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Simulation Modelling Based Methodology for Shipbuilding Production Process Design*

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In this research a simulation modeling based methodology for shipbuilding production process design is suggested. It is expected from suggested methodology to give faster, better and more efficient tool for designers of complex production processes, with special focus on shipbuilding production processes design. Within the first part of research, against available resources, various methods, techniques and tools used in production process design practice, are investigated with special focus on critical analysis of simulation modeling method appliance opportunities. In continuing, simulation modeling method, as basis of suggested methodology, is investigated and described regarding its special characteristics, advantages and reasons for application, especially in shipbuilding production process. Furthermore, suggested methodology for production process design procedure is described in details. The appliance of suggested methodology for designing a real robotized profile cutting process line within specific shipyard production process is demonstrated. Finally, methodology is tested and evaluated through comparison with installed robotized profile cutting line in specific shipyard production process. On grounds of this research and conclusions droved from comparison with real installation in specific shipyard, directions for further research are suggested.

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Simulacijsko modeliranje kao osnova metodologije projektiranja brodograđevnog proizvodnog procesa

Izvornoznanstveni članak

U istraživanju je predložena metodologija projektiranja brodograđevnog proizvodnog procesa koja se temelji na primjeni metode simulacijskog modeliranja kao osnove predložene metodologije. Pri tome, od predložene metodologije se očekuje da projektantima procesa omogući brži, efikasniji i kvalitetniji pristup projektiranju složenosti i dinamike kompleksnih proizvodnih procesa, s posebnim naglaskom na brodograđevni proizvodni proces. U prvom su dijelu rada, prema dostupnim izvorima, istraživane metode, tehnike i alati koji se općenito primjenjuju kod problema projektiranja proizvodnih procesa s posebnim osvrtom na kritičku analizu mogućnosti primjene metode simulacijskog modeliranja. U nastavku ovog istraživanja, opisano je simulacijsko modeliranje kao osnova predložene metodologije projektiranja sa svojim osnovnim karakteristikama, razlozima primjene i sa posebnim osvrtom na brodograđevni proizvodni proces. Nadalje, opisana je procedura provođenja predložene metodologije projektiranja brodograđevnog proizvodnog procesa u sedam uzastopnih faza. Osnovana metodologija je primijenjena na konkretnom primjeru brodograđevnog proizvodnog procesa za projektiranje potpuno nove robotizirane linije za obradu profila. U konačnici, metodologija je verificirana i potvrđena usporedbom sa njezinim realiziranim postavom u stvarni proizvodni proces promatranog brodogradilišta. Temeljem ovog istraživanja i zaključaka iz usporedbe sa stvarnim proizvodnim procesom, predlažu se smjernice daljnjeg istraživanja.

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Keywords
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Shipbuilding
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1. Introduction

On today's market, shipyard continuously has to invest in improvement in their production process and technology so to increase productivity an profit. Therefore, shipyard management is often conducting significant actions in their production process, especially in term of implementing new technologies into the existing production process, which is a complex task, [1]. Design of the new production process is a task that is often based on various assumption within known existing limitations, furthermore, solution is necessary the result of interaction

Symbols/Oznake

CAD	- Computer Aided Design - računalno podržano projektiranje
MS	- buffer - međuskladište
VT	- rolling conveyer - valjčasti transporter
RT	- rotation conveyer - rotacioni transporter
S_{rub}	- profile cleaning and drying station - stanica za sušenje i čišćenje rubova profila
S_R	- robotised cutting station - robotizirana stanica za obradu profila
P_{ca}	- pallet for “ca” type profiles - paleta za tip profila “ca”
P_{cr}	- pallet for “cr” type profiles - paleta za tip profila “cr”
P_{mr}	- pallet for “mr” type profiles - paleta za tip profila “mp”
P_{ost}	- pallet for scrap - paleta za ostatke
D_s	- sorting crane - sortirna dizalica
ca	- mark for profiles for automatised micropanel line - oznaka profila za automatiziranu mikropanel-liniju
cr	- mark for profiles for robotised micropanel line - profiles oznaka profila za robotiziranu mikropanel-liniju
mp	- mark for profile for subassembly - oznaka profila za malu predmontažu
pl	- mark for profiles for panel line - oznaka profila za panel-liniju

between dependent decision making variables, [2]. Regarding this issues, the author has analysed existing design methods, techniques and tools for designing production processes, and the shipbuilding process in particular, [3]. Following perceived shortcoming of existing method, the need for a new scientifically founded methodology for shipbuilding process design is identified. Such method should provide a better support within implementation of shipyards new technologies, within managing and improving of existing ones, and within decision making process overall. Therefore, the author develops a new methodology for shipbuilding production processes design based on simulation modelling method, and specially selected operation research methods.

Suggested methodology was used for real shipyard production process design and was confirmed after the investment was realized. As further research author suggest application of this methodology to other shipyard production processes and finally to whole shipyard to create an virtual and full integrated shipyard simulation model.

2. Problem approach

Within conducted research of existing methods, techniques and tools for production process design and shortcomings of such methods are identified, especially in terms of complexity of the shipyard production process. Within conventional approach, design solution is commonly defined based on comparison with other shipyards which already have similar technology, [4]. Such solution in particular cases can be satisfactory, however not necessarily optimally adapted to the observed shipyard, [5]. For that mater, the application of the scientific methods for process design and improvement is more widely accepted, i.e. relevant methods of mathematical modelling, [6-7]. However author identifies certain shortcomings of conventional mathematical modelling and analytical approaches for designing complex processes, especially shipbuilding. Certain factors are limiting the application of conventional mathematical methods, such as, [8]:

- real production process, elements and their relations are often insufficiently known and cant be mathematically defined,
- real problems are often very complex, which makes its analytical definitions very difficult to develop,
- with conventional mathematical modelling it is difficult to render dynamics of observed process.

Furthermore, regarding shipbuilding production process in particularly, it has certain specific characteristics which are distinguished shipbuilding from similar industries even more, such as, [9]:

- shipbuilding work intense industry,
- shipbuilding requires large working areas,
- shipbuilding product is very complex and often unique,
- shipbuilding have large number of diverse interim products which are very difficult to manufacture in mass production.

Following identified issues; within this research a new methodology for shipbuilding production processes design based on simulation modelling method, and specially selected operation research methods is presented.

3. Proposed methodology

Based on conducted analyses, identified problems and defined goals of the research, new methodology for shipbuilding production process design is developed with simulation modelling as its basic method. Simulation modelling is defined as imitation of operations and procedures of the real process in time, [10]. For simulation modelling in proposed methodology, an object oriented *SimTalk* language, within discrete event simulation modelling software *eM-Plant* is used, [11]. Basic element of simulation modelling method is computer simulation model of designed production process. Such computer simulation model is, compared to traditional analytic model, is more descriptive, more manageable and it allows designers to verify various decisions alternatives on computer, fast and in early design stages, [12]. For that matter, some of the most significant reasons why simulation modelling method is suggested as basic method for production process design are, [13]:

- Simulation model is relatively true presentation of the real process;
- Using computer simulation model, it is possible to spot process bottleneck on process computer model, before they happen in the real process;
- Computer simulation model can be used for evaluating different design alternatives (what-if scenarios) prior to the final investment;
- Computer simulation model can be used for verification of suggested solutions to the identified problem in real production or for experimenting with certain critical equipment parameters without influencing the real process, etc.

Such approach provides shipyard management with lot of relevant and timely information enabling more reliable decisions which will lead to the solution optimally adopted to the observed shipyard, [14]. In that context, in Table 1 a simple comparison between conventional design procedure and simulation based one, [15].

The main difference between conventional and simulation based design is that design verification and confirmation is not conducted on the real process but on its computer simulation model and before implementation, [16]. That fact provides minimization, even elimination of required design repairs.

4. Proposed methodology description

Developed methodology is structured through seven phases as described in following chapters.

4.1. Phase 1.: Problem and project goal definition

Within this phase existing process should be analysed and problems, goals and deadlines should be defined. Therefore the main tasks of this phase are as follows:

1. Define problems and their causes: It should be clearly defined what the problem with existing process is, its causes and what has to be improved.
2. Project goals definition: project goals should be clearly defined i.e. what is expected from investment in new technology.
3. Responsibilities and deadlines should be defined.

Primarly methods used within this phase are process flow chart, cause and effect diagram, paretto chart, etc.

4.2. Phase 2.: Definition of input data and conceptualization of simulation model

The main goal of this phase is to gather required input data, establish preliminary new design solution and it simulation model. Main tasks of the phase 2. are:

1. Definition of input data and preliminary new design solution: understands defining equipment CAD drawings, process flowchart, etc.

Table 1. Conventional and simulation based design comparison

Tablica 1. Usporedba konvencionalnog i projektiranja temeljenog na simulacijskom modeliranju

	Conventional / Konvencionalno	Simulation based/ Simulacijsko modeliranje
1.	Design/Projekt	Simulation model/Simulacijski model
2.	Investment/Investicija	Design verification and confirmation/Verifikacija i potvrda projekta
3.	Implementation/Implementacija	Investment/Investicija
4.	Verification and confirmation on real system/ Verifikacija i potvrda projekta na stvarnom sustavu	Implementation/Implementacija
5.	Design repairs/Popravci	-

2. Conceptualization simulation model: future simulation model of new production process should be conceptually defined.

Primarily methods used within this phase are conventional CAD tools, material flow chart, etc.

4.3. Phase 3. Computer simulation model developing

The min goal of this phase is to develop functional computer simulation model of new production process design.

Main task of this phase are:

1. Organization and systematization of gathered data: understands overview of available data and identification of missing ones.
2. Definition of input production data: input production data as basis for simulation model should be defined.
3. Developing of computer simulation model: computer simulation model of new design is developed within discrete simulation software.

Primarly methods used within this phase are regression analysis, simulation method, conventional statistical tools and *SimTalk* simulation language.

4.4. Phase 4.: Verification of simulation model

Main goal of this phase is verifications of developed simulation model and confirm it for further analysis. For that mater verification of model understands:

- remove of logical mistakes from model,
- insure full functionality of model.

The primary goal of this phase is to establish confidence in functionality and logic of developed simulation model.

Primarily methods used within this phase are simulation method.

4.5. Phase 5.: Production scenarios analysis and improvement of simulation model

Main goal of this phase is to evaluate simulation model of design solution and its potential improvement.

Main task of this phase are:

1. Analysis and validation of design solution: design solution should be analysed against project goals as to find if the goals of the project are satisfied. If not, solution should be further analysed and improved.
2. Analysis and improvement of design solution: design solution should be further analysed and improved to meet optimal solution for observed shipyard.

Primarily methods used within this phase are regression analysis and simulation method.

Hereby, suggested methods and tools are used as follows:

- for validation of design solution, material flow analysis and production line load analysis simulation method is used,
- with sensitivity analysis goal result is tested against changes of line parameters and most influence one are identified,
- production scenarios were simulated, with such identified line parameters.

This phase should result with definition of line parameters as to satisfy project goals.

4.6. Phase 6: Results documenting

Main task of this phase is to document project procedures and results on clear and understandable manner.

Primary methods used within this phase are conventional statistical methods, MS Office and CAD tools.

4.7. Phase 7: Implementation of design solutions

The main task of this phase is realization of suggested design solution into the real shipyard production process.

Main task of this phase are:

1. Implementation of the design solution into the real shipyard process: investment is conducted and new technology is constructed.
2. Improvement of simulation model: simulation model is further improved based on gathered data from real production process. Such finally improved model can be used for continuous production improvement and production planning.

5. Methodology application and verification

Developed methodology was applied and confirmed on the real project of new robotic profile cutting production line design for the particular shipyard. Methodology was conducted according the defined procedure.

- **Identifying the problem and the goals of the new robot cutting line design**

Existing profile fabrication line have inadequate throughput rate, occupies too large production are, workers and other resources. Therefore, the shipyards major goal for this investment is to design a new, robotised profile cutting line, which will require less space, be more efficient and have larger throughput rate. Within this major goal, the goals for application of developed methodology are:

- Goal A; based on develop computer simulation model, it have to be tested if shipyard suggested design solution match the basic design requiems which is that throughput rate of new robotised line should be at least 11 000 profiles per month, and
- Goal B; I suggestion of line parameters as to accomplished even better throughput rate.

- **Definition of input data and conceptualization of simulation model**

Based on initially suggested design solution of the new robotised profile cutting line and its detail analysis, process flow char is developed, Figure 1. Furthermore, preliminary technical characteristics of the line, operation and material flow characteristics and input production data are defined. This data are partially accepted from equipment supplier and partially from shipyards expert experience.

Based on conducted analysis, gathered data and defined production process, computer simulation model is conceptually defined regarding its structure, logic, functionality and organisation.

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- **Computer simulation model development**

Robotised cutting line simulation model is foundation of the computer simulation, [17], therefore, it has to be defined so to properly represents the real production process. Based on defined flow chart, input production data, technical characteristics of the line the computer simulation model of the new robotised cutting line has been developed in discrete simulation software eM-Plant.

- **Verification and analysis of simulation model of the suggested design solution**

After model verification and confirmation is conducted, in cooperation with shipyards experts, model is analysed to test if suggested design is fulfilling the project goal.

However, with simulation modelling it was determined that overall cutting time of selected characteristic fabrication sample does not complies with project goal.

Therefore, suggested design solution have to be further analysed to determine reasons of not meeting the project goal. Basics of further analysis are as follows:

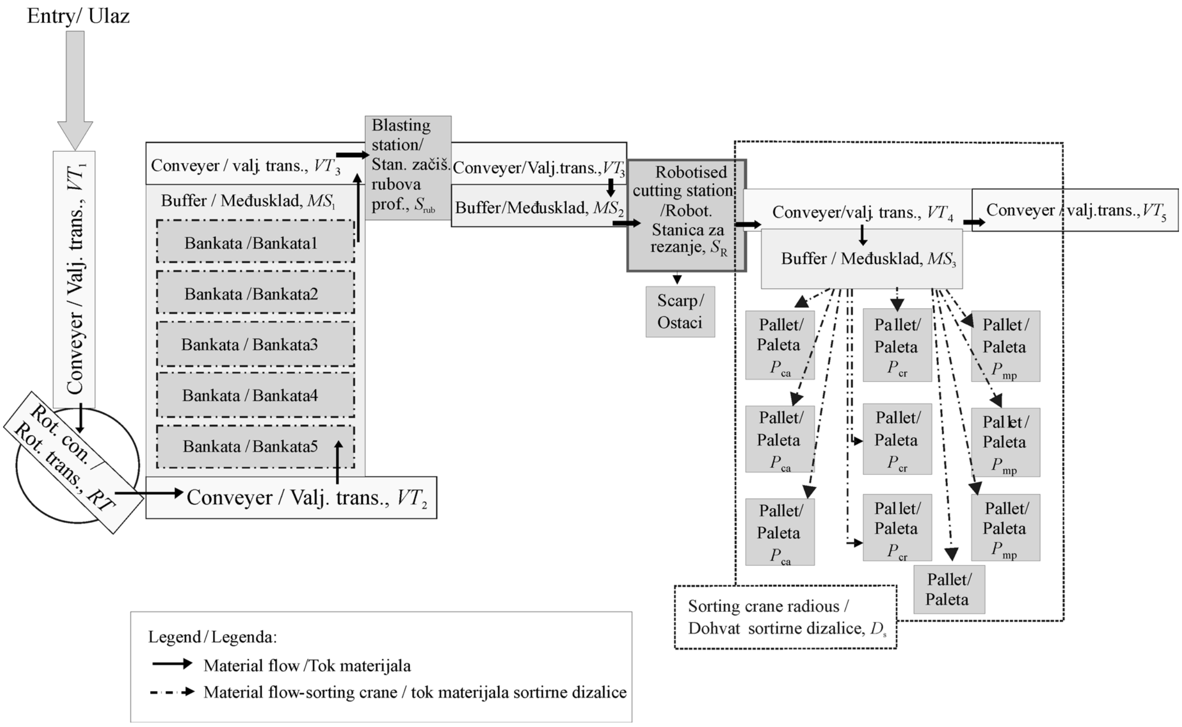

Figure 1. Robotised profile cutting line production process flow chart

Slika 1. Prikaz toka procesa robotizirane linije za obradu profila

- Material flow analysis.
- Production line loads analysis and identification of potential line bottlenecks
- Identification of the most influence line parameters on the goal function with the sensitivity analysis, etc.

With conducted analysis, it has been identified that primary bottleneck, and most influence line element on the cutting time, of the suggested design solution is the performance of crane which is sorting out cut profiles at the exit of the profile cutting robot station. Since the operation performance of that crane is insufficient, robot cutting station is blocked more that 35 % of the time, which is unacceptable, and has to be improved. Therefore, simulation of various production scenarios has been conducted, simultaneously varying crane and robot cutting stations parameters. Results are shown in Table 2. where overall cutting time is presented and its improvement against initially suggested design solution. Further more, three scenarios are suggested with difference in required financial and technological level of investment.

Table 2. Cutting time results and improvement against initially suggested solution

Tablica 2. Pregled ukupnih vremena trajanja obrade predloženih varijanti rješenja usporedba s početnim projektnim rješenjem

Sugg. sol./poč. rješenje, min	"*Economic*"/ "Ekonomična", min	"*Economic*", improve/ "Ekonomična", poboljš.	*"Optimal"/ "Optimalna", min*	*"Optimal", improve/ "Optimalna", poboljš.*	"*Maksimised.*"/ "Maks.", min	"*Maksimised*", improve/ "Maks.", poboljš.
3530	3030	14,1 %	2838	25,2 %	2531	28.3 %

Furthermore, the "*Optimal"* scenario is suggested to the shipyard management because it provides significant improvement of 25 % overall cutting time reduction, against conventionally defined design solution by shipyard, with only minor technical modification and financial investment.

- **Simulation model based methodology confirmation after project realisation and implementation in the real shipyard production process**

After the project is realised and new robotised profile cutting line has been purchased and installed into shipyard, Figure 2, developed simulation model has been tested against real production data.

Comparison results have shown good results and only minor differences due to different actual process data and performances in comparison with ones that were known at the beginning of the project. After implementing those identified differences and using real process data, it was decided that developed simulation model can further be used for continuous process improvement, planning and control in every day production.

Figure 2. Installed new robotised profile cutting line (source: Shipyard "3.MAJ")

Slika 2. Instalirana nova robotizirana linija za obradu profila (izvor: Brodogradilište „3.MAJ")

6. Conclusion

In this research, analysis of the existing methods and techniques for production process design has been conducted with emphasis on shipbuilding production process. Based on this analysis, the shortcomings of conventional approach and traditional mathematical modelling with analytic solution for complex production processes design have been determined. Furthermore, regarding identified problems, suitability of simulation model method application for designing such complex production processes, shipyard processes in particular, has been determined. Therefore, a new methodology for designing shipbuilding production processes, based on simulation modelling method and selected operations research methods and tools, has been developed. Developed methodology was applied for designing the real shipbuilding production process within investment in new robotised profile cutting line. Design solution, accomplished with suggested methodology, had cutting time 25 % lower that design accomplished with conventional method initially suggested by shipyard. Results are tested and confirmed in comparison with real production process data. Finally, the primarily contribution of developed methodology is improvement in shipbuilding production processes design practice. Such methodology provides shipyard management with efficient tool for validating design alternatives in early design stage, efficient tool for production process planning and control and also enables management to make decisions with lower risk level. As further research author suggest application of this methodology to other shipyard production processes and finally to the whole shipyard process, to create an virtual and fully integrated shipyard simulation model.

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