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METHODOLOGY FOR ANALYSIS OF FUNCTIONING AND IMPROVEMENT OF PRODUCTION SYSTEMS BASING ON COMPUTER SIMULATION

Abstract

Modelling and simulation with optimization finds wide usage in the improvement of production systems. Production systems are so complex, that without computer it is not possible to realize detailed analysis of processes taking place in them. The methodology for realization of simulation projects with ARENA for improving production processes is presented in this paper.

1. INTRODUCTION

A designing process and also the analysis of production system functioning embrace a series of subsequent activities realized one after the other or simultaneously. Such an activity can consist of a group of stages, one stage, phases, runs, actions, etc. Each activity is characterized by plurality of solutions. From all the existing solutions, it is possible to distinguish for realization a set of possible solutions from which we should eliminate non-perspective ones, which will not give satisfactory solutions.

As a result of execution of the proposed variants evaluation, it is possible to select solution, which is optimal according to the chosen criteria. The proper solution of optimization already on the stage of conception study and construction design should take into account the evaluation from the point of view of time, cost and quality criteria. The same relates to next stages – designing of production processes and their organization. These aspects should be the basis for realization of simulation projects, and also the simulation method can be a tool for creating feedback between construction and technology.

The starting point for the introduction of new undertakings is general business plan and manufacturing strategy, creating the basis of an integrated programme. The strategy comprises both adaptation of a new technology and getting rid of the old one. In case of multi-plants companies the latter procedure is not necessarily the result of the first one. An international company, taking over new technology, usually leaves the old one in its other, foreign plants [2, 6].

Growing attention has been lately paid to the organizational side of implementation processes. The most crucial clues comprise the following items [6]:

– one of the managers should be responsible for production strategy and production operations,

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- the departments of marketing, design, production and finances should be tightly bound, especially in the period of a new product development,
- the board of directors should be responsible for the research and development of products and production processes,
- initial planning and estimation of company capabilities should be carried out by the core of a technically qualified group having time and resources,
- in an early phase of research and evaluation of projects related to new products and production processes, book-keepers should be engaged for cooperation,
- it is advisable to prepare procedures informing workers of all levels and trade unions about company's competitive position, its investment plans and to consult these issues with them,
- a system of labour planning should be worked out to deliver current information both about skills and experiences of company staff and about potential need to start special trainings for updating knowledge and qualifications.

Designing is a sequential process where some activities can be performed simultaneously. At different stages some characteristic activities are repeated several times, so it is also an iterative process. A production process can be designed for conditions of existing production system (the most often occurring case) or for a new or restructured production system. The activities can have a postulating character (management instruction, how it should be done) or a descriptive one (how the others do it, relying on a description of each standard cases of designing) [2, 5, 6].

2. STAGES OF IMPROVEMENT PROJECT REALIZATION

Each project of a production process consists of activities presented in figure 1. The stages of this process are described more exactly below.

Elaboration of task conception

Within the limits of project preparation, starting from an idea, the project's justification is defined and the rightness of first formulas as well as consistency of the idea is verified. Methods and means used in this case are: environment's analysis, exchange of opinions, finding data, analysis of similar projects [5, 6].

Within the limits of a stage both composition and roles of the team as well as the participants of the project are determined:

- decision-makers – a person or a collective body independent from the team project, (e.g. company manager), who decides about project's proceeding etc.,
- the project team,
- experts – a person or a team of specialists making suggestions in regard to the solution of the problem, which is connected with the realization of the undertaking,
- operators – e.g. the machine operators who are executing the given prototype, the proper product,
- receivers – users, who are the addressees of the project and production works.

One of the first activities is often the analysis of feasibility. It is the first estimation of the proposals coming into being. It refers to technological risk, the necessity of development and application works, to the size of the required investment, to the basis costs of the production and probable profits coming from the acceptance and use of a new technology. Production strategy delivers the criteria, by means of which we can estimate the presented proposals. It is the most profitable period for considering the alternative technology and processes as well as the levels of preferred technologies and systems. The analysis of feasibility is often an unofficial form of activity. Significant organizational resources can be engaged only after confirmation of feasibility and assigning the design status to the research.

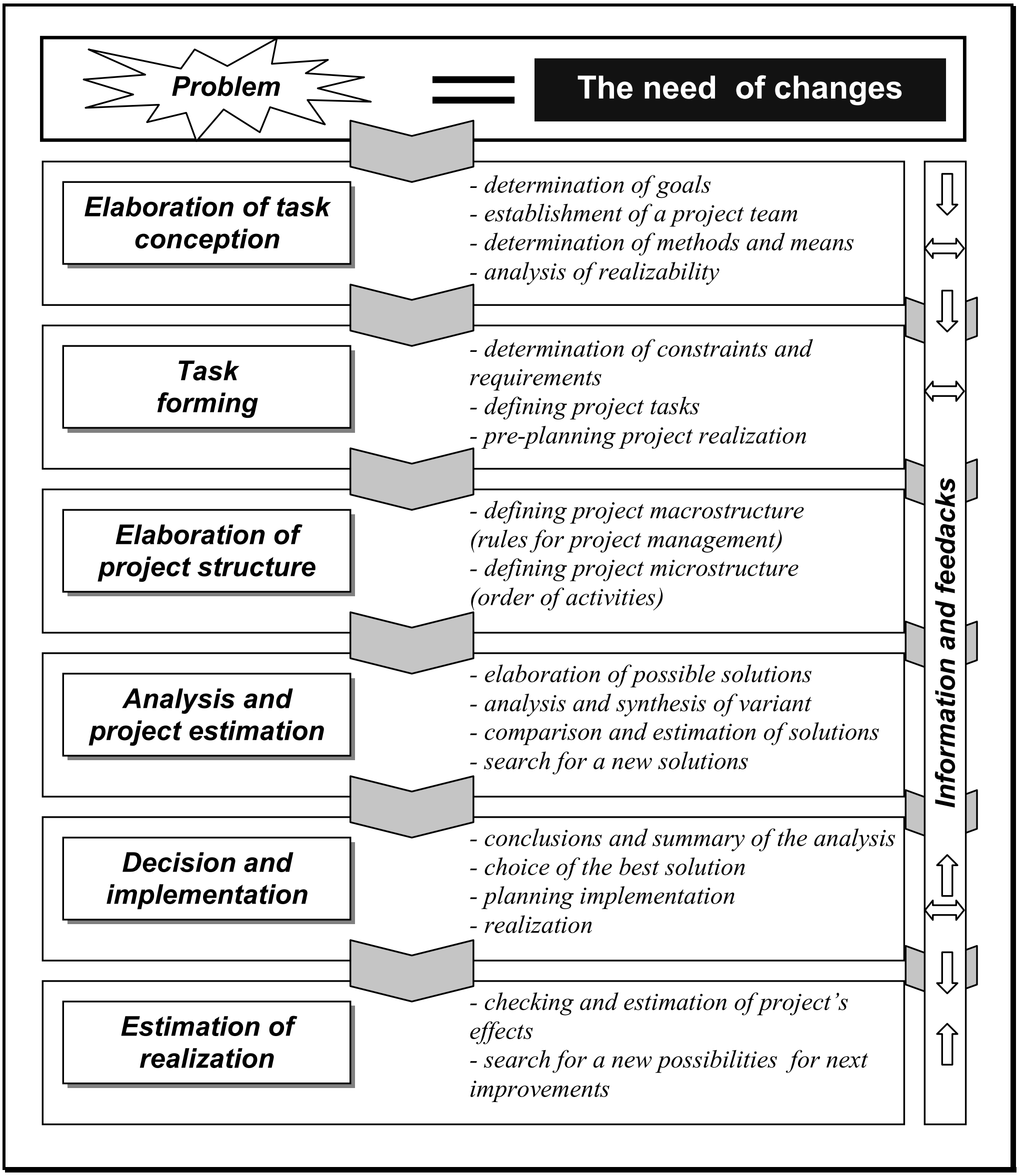


Fig.1. Stages of production system improvement

Task forming

At this stage of the design process, the project of the production process is precisely formulated, the constraints and project requirements are determined, the superior and the detailed goals of the project are distinguished for presentations and adjustments with the decision-makers. The task forming is realized according to the following phases: analysis and synthesis, planning of the design works, quantitative description of the task. Determination of the project structure and delimitation of the variables of the design process is very helpful here.

Project structure elaboration

Within the limits of the analysis, the project structure is determined. The following issues can be distinguished here:

– macrostructure (arrangement of the whole undertaking, its inspection, calculation, controlling, tasks' hierarchization and partition, making decisions, delivery of information),
– microstructure (which is connected with each particular task realized by a given contractor) is understood as an order of activities of particular design process.

Microstructure can concern [6]:

– successive task units ordered one after another
– simultaneously realized tasks units (in case of solving tasks with autonomous character, we have to deal with decomposition in designing).

The factors, which permit to distinguish the elements of the process structure, are:

– main decisions in the process,
– dissimilarity of each activity,
– features of individual performers.

Each phase of the macrostructure should be realized in accordance with the project microstructure.

Analysis and project estimation

This stage contains issues connected with searching for the process design solutions according to its structure specified in the previous point, analysis and synthesis of solutions, exact research, diagnostics, searching for a collection of possible solutions, estimation of solutions and putting forward hypotheses for decision-makers.

Analysis and estimation of the project can be done by means of modelling and simulation method. The proposed solutions can be modelled. By computer simulation, the future behaviour of a production system can be analysed with reference to the assumed criteria e.g. time, costs, or quality. This way we can estimate and compare several proposed variants of solutions. The simulation results are the source of indispensable information for decision making which should be undertaken at the next stage of the project.

Decision

The issue of choice consists in accumulating and transforming information, whose target is making a decision. The taken decisions can be different. Mostly, it is a choice of the variant from the proposed solutions, which will be realized. There are also such situations, when none of the proposed solutions fulfils the assumed requirements. Then, it is necessary to come back to one of the earlier stages of project realization, for example in order to form the task once again to verify constraints and requirements, to search for new solutions or to improve the objective function.

Putting into practice

The realization phase of the decision results follows the choice of the project solution variant. The stage of putting into practice begins from project decision and makes it possible to check the solution proprieties e.g. by the research of the subassembly and other solutions up to the prototype and implementation.

The implementation is a stage when the project is realized (beginning from the phase of a prototype, test run up to the production). At this stage we obtain real data about the product – the project object, thanks to which the estimation the phase becomes possible.

Evaluation of realization

This is a current evaluation of the realized project for making a decision, whose usefulness will be of the highest value for an evaluating decision-maker.

The decision-maker looks at "a customer" by the interdependence triangle of quality – cost – time of delivery. This demands constant research of the product with regard to the basic criteria, which are: quality, cost and time of realization.

The main engineer from the production unit, a research manager and a specialist of planning should be members of the evaluating team. Such composition of the team will assure that the used technologies will be estimated with regard to three basic issues.

Technology evaluation is in fact a task of personnel, but the members of the estimation team, cooperating closely with the directors and with the production management, are generally expected to give recommendations, which are directed to the optimal implementation of a new or improved technology and its integration with the whole operation system of the company.

Information and feed-back

Information flow and feed-back are indispensable at the realization of a project solution by doing research on sub-assemblies and prototypes, checking the object proprieties and comparing them with the supreme values of the decision variables.

Information and feed-back phase runs constantly irrespective of the project stage, starting from the marketing preparations of designing. Information should include not only the specialists from the company, but also the suppliers of components and receivers of product.

3. RULES OF EFFECTIVE MODELLING AND SIMULATION

Using the tools for modelling and simulation the following rules should be taken into account [3]:

a) Profits obtained by the use of modelling and simulation have to be bigger than the expenditures, which is necessary for realisation of simulation and for improvement of the production system. The main criterion in taking the decision about the utilisation of simulation in practice are the benefits resulting from its utilization. These advantages can be divided into quantitative and qualitative ones. In many cases, a target of modelling and simulation is not to achieve a precise economic result, but e.g. to improve the functionality, effectiveness, or reliability of the system run [1].
b) To get the best effect from the simulation, it must be conducted at the right time, i.e. at initial phase of preparing a project because then, at the beginning, it is possible to determine suitable parameters of the system under design. Additionally, the costs of realisation of changes proposed on the basis of the conducted simulation, are the lowest at the beginning of project

realisation. Later, it is more difficult to introduce changes and also additional costs, which exceed the expected profits [1, 5].

c) System for modelling and simulation of a production processes should be integrated with the information system of the company. Company's databases should be a direct source of data for simulation. In a modelled production system one can easily and quickly change the production plan, check both different variants of production schedules and possibilities of realisation of different production orders.

4. CONDUCTING SIMULATION EXPERIMENTS

4.1. Gathering, preparing and interpreting data

One from the first steps of simulation project is data identifying, which are necessary for building a model. Finding and preparing data for a model is very time-consuming and expensive, and also accessibility and quality of data additionally influence research efficiency.

There are many types of data which can be necessary. The majority of models require wide range of data such as: delays, breaks between deliveries, operation time, transfer time, schedules of operators' work, etc. In many cases also stochastic quantities should be determined, for example proportions for given types of customers and probability of failures. For material flow modelling, it is necessary to define operating parameters and layout of physical elements in the analysed production system.

It is possible to use many sources of data from electronic data bases to interviews with employees working in the studied system.

In every case of collecting necessary data for building a model, the following should be carried out:

- The analysis of parameters importance – one from often ignored aspects of conducted simulation research is to understand what is important and what is not. The analysis of parameters importance can be conducted even very early. If it is not possible to estimate some parameter of the analysed system, we should examine model's behaviour assuming different values of the evaluated parameter to check how significantly system's efficiency will change.
- The analysis of costs - collecting and preparing data can be too expensive to use in a model.
- The analysis of variability - one of the basic reasons, for which simulation is a popular tool aiding decision making is a possibility to use it in order to show variability of systems. In case of changeable system, it is necessary to collect much more data.

From a theoretical point of view, the gathered data show what happened in the past, what can or can not be foreseen, and what will happen in the future. If conditions, in which historical data was accumulated, change, the gathered data can be inaccurate. For example, if historical data come from a database of product orders for the last 12 months, and 4 months ago a new product was introduced, the data from the first 8 months is not already useful because it does not take into account a new version of this product.

Irrespective of the way of gathering data, Arena (simulation software which is used in the described examples) has a built-in tool for gathering and analyzing input data – Arena Input Analyzer. This software automates the choosing process of probability distribution, creating examples of expressions which are possible to use directly in the simulation model. Figure 2 presents the result of statistical analysis for a set of registered values. Normal distribution is recommended, because it is characterized by the smallest square error.

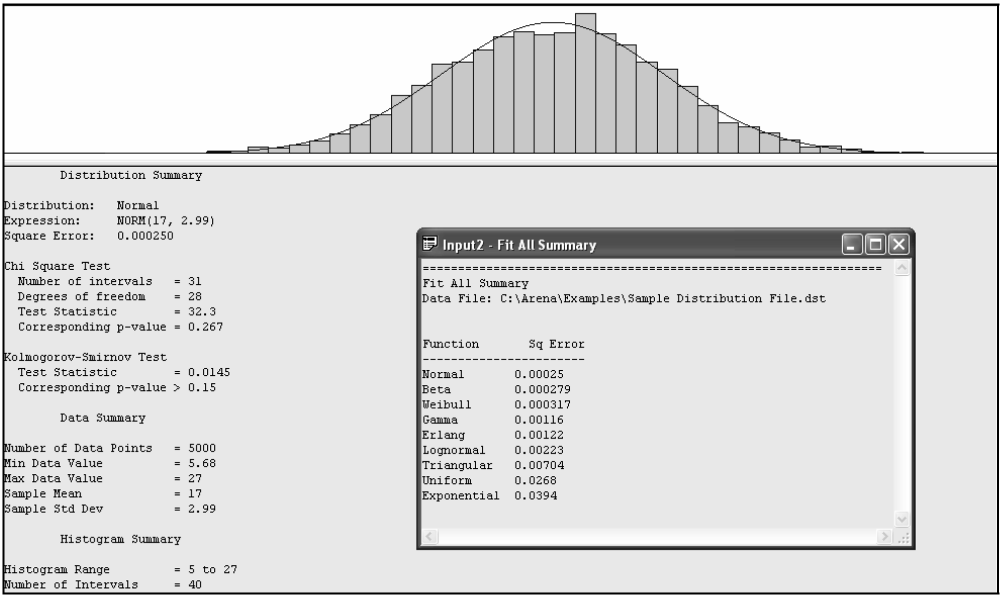


Fig.2. Determination of distribution for a set of measured values

Arena contains a set of built-in functions for generating random numbers from commonly used probability distributions. These distributions appear on pull-down menus in many Arena modules where they are likely to be used. Each of the distributions in Arena has one or more parameter values associated with it. We must specify these parameter values to define the distribution fully. The number, meaning, and order of the parameter values depend on the distribution.

In order to use historical data directly, it is also possible to use data import creator, or read data dynamically during the simulation course.

4.2. Creating of a simulation model

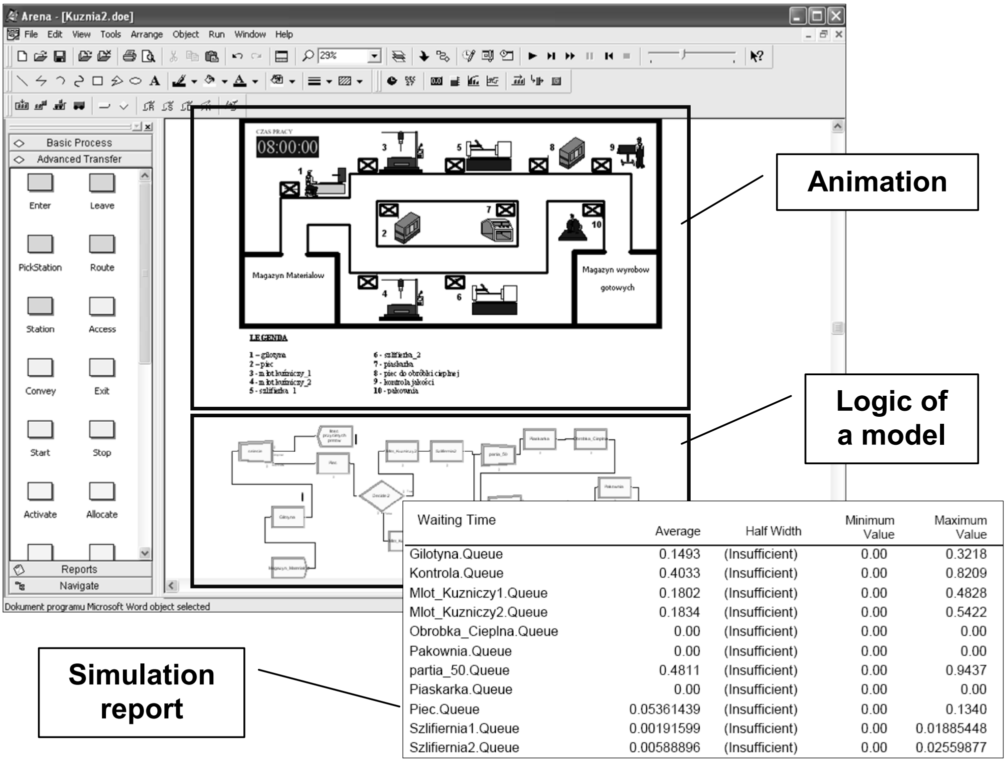
Having identified the way of improvement of a production system, a simulation project can be started. Firstly, the problem and its goals should be fixed. Then, tasks and analyses necessary to achieve the assumed goals are realized. Finally, the results and the proposed changes are presented. At each stage of the project, the need to return to the earlier stage can appear, e.g. when the foundations change or when the carried out analyses and the attained results change the project's goals.

It is very important to plan a project (collect data, build a model, analyse etc.) and check its goals beforehand. With this kind of approach to modelling and simulation, it is possible to understand aspects of the analysed production system, which can allow for foreseeing possible errors of the system (like the lack of suitable type of data).

A simulation model (figure 3) is a presentation of production system functioning. This model contains the logic, which shows the behaviour and interaction among particular elements of the system and the data, which characterize the parameters of the system. The model presents the system graphically by animation and it introduces the results as a collection of reports and statistics, within the usage of staff and equipment, the size of queues, the time which customers or parts spend in the system etc.

Creating a model (figure 3) is only a part of a simulation project. Each project begins with defining the problem and collecting data suitable for execution of a representative simulation. When the model is ready, it should be verified whether it acts correctly and then the obtained output data should be analysed. By the analysis of these data, critical areas of the model can be determined and conclusions drawn regarding modification of the system aiming at efficient realization of the accepted goals.

Simulation models can present different processes which take place in a production system. These can be discreet processes – the ones, where changes are the events which occur in definite points of time, e.g. a produced part leaving the model. If changes in the system occur continually, as, for example liquid metal flowing in the channel in the foundry, we deal with continuous process. A model can consist of only discreet or continuous processes or it can be their combination.



Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Gilotyna.Queue	0.1493	(Insufficient)	0.00	0.3218
Kontrola.Queue	0.4033	(Insufficient)	0.00	0.8209
Mlot_Kuzniczy1.Queue	0.1802	(Insufficient)	0.00	0.4828
Mlot_Kuzniczy2.Queue	0.1834	(Insufficient)	0.00	0.5422
Obrobka_Cieplna.Queue	0.00	(Insufficient)	0.00	0.00
Pakownia.Queue	0.00	(Insufficient)	0.00	0.00
partia_50.Queue	0.4811	(Insufficient)	0.00	0.9437
Piaskarka.Queue	0.00	(Insufficient)	0.00	0.00
Piec.Queue	0.05361439	(Insufficient)	0.00	0.1340
Szlifiernia1.Queue	0.00191599	(Insufficient)	0.00	0.01885448
Szlifiernia2.Queue	0.00588896	(Insufficient)	0.00	0.02559877

Fig.3. Simulation model of a manufacturing cell

Another division of simulation models is connected with the way in which the system variability is presented. Stochastic models register the variability with the use of probability distribution functions (e.g. normal, triangular or exponential distributions) or by application of the probability of delay, appearance for logical decisions being undertaken etc. On the other hand, in the deterministic model, this variability is not taken into account.

The creation of a simulation model can proceed as follows. At first, a general model of the system, using e.g. the creator („Model Jump-Start Wizard" – ARENA package) can be prepared. The creator will automatically create a complete model with basic logic, data, animation and statistics. Later, such a model can be gradually developed.

4.3. Analysis and evaluation of results

Creating a model of the analysed production system and simulating the realized processes gives results and makes it easy to draw conclusions. The modelled production system can be constantly improved and next simulations for other variants of improvements may be conducted (new machines, different quantity of manufactured elements, different sizes of buffers, foreseen disturbances and possible breaks connected with planned repairs of machines, alternative production processes, etc.). In the realized analysis, it is also possible to take into account the costs of investment, or else the costs of manufacturing for different variants of the designed system [1, 3, 4].

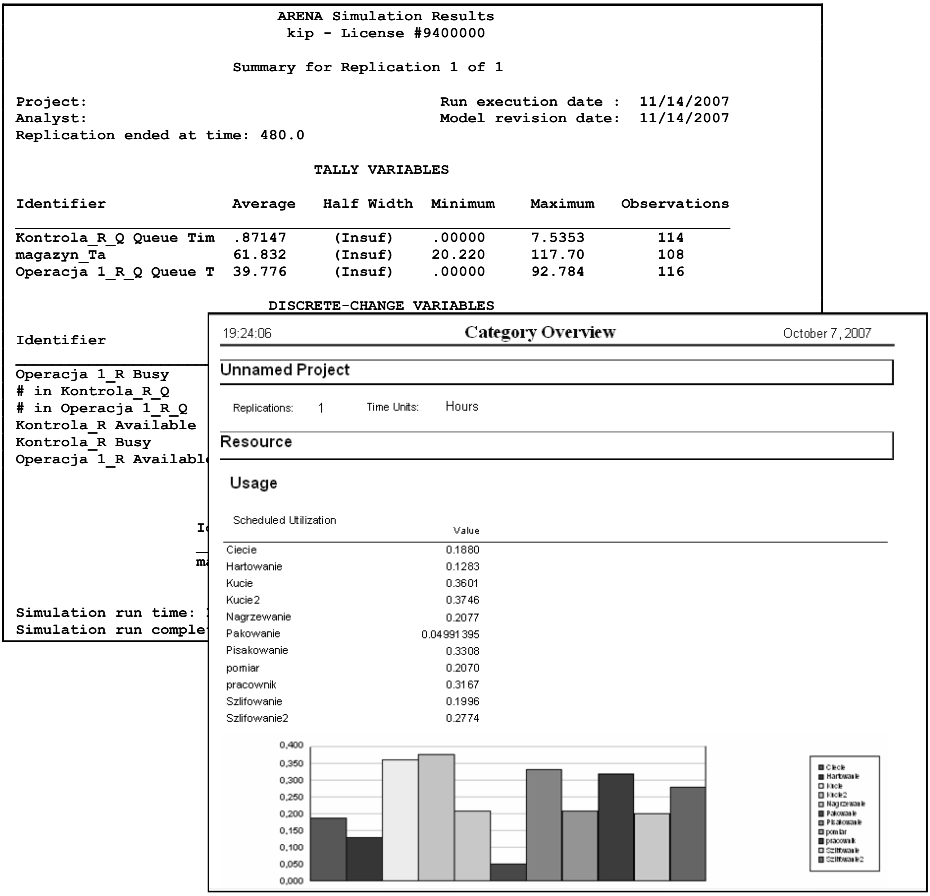


Fig.4. Reports from the conducted simulation

Simulation software contains different tools for analysis of results from simulation. There are:

- Reports - basic way for presenting results from simulation in older versions of simulation software. Now, these reports are completed by different kind of graphic elements such as tables, graphs, clip charts etc. (figure 4). Often, it is also possible to create own forms of reports and also to export them to other different popular formats (PDF, doc, xls, etc.).
- Special applications for analysis of results – an example of such software is Arena Output Analyzer which is the part of the ARENA package. In simulation software it is often possible to register different data, for example lead time registration through the whole production process for every part. During simulation this data is recorded in separate files in the format required by external application. The set of gathered input data from simulation can be analysed in different ways. It is possible to generate different graphs, for example bar charts (figure 5), linear graphs (figure 6) and histograms (figure 7). Thanks to graphs, it is possible to analyse functioning of the system more exactly and to find problems which are not possible to find in reports. For example, if we accept too many orders or if we estimate production possibilities wrongly, there appear problems connected with realization of orders in time. The lead time for next products will be longer and longer, which is visible on figures 5 and 6. The aim of production planning should be creation of a stabilized system which will be characterized by relatively constant lead times. A system where the average time of orders realization will by constant on the same level in spite of disturbances, which exist in all enterprises. An example of such solution is presented on figure 8. The next function of such special applications is possibility to realize statistical analyses. For a registered set of data, it is possible to mark its statistical parameters and trend lines (figure 9).

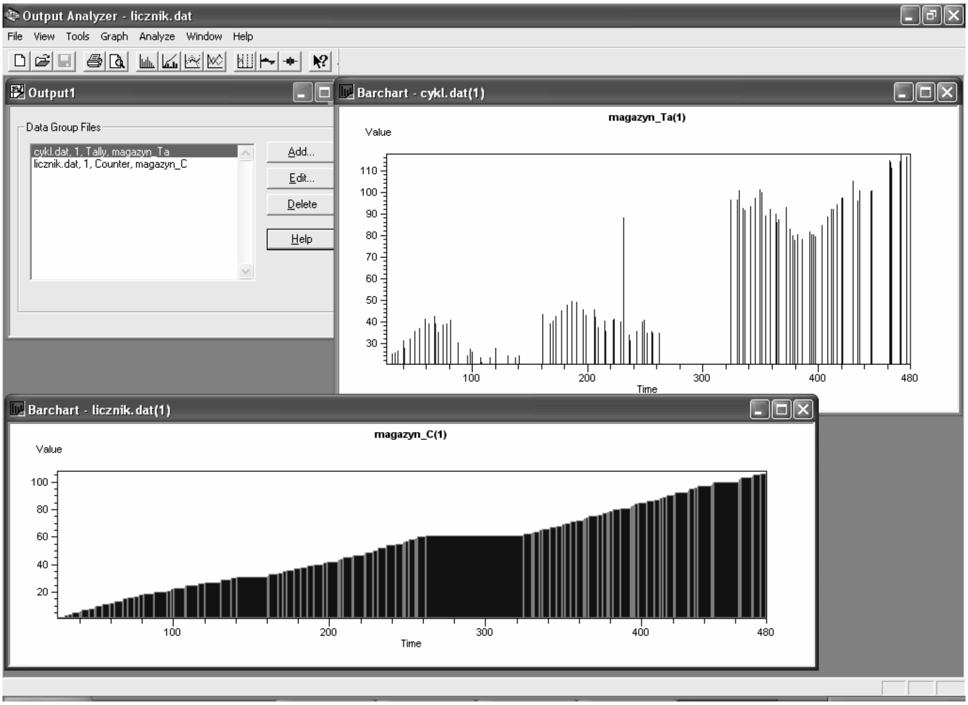


Fig.5. Bar charts - lead times for following produced parts

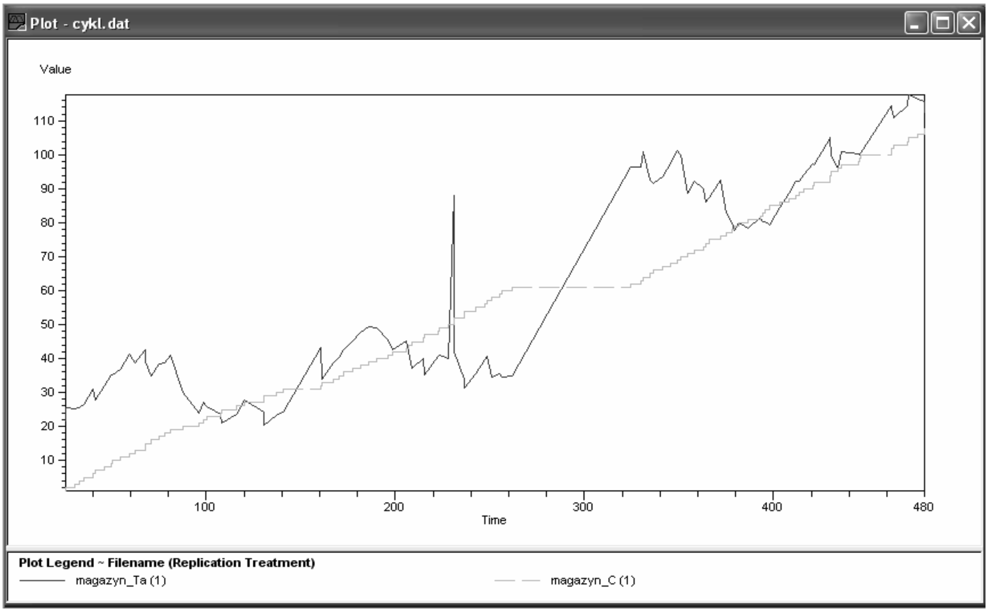
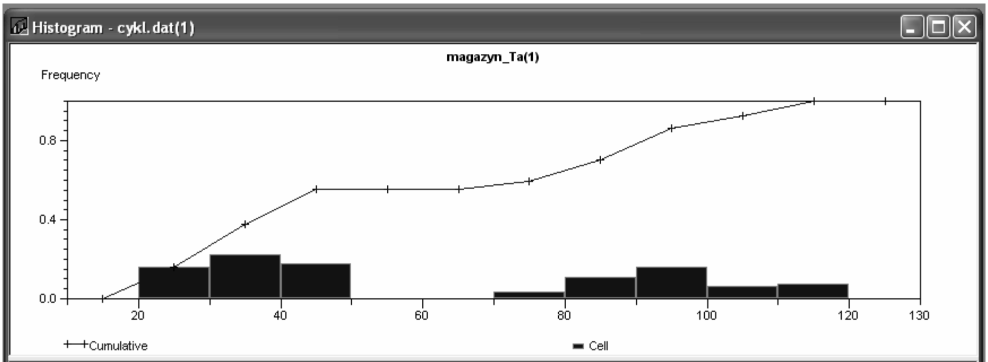


Fig.6. Linear graphs - lead times for following produced parts



Histogram Summary
magazyn_Ta(1)

Cell	Cell Limits From	Cell Limits To	Abs. Freq. Cell	Abs. Freq. Cumul.	Rel. Freq. Cell	Rel. Freq. Cumul.
1	-Infinity	20	0	0	0	0
2	20	30	17	17	0.1574	0.1574
3	30	40	24	41	0.2222	0.3796
4	40	50	19	60	0.1759	0.5556
5	50	60	0	60	0	0.5556
6	60	70	0	60	0	0.5556
7	70	80	4	64	0.03704	0.5926
8	80	90	12	76	0.1111	0.7037
9	90	100	17	93	0.1574	0.8611
10	100	110	7	100	0.06481	0.9259
11	110	120	8	108	0.07407	1
12	120	+Infinity	0	108	0	1

Fig.7. Histogram - lead times for following produced parts

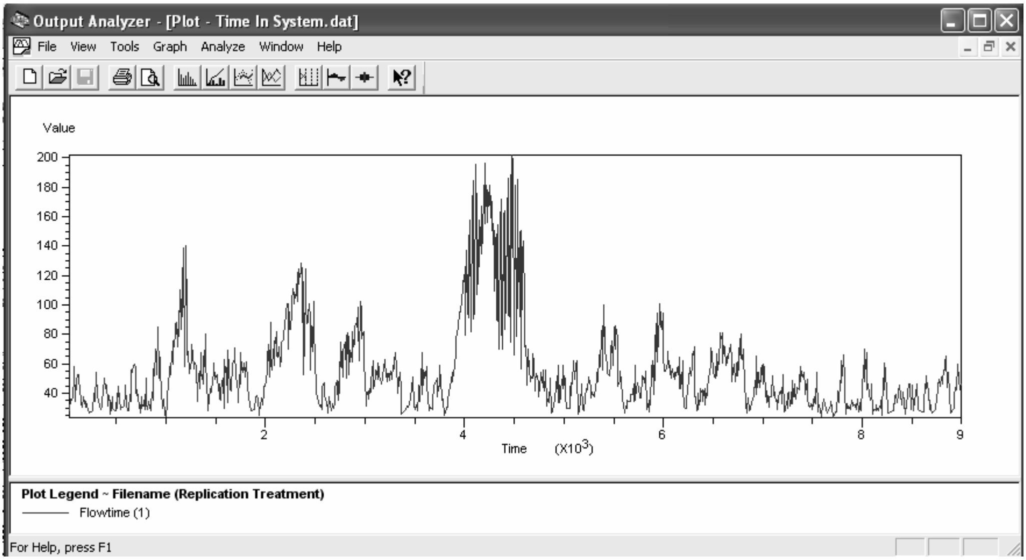


Fig.8. Linear graph for lead times of the produced parts in the stable production system

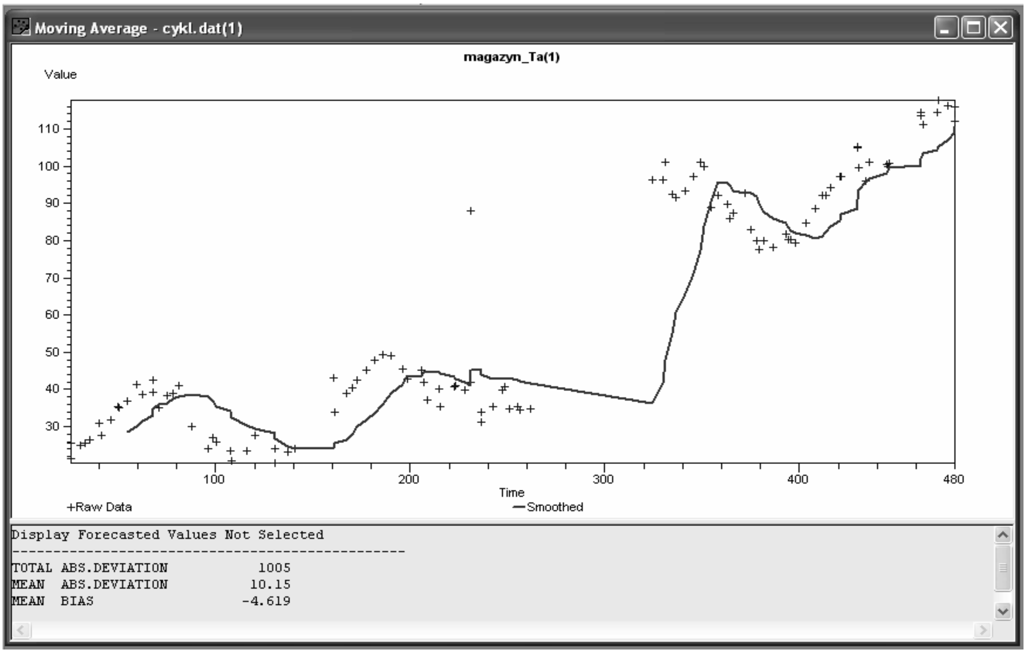


Fig.9. Moving average for lead times for following produced parts

5. OPTIMIZATION IN SIMULATION PACKAGES

The difference among notions of modelling, simulation and optimization is in tasks, which they have to fulfil. These tasks are [1]:

- for modelling – creating a model of the analysed system,
- for simulation – determining results of its functioning,
- for optimization – determining proper input data, optimal parameters of the process run.

By optimization of production system we understand such designing of a production system (all its components), which assures the optimum of its functioning [7].

When many variants of proposed solutions appear while modelling and simulation, research of all the possible combinations and all possible value arrangements of the studied factors is very time-consuming. If it is not possible to examine all arrangements, only these variants should be studied, which are chosen on the basis of subjective opinion of the researcher, his intuition and knowledge about the research object.

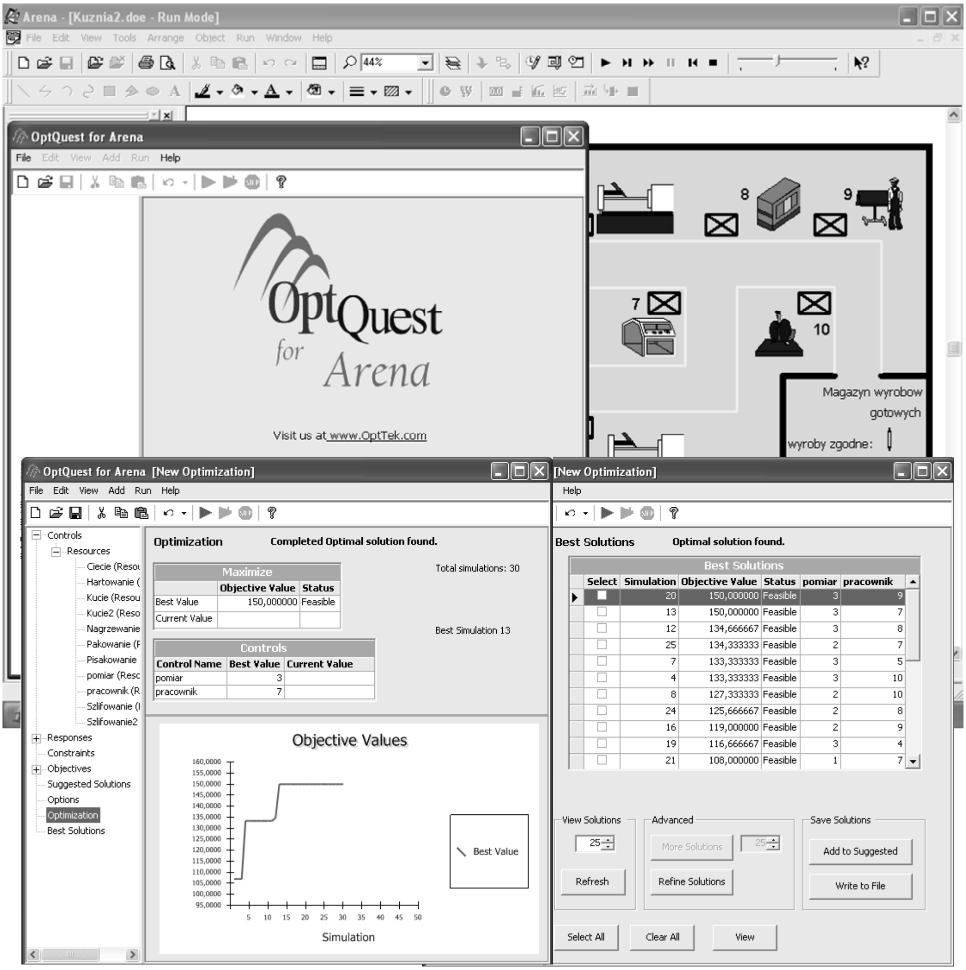


Fig.10. Optimization model for the treating seat

Simulation packages are more and more often replenished by optimizing modules, which make it possible to generate and check all possible variants automatically and find the best solution. For example the OptQuest is an additional tool being a part of the ARENA simulation package [8]. This software enlarges the possibilities of analysis of production systems which are modelled in ARENA. It allows for finding the optimum solution in the prepared simulation models – figure 10.

OptQuest is a generic optimizer that makes it possible to separate successfully the optimization solution procedure from the simulation model. This design adaptation of meta-heuristic methods lets us create a model of the system that includes as many elements as necessary to represent the "real thing" accurately. While the simulation model can change and evolve to incorporate additional elements, the optimization routines remain the same. Hence, there is a complete separation of the model that represents the system and the procedure that solves optimization problems defined within this model.

The optimization procedure uses the outputs from the simulation model to evaluate the inputs to the model. Analyzing this evaluation and previous evaluations, the optimization procedure selects a new set of input values. The optimization procedure performs a special "non-monotonic search," where the successively generated inputs produce varying evaluations, not all of them improving, but which over time provide a highly efficient path to the best solutions.

After creating the model (fig.10), the first simulation was conducted in order to check its correctness, determine present production abilities, find a bottle-neck and determine the duty for workplaces.

Several simulations of the run of process altering the objective function were conducted. At the beginning of the presented below analysis, the aim of research was to find the solution with the maximum size of production of final products.

On the basis of the conducted analysis of reports form the first simulation, critical resources were indicated, which decisively influence the whole system functioning. Parameters describing these resources are controls in the optimization model. They are input variables in the simulation model, which will be changed in the settled range of value by the optimization software. In the analysed example, the following parameters were chosen as controls:

- batch size,
- number of workers working in the seat,
- number of quality inspection stations.

For the above-mentioned variables, lower and upper bounds were determined, which results from the real production conditioning, for example from the way of transport of parts, the maximum level of employment, accessible production surface etc. In the analysed example, the following constraints were accepted:

- possible batch sizes from 10 to 80 at 5 parts,
- number of workers not larger than 14,
- maximally 3 quality inspection stations (it is the bottleneck).

After simulation and optimization it turned out that many variants fulfil the determined requirements (150 parts). These variants were sorted according to the number of workers and number of parts waiting for the inspection station. The best variant is characterized by six production workers and two quality inspection stations, and the number of produced units is 150.

6. CONCLUSIONS

At the beginning of every analysis it is necessary to define input parameters of the analysed system, and also output parameters which will be the result of the conducted analyses, and on the basis of which the opinion about the analysed system will be accomplished. We can define here two cases. In the first one, simulation for checking behaviour of the system is realized for the defined input parameters. In the second case, we have the set of different input data, where exists the problem of finding the optimum. It is connected with finding such input data which gives the best result according to the assumed criteria. In this approach the problem is to find the optimum solution. It is necessary to plan particular stages of experimental research properly to find possible variants of solutions, and first of all to set criteria for evaluation of the proposed variants in a proper way.

If during modelling and simulation many variants of the proposed solutions appear, the research including all possible combinations, all possible arrangements of values of factors will be too time-consuming. If it is not possible to check all possible variants, we should use the modelling and simulation like for example ARENA with OptQuest. This software automates the process of checking variants of improvements. Thanks to this, we can find the best solution quickly and easily.

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