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MODELING & SIMULATION AS TOOLS FOR OPTIMISATION OF MATERIAL FLOW IN PRODUCTION SYSTEMS

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ABSTRACT

This paper describes the research results related to use of modeling and simulation as tools for optimisation of the material flow. Starting from presenting the motivation, scope and methodology for the undertaken research, the paper later presents briefly some of the key areas tackled in the research activities. The largest emphasis is placed on the steps undertaken in the so-called simulation study used for testing the research results in practice. The research is aimed at contributing to better understanding and utilisation of modeling and simulation as tools for improved understanding and operation of manufacturing companies in Macedonia, especially the ones belonging to the traditional sectors and using conventional processing methods (including machining, plastic deformation etc.).
Key words: *material flow, modeling, simulation, simulation study, simulation software, statistical models, experimental design*

1. INTRODUCTION

Increasing the competitiveness and innovation is a key prerequisite for successful performance of enterprises in the global economic market. In developed economies, special emphasis is placed on improving the management of supply chains (logistics) in enterprises.Managing the material flow as part of logistic processes in production systems, aims at efficient use of resources in order to create added value for customers, reduce the costs as well as the duration of the production cycle [1]. Information technologies follow the development of numerous mathematical, statistical and graphical methods for optimization of the material flow. Specialized software solutions facilitate the process of analysing and improving the flow and provide better knowledge on the production system.

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1.1 Scope of the research

The optimisation of material flow contributes to the efficiency of the manufacturing processes and reduction of the overall manufacturing cycle. With adequate planning and control, it enables reducing the production costs, improving product quality and customer satisfaction [2]. The practice shows that small number of manufacturing enterprises in the Republic of Macedonia is familiar with methods for material flow optimisation. A key element in the process of promoting the benefits of the optimisation of material flow is the transfer of knowledge from academic to business environment. Main emphasis is to be placed on applied research as well as on adapting the advanced methodologies to current conditions in the traditional manufacturing sectors. The undertaken simulation study in the scope of this research is one such an example i.e. practical show case on how to adequately formulate and implement modeling and simulation project in industrial environment.

Modeling and simulation were chosen as tools for analysis and optimisation of material flow. For the purpose of the research, the known advantages and disadvantages of this approach were carefully examined. The modeling of input data as a key driving force for the simulation process, and the analysis of outputs from the modeling and simulation which provides important guidelines for improvement of the modelled production system, were among the key research areas. The time and economic dimensions of the material flow was also subject of the research.

The use of software packages for modeling and simulation in Macedonian companies is rare mainly due to the common belief that they are expensive tools, but also due to their unavailability on the domestic market of information technologies. Thus, the research intended to contribute to creating the knowledge base in this area as well.

1.2 Applied research methodology

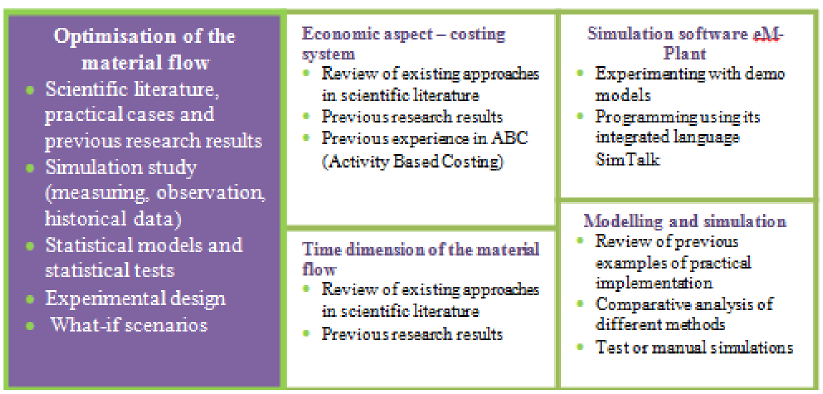

Fig. 1 - Research areas and some of the used methods

2. MODELING AND SIMULATION

Modeling and simulation of manufacturing systems is a process of creating and experimenting with mathematical and logical model of a physical system. The model is actually a set of assumptions regarding the operation of the system. These assumptions are expressed by mathematical, logical and symbolic relationships between entities or objects of interest in the system [3]. Once developed and validated, the model can be used to evaluate a number of different what-if scenarios relating to the real system, by performing the simulation.

Whether performed manually or computer based, the simulation enables generation of an artificial history of the system and prediction of the operational characteristics of the real system. The simulation can be used as analytical tool for predicting the effects of changes on existing systems, and as a design tool for predicting the performance of new systems under different set of conditions [4].

The whole process from defining the problem to be solved or parameters to be analysed, through modeling the system and simulation of the model represents a complex project referred to as simulation study.

Several issues need to be considered when setting-up and managing such projects. These issues include the time-scales for simulation study, the members of a simulation project team, the hardware and software requirements, the cost of a project and the selection of an appropriate project. Proper management of a simulation study requires more than just the appropriate technical skills; there is also a need for project management and socio-political skills. It is also emphasized that simulation modeling is not a linear process, but that it involves repetition and iteration of the processes involved.

2.1 Steps in a simulation study

The steps in a simulation study as presented on Fig. 2 include [5]:

- *Formulation of the problem.* Each study should begin with a statement of the problem.
- *Setting the goals and project plan.* The objectives indicate the questions to be answered by simulation. Assuming it is decided that the simulation is an adequate method, the project plan should include: defining the variant systems to be considered, the method for evaluating the effectiveness of variants, the number of people involved, the cost of the study, the number of days needed, and expected results at the end of each phase.
- *Conceptualization of the model*. Creating the model is probably as much art as science. It is best to start with a simple model and upgrades. However, the complexity of the model must not exceed the purpose for which it is created.
- *Data collection.* There isconstantinteractionbetweenthemodelbuildingandcollectingthe necessaryinput data. The objectivesofthe studylargelydictatewhat typeofdatawillbecollected. *Model translation.* Given that most models of real systems require storage of large amount of information and calculations, the model must be entered into a computer recognizable format, either by programming languages or specialized software packages.
- *Verified?* Verification depends on the computer program prepared for the simulation model. Whether the computer program works properly? In complex models is very difficult, if not impossible, to translate the complete model without need for corrections.
- *Validated?* Validation is the determination that the model is an accurate representation of the real system. Validation is usually achieved by calibration of the model, an iterative process of comparing model behavior with that of the real system and using the discrepancies between them to improve the model. This process is repeated until the accuracy of the model is assessed as acceptable.

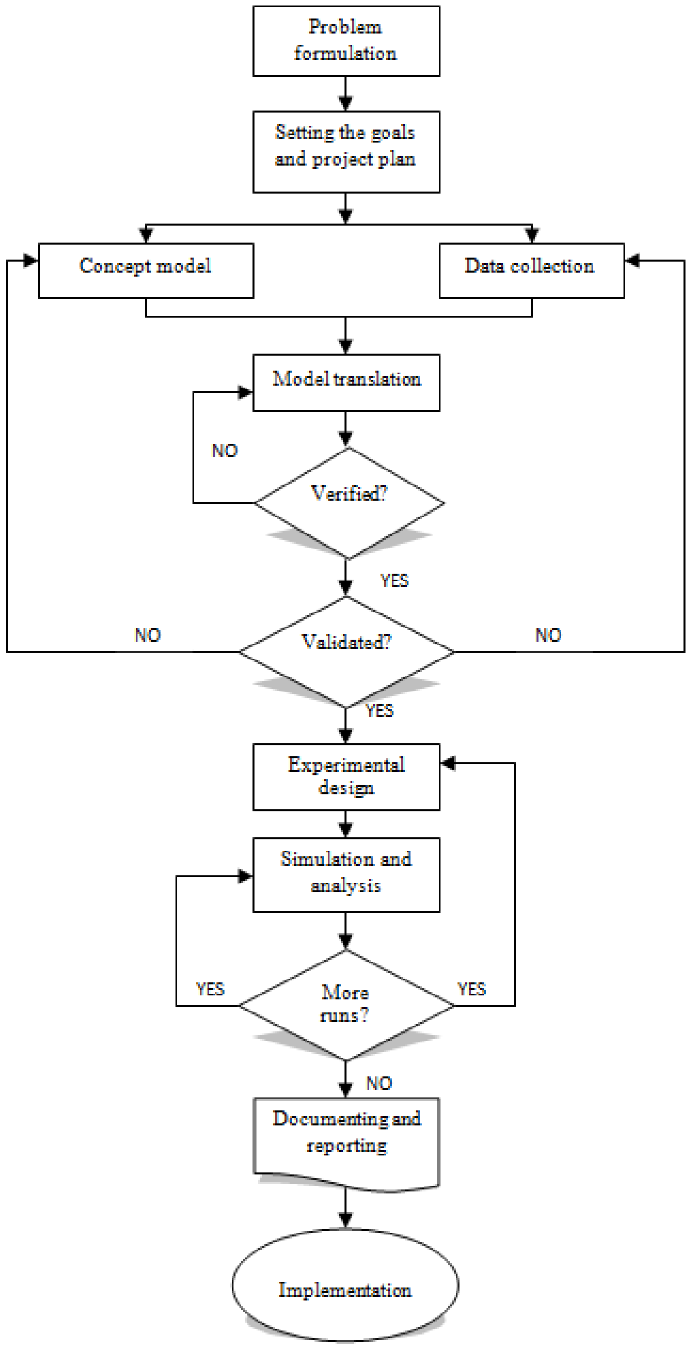

Fig. 2 - Steps in a simulation study

- *Experimental design.* Variants that will be simulated must be defined. For each system design that will be simulated, decisions regarding the length of warm-up period, the length of simulation runs etc. must be made.
- *Simulation and analysis of output data.* Simulation runs and adequate analysis of their results are used to assess the performance of the simulated system designs.
- *More runs?* Based on the analysis of completed runs, the analyst determines whether additional runs and experiments, and for which design should be carried out.
- *Documentation and reporting.* There are two types of documentation: a program and progress. If the program will be used again by the same or another analyst, it may be necessary to understand how it works. Another reason for documenting the model is that model users can whenever needed change the input parameters in order to determine those input parameters that optimise some output performance indicators. The result of all the analysis should be clearly and concisely stated in the final report. It allows users of the model to examine the final formulation, variant systems considered, the criteria by which the variants are compared, the results of experiments and recommended solution.
- *Implementation.* There are three types of implementation: implementation of the findings of the simulation study, implementation of the model and implementation of knowledge [6]. A simulation study may include any type of implementation, or all three. The success of implementation depends on how well the previous steps were performed. If the model and its assumptions are not understood, implementation is likely to encounter problems, despite the validity of the model.

The different steps in the simulation study represent phases in the simulation modeling projects and involve various activities, methods and tools. Thus, the team must possess relevant experience from different disciplines including materials management, plant layout design, statistics, modeling, simulation and programming using specialized simulation programming languages. With the rapid development in information technologies, numerous specialized simulation software packages such as ARENA, QUEST, EXTEND, eM-Plant and many others have been developed. By using these packages, process modeling, simulation and analysis is largely simplified, but to use most of the advantages of the same (and in particular to make an adequate choice), the analyst must understand the process of simulation and possess knowledge in the field of mathematical, statistical and logical models.

2.2 Building a model using eM-Plant simulation software

eM-Plant is standard software for object-oriented, graphical and integrated modeling for discrete event simulation and visualization of systems and business processes. The power of object oriented techniques lie in the ability to produce ‘modular’ code (known as classes) that can be "easily" modified and reused [7]. Discrete event simulation is one way of building up models to observe the time based (or dynamic) behavior of a system. It defines the real system by number of important concepts, namely entities and logic statements [8]. Entities are tangible elements found in the real world, e.g. for manufacturing these could be machines or trucks. The entities may be either temporary (e.g. parts that pass through the model) or permanent (e.g. machines that remain in the model). Logical relationships link the different entities together, e.g. that a machine entity will process a part entity. The logical relationships are the key part of the simulation model; they define the overall behaviour of the model.
eM-Plant enables creation of well-structured, hierarchical models of production facilities, lines and processes. This is achieved through its powerful object-oriented architecture and modeling

capabilities. Simulation models can be created in short time by using predefined objects from the following library classes:

- Material flow: containing different material flow objects, from processing units and buffers, through simulation clock, to movable units (e.g. entities and transporters)
- Information flow: containing objects like tables, variables, methods and generators.
- User interface: provides objects for graphical and visual presentation of the simulation results as well as for creating user defined dialogs.

The functionality of the library can be extended by creating user-defined objects which will incorporate certain best practices and allow closer conceptualisation of the real system being modelled. Furthermore, users can load objects from variety of add-in programs compatible with *eM-Plant* as well as import CAD models. The key advantage of this simulation package is that has built in programming language, *SimTalk*, which extends the ways of modeling considerably. Each object has basic properties providing many useful features. Depending on the model, there might be a need for more detailed or completely different properties. Those can be programmed by the user in the programming language *SimTalk.* This feature of *eM-Plant* combines productivity and flexibility.

3. PRACTICAL EXAMPLE: SIMULATION STUDY FOR OPTIMISATION OF THE MATERIAL FLOW

The simulation study involved a company from the manufacturing industry with a production system of highly variable and non-deterministic nature. The initial steps in the study included:

- Problem formulation: lack of clear knowledge on the material flow and resource utilisation.
- Project goals: optimisation of the material flow in the plant, identifying potential bottlenecks and generate information about the resource utilisation.
- Project plan and project team were set in accordance with the needs of the study, involving company representatives in different steps and based on diagram of linear responsibility.

3.1 Conceptualisation of the model

- Defining the components of the system: entities and events to be modelled. The structure of the product(s) and the resources to be used (e.g. machines, people) are defining the entities. The events can be identified by analysing and mapping the technology of production (processes, operations, machine and manual based etc.).
- Defining the input data: in the next phase the input data (variables) to be modelled are identified including the time of the material flow on different operations, percentage of rejects, percentage/number of products for rework and related operations etc. The in-process transportation time was not sufficiently relevant (except in the last operation), thus it was excluded from the time dimension of the material flow. For the purpose of defining the time dimension, the structure of the time norm [9] has been used, found that it is suitable for the modelled processes as well as the inputs needed in eM-Plant (set-up time, processing and failure time).
- Defining the output data is done in accordance with the stated goals of the simulation study. Thus, the expected outputs from the study should include among other: complete statistics for each processing unit, identification of bottlenecks, design an experiment for comparison of variant solutions, and information of human resource utilisation on 2 identified (manual) processes.

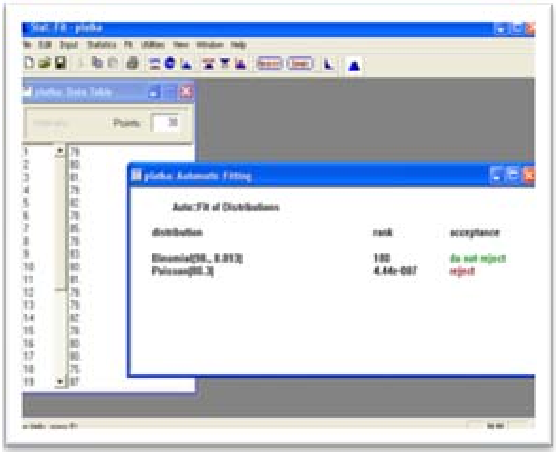

Fig. 3 - Defining possible distributions

3. 2. Modeling of input data

• *Data collection from the real system.* The input data has been collected using two main methods: measurement and analysis of experience data (estimations done by the operators and recorded data in company process documentation). Regarding the time dimension of the material flow it is essential that the different components of the time norm are analysed from the aspect of their variability and source of generation. For instance, the variability of the inputs collected from the operators was modelled using the triangular distribution.

• *Identification of the distributions* Next step in the simulation study is the definition of the theoretical distribution of empirical data collected in the previous phase. To achieve an effective approximation to a certain type of theoretical distribution, iterations with different types of distribution and values of the parameters are needed. If it is done manually, this process can be very time consuming. Therefore, for the needs of the study, a specialized tool is used (Stat:: Fit).

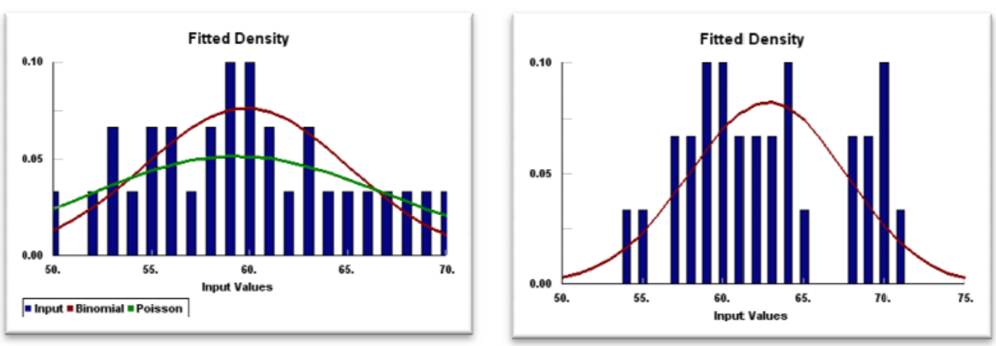

Fig.4 - Graphical presentation of goodness-of-fit test results

- *Goodness-of-fit testing.* Goodness-of-fit tests are based on a comparison of the distribution of empirical data with an appropriate theoretical distribution. If the difference between them is small, then with some level of security can be assumed that the input data coming from the set of data are with the same parameters as the theoretical distribution. Stat:: Fit allows performing a number of different types of tests, but for the needs of the simulation study the Chi-square test as the most widely used test, and Kolmogorov Smirnov test was used. At the same time the graphical method is used, i.e. generating a graphical representation of a comparison of distributions (Fig. 4).
- *Defining the distribution parameters.L*As a result of the two previous steps, the distribution parameters for all events in system are defined. These parameters are of an essential importance when modeling the system in the eM-Plant and performing valid simulation.

3.3. Creation of the simulation model

Following step in the simulation study was the creation of the model of the real system based on the developed conceptual model, results from the input data analysis and using the specialised simulation software eM-Plant. As already mentioned, the modeling in eM-Plant is object oriented, i.e. pre-defined objects from the classes of objects of material flow, information flow and interface with the user were used for modeling purposes. A bottom-up strategy for modeling the system was used, thus modeling first starts with the manufacture of parts from the lowest level of detail, while certain features of objects are defined using a programming language SimTalk, which is embedded component of eM-Plant. The results of the modeling efforts in eM-Plant are presented in Fig. 5 showing the so-called simulation model or model that in the next steps of the simulation study is the subject of further research.

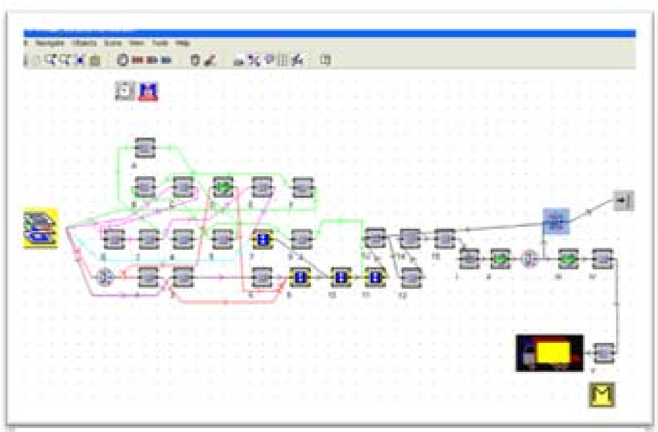

Fig. 5 - Simulation model in eM-Plant

3.4. Verification of the simulation model

Following approaches/tools were used in the scope of the simulation study, verifying that the simulation model sufficiently well represents the real system:

- Review of the model by a person who is not involved in the development of conceptual and simulation model

- Simulation of the model included comparison of the material flow with one outlined in the technology of the production
- Graphic display (using the appropriate objects of eM-Plant) on specific statistical indicators
- Review the output statistics of the derived model by simulation.

3.5. Validation of the model

The following approaches for validation of the model were used in the simulation study:

- Building the model validation by persons who know well the production process.
- Performing statistical tests on the input data to determine their distribution and their characteristics.
- Comparison of the model outputs with the ones from the system using statistical tests (statistical validation) regarding their normality and statistical similarity. For the purpose of statistical validation following steps were undertaken: collection of information (e.g. time norms measured during the simulation run and measurement of real times in the system), analyzing the normality of the obtained data (for instance using the Excel SigmaXL tool for analyzing the normality of the data set from the model and from the system), and analyzing the statistical similarity by using the F-test and independent t-test.

3.6. Analysis of output data – getting precise results from the simulation

After the validation, the simulation study continues with experimentation with the model. However, in order to ensure that the results will be as accurate as possible, a common practice in simulation studies is to first define the state of equilibrium and the number and duration of the simulation runs.

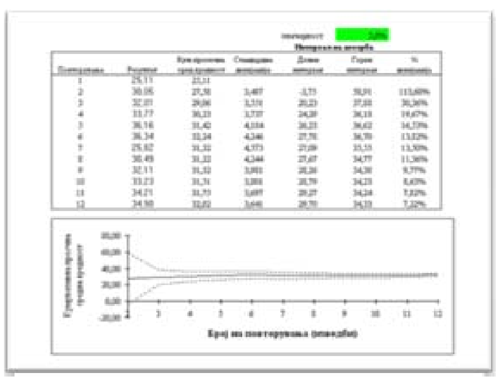

Fig. 6 - Confidence interval results

- *Defining the state of dynamic balance* using the time-series inspection method and so-called Welch method. For both methods there Excel based models are available for free at www.wileyeurope.com/go/robinson. The results from both methods confirmed that the dynamic balanced regarding the treated system is reached on the fourth day of production. All results obtaining before achieving the balance will not be taken into account during the experimentation phase.

- *Defining the length of the simulation run*: With the support of mentioned models in Excel, it was defined that in order to get more accurate results, the simulation run should last at least 11 days.
- *Defining the number of simulation runs:* by using the method of confidence interval, it was defined that the number of simulation runs should not be less than 6 (six).

3.7. Experimentation with the simulation model

- *Comparison of variant scenarios.* Having defined the conditions under which the simulation can obtain accurate results, the simulation study continues with the experimentation in order to find solution to the defined problems. One such an approach is the comparison of variant scenarios i.e. using the method of confidence intervals to define whether one scenario is better than the others. For instance this approach was used to define the optimal number of operators on certain processes and shortening the total production time. The comparison of more than two scenarios is facilitated by using the Bonferroni inequality.
- *Experimental design:* formal methods of experimentation that allow the identification of those significant factors of the experiment which change will lead, with high level of probability, to the desired results. One such method that was used in the simulation study is the 2k design (involving two important factors e.g. factor 1 number of direct operators in control and factor 2 number of indirect operators in control). By using the methodology for such experimental design, it can be evaluated what will happen in the system in case of increase or decrease of the factors, thus provide input for decision making processes.
- *Interactive experimentation.* The simulation model can be further used for different in-process experimentation and performing of what-if scenarios in the model itself (e.g. smaller number of machines, simulation of defects, increasing the series, additional processing units etc.). All of this is done very fast, easily and without incurring costs and disturbances typical for experimentation with the real system.

3.8. Implementation

The last process of the simulation study is the implementation, or process in which the results of modeling have an effect on the real system, by applying the findings from modeling and simulation processes. Implementation can be interpreted as: the implementation of the results of a simulation study, implementation of the model and implementation as learning [5]. The implementation in presented simulation study is combination of implementation of results and implementation as learning, for the purpose of both the company understanding of the system as well as the research in the field. The short term impact from the implementation of the results demonstrated that the stated objectives were achieved and more efficient material flow and resource utilisation was enabled. Nevertheless, in order to define the long term impact on relevant performance indicators of the company (e.g. production time, costs, financial gains etc.) additional analysis is needed. These issues are considered and presented in the final report of the simulation study.

From a learning point of view, the simulation study confirmed, among other, that the phase of collecting and analyzing the input data is among the most intensive tasks. It further emphasized the benefits of such a study for companies to better understand and optimise the material flow and other aspects of the production systems.

4. CONCLUSION

Different theoretical and practical studies identify the modeling and simulation as suitable tools for analysis and optimisation of the material flow in production systems. The challenges related to the presented research mainly originated from lack of such a practice in the domestic manufacturing industry as well as lack of sufficient number of similar research results in the country. By identifying the most appropriate approaches and based on previous experiences in modeling and optimisation of material flow, the imposed challenges were tackled in an adequate manner. The results from the simulation study are from one side beneficial for proving the known concepts in the field as well as for identifying the key priority areas for future research.

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MODELIRANJE I SIMULACIJA ALATA ZA OPTIMIZACIJU TOKA MATERIJALA U PROIZVODNIM SISTEMIMA

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REZIME

U ovom radu je opisano istraživanje vezano za primenu modeliranja i simulacije za optmizaciju toka materijala. Najveći naglasak je stavljan na takozvanu studiju simulacije korišćenu za testiranje rezultata istraživanja u praksi. Najveći izazov predstavlja nedostatak prakse modeliranja i simulacije u domaćoj proizvodnoj industriji. Istraživanje doprinosi boljem razumevanju i upotrebi modeliranja i simulacije rada proizvodnih kompanija u Makedoniji, a naročito u onim kompanijama koje pripadaju tzv. tradicionalnom sektoru (obrada rezanjem, plastičnom deformacijom i sl.).Kao najvažnije korake u studiji simulacije navode se: definisanje problema, postavljanje cilja i plana, konceptulizacija modela, prikupljanje informacija, provera i validacija modela, izrada dizajna eksperimenta, simulacija, izrada dokumentacij i izveštaja i na kraju implementacija. U poslednjem poglavlju data je praktičan primer implementacije simulacije u analizi toka materijala.

Ključne reči: t*ok materijala, modeliranje, simulacija, statistički modeli, dizajn eksperimenta*