is a manner to directly influence the increase in amounts processed in separate operations. Observing the sizes through the prism of application of simulation model and executing comparative analysis of the well-known way to determine sizes and their optimization and simulation results of the set model, there appears the key difference seen in the time necessary for calculating relevant sizes and predicting system behaviour after local or global change.

If the first two above mentioned important values are placed in the group of characteristics significantly dependent on the behaviour of surrounding/market, there remain, as the objects of observation, the degree of technological complexity as the value significantly dependent on the observed technological systems and the capacity of system elements.

The noticed “throat” in the system presented as the operation of working objects painting was observed with the introduction of certain improvements. Setting two technological systems instead of one, the situation is significantly changing. The presentation of situation change and the effects made by the change (throat dislocation to another operation) are clearly and simply shown in the paper. Using traditional methods for system design, the change chain noticed while changing the capacity in the painting operation could be defined by renewed system element calculation, where it should be repeated as many times as the there are operations performed on the working object after the stated operation.

Quantifying the above is not necessary, considering the obvious speed of calculating the necessary values. On the other side, time, energy and creativity can be used for developing different variations of system setting.

Taking into observation the sizes gained by the process of material flow optimization through varying the shapes of working objects which are processed on the first, that is on the second machine of the stated operation, one comes to conclusion that the process simulation can be further improved by building experienced knowledge while defining starting values in optimization process.

Finally, the time needed for finding function optimum with the condition of time minimum of keeping the working object in the system is less than one minute. Striking improvement receives its final marks only when the optimization process by applying OptQuest tool is introduced to the large number of places in the system predicting the possibility of alternative solution.

ACKNOWLEDGEMENTS

The research was partly realized within the activities of the CEEPUS II Project (CII-SR-0065-01-0506). The authors thank two anonymous referees for helpful suggestions on the manuscript.

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