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VREDNOVANJE PROJEKTA BRODOGRAĐEVNOGA PROIZVODNOG PROCESA SIMULACIJSKIM MODELIRANJEM
SHIPBUILDING PRODUCTION PROCESS DESIGN EVALUATION BY SIMULATION MODELLING

Marko HADJINA – Nikša FAFANDJEL – Rajko RUBEŠA – Tin MATULJA

Sažetak: *Projektiranje novoga proizvodnog procesa zadatak je koji se izvodi temeljem raznih pretpostavki uz poznata ograničenja. Rješenje je nužno rezultat složene međuovisnosti elemenata u postupku odlučivanja. Autori su prethodno predložili nov pristup projektiranju proizvodnog procesa, temeljen na propusnosti proizvodne linije, kao osnovnoj pretpostavci uravnoteženog procesa. Propusnost se pri tome definira kao skupna tehničko-proizvodna jedinica mjere koja pokazuje vremensku zauzetost odabranoga proizvodnog procesa s točno određenom mjernom jediničnom količinom obrade. U ovom je radu za provjeru i potvrdu ovih teorijskih postavki primijenjena metoda simulacijskog modeliranja. Njome je potvrđeno da takav pristup omogućava pouzdanije uspoređivanje zamjenskih tehnologija i definiranje* layouta *proizvodnog procesa, u odnosu na konvencionalni pristup temeljen na proizvodnom kapacitetu kao prosječnoj veličini te na nizu nedovoljno točnih pretpostavki. Vrednovanjem je ujedno potvrđeno da pristup temeljen na propusnosti umanjuje financijski rizik i osigurava zadovoljavajuću razinu kvalitete definiranoga projektnog rješenja.*

Ključne riječi:
– brodograđevni proizvodni proces
– projektiranje procesa
– simulacijsko modeliranje
– propusnost
– kapacitet
– odzivna moć procesa

Abstract: *Any improvement from an existing fabrication technology level to a higher one is a task performed upon different assumptions and within known limitations. The solution should be the result of the interaction of complex elements derived from the decision making process. The authors have previously suggested a new approach for the definition and verification of new production line parameters based on the production process throughput as one of the critical assumptions for defining continuous workflow in the production process. Throughput is a group unit based technical production measure for expressing processing time of a particularly complex production group along the analyzed line. In this paper, for testing and evaluation of such an approach, simulation modelling has been applied. Furthermore, the proposed approach was confirmed as more suitable for defining new technologies and optimal production line layout, compared to the conventional approach, which is based on production capacity as an average category, and on many uncertain assumptions. Furthermore, the authors emphasize that the proposed approach also enables lower risk in terms of financial investments and a higher quality solution for the shipyard.*

Keywords:
– shipyard production process
– process design
– simulation modeling
– throughput
– capacity
– process response

1. UVOD

Autori su prethodno kod projektiranja brodograđevnoga proizvodnog procesa, kao podskupa cijelog procesa gradnje broda, uočili nedostatke upotrebe kapaciteta kao

1. INTRODUCTION

When the designing a shipyards production process as a subset of the whole shipbuilding process, the authors have previously perceived the drawbacks of using capacity as planske veličine opterećenja procesa [1]. Kapacitet je uobičajeno vezan uz količinu obrade u određenom razdoblju koje zadovoljava dinamiku gradnje broda (npr. tone po mjesecu) temeljen na prosječnom uzorku elemenata obrade, a kao takav je neprikladan u kontekstu valorizacije i usporedbe parametara nove tehnologije s tehnologijom postojećega proizvodnog procesa. Stoga su predložili nov pristup definiranju potrebnih značajki za vrednovanje i odabir nove tehnologije. On se temelji na propusnosti proizvodne linije kao jedne od osnovnih pretpostavki uravnoteženog procesa obrade. Za vrednovanje predloženog pristupa projektiranju procesa ovdje su primijenili simulacijsko modeliranje odabrane konfiguracije proizvodne linije.

2. ODREDNICE PREDLOŽENOG PRISTUPA PROJEKTIRANJU PROCESA

Propusnost autori definiraju kao skupnu tehničko-proizvodnu jedinicu mjere koja pokazuje vremensku zauzetost odabranoga proizvodnog procesa s mjernom jediničnom količinom obrade. Zauzetost je definirana međuvremenima izlaza proizvoda iz jedne faze proizvodne linije i ulaska u sljedeću fazu.

Međuvrijeme isporuke proizvoda iz promatrane faze mora biti manje ili jednako vremenu potrebnom za aktiviranje one sljedeće. Stoga zauzetost linije ukazuje na potrebnu veličinu faznih međuskladišta, brzinu obrade, brzinu i vrstu transporta, veličinu paleta za profile i sl. Simulacijskim modeliranjem vrednovana je gornja analiza kako bi se provjerilo omogućava li ona pouzdanije uspoređivanje zamjenskih tehnologija i definiranje *layouta* procesa.

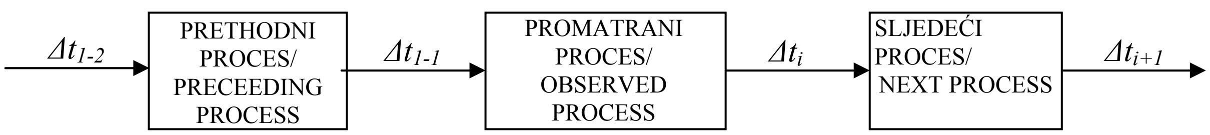
Propusnost tehnološke linije u fazi projektiranja temelji se na dinamičkoj ravnoteži sljedećih i prethodnih faza procesa obrade u odnosu na promatrani proces, slika 1. Ona je, prema (1), određena međuvremenom čekanja izvršenja sljedećeg procesa Δt_i, definiranog kao razlika vremena sljedećeg i promatranog procesa obrade. Ako je međuvrijeme čekanja sljedećeg procesa Δt_i jednako nuli, proizvodna linija je taktno usklađena. Sve što se proizvede u i-tom procesu kontinuirano ulazi u (i+1) proces, bez potreba za stvaranjem proizvodnih zaliha i međuskladištenja proizvoda.

a measure to describe the process workload, [1]. Capacity is commonly related to quantity of fabrication within a certain time period that satisfies ship construction dynamics (tons/month) based on the average sample of fabricated elements. Such a measure is unsuitable for the evaluation and comparison of parameters between new technology and existing technology already in use. Therefore, the authors have proposed a new approach for defining the required characteristics of evaluation and selection of the new technology. Such an approach is based on production line throughput as a basic premise of well-balanced manufacturing. For evaluation of the proposed production process design approach, here they use simulation modelling of the selected production line layout.

2. DETERMINANTS OF THE PROPOSED PRODUCTION PROCESS DESIGN APPROACH

Throughput is a group unit based technical-production measure for expressing processing time of a particularly complex production group along the analyzed line. Process time is defined by the interval of time from theexit of one production phase to the entrance of the following production phase. The interval of time for the product delivery from the observed phase must be less or equal to the amount of time necessary for activating the next phase. Consequently, from line occupation, the requirements are derived for size of buffers, process speed, type and speed of conveyors, size of sorting pallets, etc. Here, simulation modelling has been used to evaluate whether or not the suggested approach is more reliable in terms of comparing and evaluating the new technology with the old one, and furthermore it is more suitable for defining an optimal production line layout. Throughput of the technological process line in the design phase is based on dynamic balancing of the next and the preceding phases of fabrication in relation to the observed process, Figure 1. Throughput is defined by the interval of the waiting time for activating the next process Δt_i, which is defined as the time difference between the next and the observed fabrication process, eqn (1). If the interval of time of waiting for the next process Δt_i equals zero, then the production line is balanced.

$$\Delta t_i = t_{i+1} - t_i \tag{1}$$



Slika 1. Blok-shema serijskoga proizvodnog procesa
Figure 1. Block diagram of serial production process for panel production line

Ako je $\Delta t_i < 0$, onda je (i+1) proces potkapacitiran, proizvodna linija radi diskontinuirano bez proizvodnih zaliha i međuskladištenja proizvoda, a (i+1) proces čeka na izvršenje i-tog procesa. Ako je $\Delta t_i > 0$, onda i-ti proces proizvodi određenu količinu proizvodnih zaliha za potrebe izvršenja sljedećeg procesa obrade, odnosno poluproizvodi i-tog procesa čekaju u međuskladištu na daljnju obradu u i+1 procesu. Propusnost proizvodne linije zasniva se na poznavanju međuvremena čekanja između sljedećeg i promatranog procesa obrade, mjereno za cjelokupnu proizvodnu liniju, [2]. Maksimalno međuvrijeme čekanja, prema (2), definira kritično mjesto propusnosti proizvodne linije. Poznavanjem karakteristika sljedećeg procesa može se utjecati na karakteristike onoga promatranog, tako da međuvrijeme čekanja Δt_i bude što manje.

$$\Delta t_{i\max} = \max\left(\left|t_{i+1} - t_i\right|\right), \quad i = 1, n \tag{2}$$

Poželjno je da se za svaki proces obrade osigura određeno međuvrijeme čekanja, koje se definira kao vremenska rezerva. U tom je slučaju Δt_i uvijek pozitivna vrijednost, a poslije tako definiranog procesa predviđa se adekvatno međuskladište za poluproizvode koji čekaju na sljedeći proces obrade. Smanjenje međuvremena čekanja sljedećeg procesa rješava se usklađivanjem karakteristika promatranog i sljedećeg procesa obrade. To se ostvaruje smanjivanjem trajanja obrade sljedećeg procesa ili povećanjem trajanja obrade promatranog procesa. Propusnost cjelokupne proizvodne linije mjeri se razlikom suma svih vremena obrade i suma apsolutnih međuvremena čekanja, odnosno praznog hoda. Ako se određeni procesi odvijaju paralelno i istodobno ulaze u sljedeći proces, u proračun se uzima onaj proces čije međuvrijeme na čekanje izvršenja sljedećeg procesa najdulje traje. Na ukupno trajanje proizvodnog procesa može se djelovati promjenom trajanja procesa obrade t_i i promjenom međuvremena čekanja sljedećeg procesa obrade Δt_i. Trajanje procesa obrade konstantna je veličina i ovisi o karakteristikama proizvodne opreme i radnih mjesta, dok je međuvrijeme čekanja promjenjiva veličina i ovisi o organizaciji tehnološkog procesa i stupnju složenosti elemenata obrade. Proizvodni proces s najduljim međuvremenom čekanja Δt_i, predstavlja kritično mjesto propusnosti proizvodne linije, na temelju kojega se usklađuju karakteristike ostalih proizvodnih procesa unutar proizvodne linije. Međuvrijeme čekanja usklađuje se promjenom karakteristika sljedećeg i promatranog procesa, nabavkom produktivnije proizvodne opreme, ili osiguranjem većeg broja radnih mjesta s potrebnom opremom i radnom snagom, koja će osigurati zahtijevanu proizvodnost. Proizvodna je linija potkapacitirana ako ukupno trajanje proizvodnog procesa ne zadovoljava zahtijevanu dinamiku izrade prema planiranim potrebama radnim mjestima s najduljim

Everything that is produced in the process i continuously enters the process (i+1), without the need for using production stocks and buffers. If $\Delta t_i < 0$, then the process (i+1) is considered to be under-capacitated and the production line operates discontinuously without production stocks and buffers and the process (i+1) is waiting for the process i to finish. If $\Delta t_i > 0$ then the process i is creating a certain amount of production stocks for the needs of the following fabrication process, respectively, and intermediate parts of process i are waiting in the buffer for further fabrication in the process i+1. Throughput of the production line is based on knowing the interval of waiting time between the next and the observed fabrication process, measured for the whole production line, [2]. Max. waiting time, eqn. (2), defines critical point in the throughput of the production line. By knowing the characteristic of the following process, we can influence the characteristic of the observed one, so that the interval of waiting time Δt_i would be minimal. It is recommended that for any fabrication process, there is provision for some interval of waiting time, which is defined as the reserve time. In such case, Δt_i is always a positive value, and following such a defined production process, an adequate intermediate buffer is foreseen for intermediate parts that are waiting for the remaining fabrication process. Decrease in the interval of waiting time for the following process is resolved by harmonizing characteristics observed in the following fabrication process. This is realized by decreasing the fabrication time needed for the next process or by increasing the duration fabrication time needed for the observed process. Throughput for whole production line is measured by differences in the total fabrication time and the absolute value of the total interval of time, respectively idle. If a certain process is parallel and entering the following process at the same time, the process that has the longest interval of waiting time is taken into calculation. The total production time can be influenced by changing the time of the fabrication process t_i and changing the interval of the waiting time of the following fabrication process Δt_i. Duration of the fabrication process is a fixed value and it depends on the characteristics of the production equipment and work places. However, the interval of waiting time is a changeable value and it depends on the organization of the technological process and on the degree of complexity in fabrication. The fabrication process with the longest interval of waiting time Δt_i represents the critical point of throughput for the production line, which is the base value for adjusting the characteristics for other production processes within the production line. The interval of waiting time is adjusted by changing the characteristics of the following and observed process, purchasing more productive production equipment or applying more work places with adequate equipment and trajanjem procesa obrade primjenjuju zahvati u poboljšanju proizvodne opreme i brodogradilišta, a ne može se poboljšati daljnjim djelovanjem na međuvrijeme čekanja Δt_i. Tada se na karakteristika radnih mjesta, s ciljem skraćenja vremena izrade, povećanja propusnosti i proizvodnosti proizvodne linije.

workers that would satisfy the requirements of productivity. The production line is under-capacitated if the total time of the production process fails to satisfy the required dynamic of fabrication parts for planning shipyard demands, and it is not possible to improve with further action on the interval of waiting time Δt_i. In such case, on the work places with the longest fabrication time, changes through improvement of production equipment and characteristics of working places are applied, with the main objective being to decrease fabrication time, and to increase throughput and efficiency of the production line.

3. PREDLOŽENI PRISTUP PROJEKTIRANJU PROCESA

Pristupi projektiranju kod zamjenske tehnologije mogu se kretati u domeni zadržavanja postojećih tokova, reduciranju tokova i povećanju tokova obrade.
U svim se slučajevima postavlja pitanje propusne karakteristike postojeće tehnologije, kao stanja, i zamjenske tehnologije, kao zahtjeva. Takva propusna karakteristika mora se uklopiti u planske zahtjeve vođenja gradnje trupa broda [3]. Planski zahtjevi temelje se na propusnim karakteristikama odziva procesa na opterećenje. Jednostavno se može reći da propusnost predstavlja odzivnu moć procesa na pobudu. Prema odzivu tok obrade raščlanjuje se na:

a) diskontinuirani tok obrade,
b) kontinuirani tok obrade.

U prvom se slučaju propusnost izražava međuvremenom realizacije odziva na pobudu, a u drugom se slučaju propusnost izražava trajanjem odziva na pobudu. Oba toka obrade, diskontinuirani i kontinuirani, podrazumijevaju kontinuiranu pobudu, zadanog trajanja. Pobuda se zadaje opterećenjem proizvodnog procesa koje ima sve ili gotovo sve karakteristike ponašanja rada testiranog procesa. Propusna karakteristika i pripadajuća vremena obrade na proizvodnoj liniji upućuju na bolje ili lošije karakteristike projektiranog *layouta* proizvodnog procesa.
Kada je u pitanju tehnološka linija koja je u projektnoj fazi izrade, treba voditi računa o tome da se analiza ne temelji na prosječnim karakteristikama vremena obrade ili prosječnoj vrsti predmeta obrade. Tek analiza stvarnog opterećenja, pobude, te realnih stanja vremena može dati pouzdane rezultate za propusnost.
Postojeće okruženje brodograđevnog procesa predstavlja polaznu osnovu projektiranju konfiguracije procesa obrade elemenata trupa koja ima svoje ishodište u sljedećim zahtjevima:

a) tok obrade ne mijenja se u ovisnosti o tipovima obrade elemenata trupa,
b) istodobno se vrši paletiziranje i sortiranje elemenata trupa poslije obrade,

3. PROPOSED PROCESS DESIGN APPROACH

Approaches in designing new technologies could be related to keeping the existing process flow, reduction of the process flow and increasing the process flow.
In any case, there is the question regarding definition of throughput of the existing technology, in terms of the current state, new technology, and project requirements.
Such throughput has to fit into the planning requirements of the overall shipbuilding production process, [3]. Planning requirements are based on throughput as a response of the production process to workload impulse.
In general, it can be said that throughput represents the production process response to workload impulse. Related to production process flow, responses can be divided into:

a) discontinued production process flow,
b) continued production process flow.

In the first case, throughput is expressed with inter-mission response to workload impulse. In the second case, throughput is expressed with continuous response to workload impulse.
Both discontinued and continued production flows assume a continuous workload impulse within a predefined time interval. Throughput characteristics and related fabrication time of the observed production line indicate successful or less successful design layout of the production process.
When working on a production line that is in the design stage, analysis of the line must not be based on the production time of average element fabrication. Only analysis of real workload impulse with a realistic timeframe required for fabrication can provide a quality throughput result.
The existing environment of the shipbuilding process represents the starting point for designing and implementing new technology with respect to the following demands:

a) Fabrication flow is continuous and independent of fabricated elements,
b) Simultaneous storage and sorting of fabricated elements after fabrication,

c) *layout* procesa obrade mora biti rezultat tražene propusnosti linije,
d) integrirati proces obrade s logističkom podrškom iz okruženja,
e) minimalizirati broj izlaza linije u funkciji elemenata trupa i sastavljanja,
f) minimalizirati broj međuskladišta u fazama procesa obrade,
g) propusnost linije temelji se pronalaženju dinamičke ravnoteže sljedećih i prethodnih faza obrade,
h) uključiti prostorna ograničenja zauzetosti linije,
i) izbor palete temelji se na transportnim ograničenjima i zahtjevima sljedećih faza proizvodnje,
j) prihvaćanje obrađenih elemenata trupa na izlazu je u nizu, a ne pojedinačno.
k) točnost obrade na izlazu treba biti u skladu sa zahtjevima,
l) kontrola točnosti ulaznog materijala.

4. ODABIR KONFIGURACIJE PROIZVODNOG PROCESA

Predloženi pristup projektiranju i definiranju proizvodnih procesa nalazi vrlo široku primjenu, dok su autori spomenuti pristup primijenili na primjeru implementacije jedne proizvodne linije za izradu elemenata trupa u postojeće okruženje brodograđevnog procesa na optimalan način za brodogradilište.
Ako se ne pristupi analizi propusnosti linije, lako je moguće da linija bude potkapacitirana ili prekapacitirana. Naime konvencionalno definirani kapacitet linije temeljem prosječnog elementa obrade često dovodi do tako projektirane linije koja će u slučajevima složenije obrade uzrokovati usporenje proizvodnog procesa, a u slučaju obrade manjeg stupnja složenosti radit će u praznom hodu. Stoga se predlaže propusnost koja se temelji na taktnoj usklađenosti prethodne, promatrane i sljedeće faze obrade proizvodnog procesa, odnosno potprocesa.
Analizirano je nekoliko konfiguracija proizvodnih linija. Polazišnu liniju konfigurirao je i ponudio proizvođač temeljem uobičajeno iskazanoga kapaciteta kao planske veličine s prosječnim uzorkom obrade.
Ta konfiguracija promatrani proizvodni proces dijeli na dvije linije prema vrsti elemenata obrade.
U ovom se slučaju elementi obrade dijele na dvije radne stanice prema ulazno-izlaznoj specifikaciji. Takav *layout* zahtijeva više prostora i više financijskih sredstava te ima veću propusnu moć. Međutim važno je ocijeniti je li takav *layout* nužno potreban promatranom proizvodnom procesu.
Naime autori su temeljem opisanoga novog pristupa projektiranju utvrdili da se traženi učinak linije može postići proizvodnom linijom s jednom radnom stanicom

c) Production process layout must be the result of required throughput,
d) The fabrication process should be integrated with shipyard logistic support,
e) Production line output should be minimized in relation to the types of fabricated elements and the resulting production demands,
f) The number of storages should be minimized,
g) Throughput is based on finding the dynamic balance between the following and preceding fabrication phases,
h) Space limitations should be taken in consideration,
i) Selection of sorting palettes should consider transport limitations and requirements of the following production,
j) Output is grouped, not individual,
k) Fabrication accuracy of output should meet the required demands, and
l) Raw material deviation control of input.

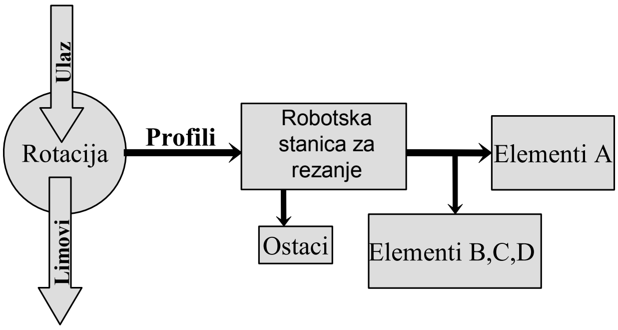
4. PRODUCTION PROCESS CONFIGURATION SELECTION

The suggested approach to design and definition of production processes is widely applicable. The authors apply this approach to the example of implementation of a hull elements production line considering the present environment of the shipyard's process. It is meant to define the optimal method regarding the shipyard.
If the throughput of the line is not well analyzed, there is a great risk of the line being under-capacitated or over-capacitated. The issue with the conventional line capacity definition, based upon an average fabrication element, is a significant slowdown of the process in the case of a more complex fabrication and in the case of a below average fabrication element it will idle. Therefore, the authors suggest basing the throughput expression upon a balancing of preceding, observed and following fabrication phases of the production process and sub process. The authors have analyzed a few configurations of production lines. A starting point was the line configured and offered by the manufacturer, with capacity expressed ordinarily as a planned value based on the average sample of fabrication.
This configuration splits the observed production process into two lines considering the type of fabrication elements. In this case, the elements are shared between two working stations as defined in the input/output specification. This layout requires more space and more financial recourses. Nevertheless, it is important to evaluate whether a layout of this type is indispensable for the observed production process. The matter is, while considering this new approach to design, the authors have established that a production line with a single working station can obtain the requested efficiency of the line,

koja pritom zauzima manje mjesta i iziskuje manje financijskih sredstava. Taj su slučaj autori prihvatili za konkretan proizvodni proces, a temelji se na jednoj suvremenoj radnoj stanici i dvama izlazima jer takav najviše odgovara proizvodnom, prostornom i logističkom okruženju brodogradilišta, slika 2. Za tu varijantu primijenjen je nov pristup projektiranju proizvodnog procesa obrade elemenata trupa.

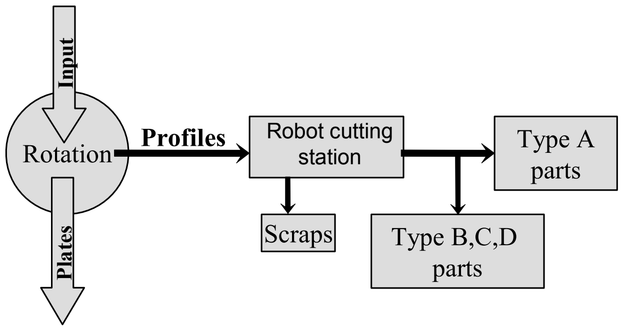
Projektiranje *layouta* procesa tehnološke linije temelji se na propusnosti kao odzivnoj moći procesa na pobudu [4]. Pobudom se smatra točno određeni asortiman elemenata trupa, a odzivnom moći vrijeme potrebno za obradu obrađivanog asortimana.

which would need less space and less financial investment. The authors accepted this solution as optimal for a concrete production process. It is based upon a contemporary working station and two outputs, being the most suitable for a shipyard's production, space and logistic environment (Fig. 2). A new approach to the layout of the fabricating hull elements has been applied. The design of process layout finds its basics in the throughput as the evaluation of the process considering the workload impulse, [4]. In this case, the impulse is thought of as a specific assortment of hull elements, and the response determines the time necessary to fabricate this specific assortment.



Legenda: Elementi tipa A,B,C i D predstavljaju vrste profila razdjeljenih prema kriteriju veličine

Slika 2 Proizvodna linija s jednom radnom stanicom i dva izlaza



Legend: Parts type A,B,C and D are representing different profile types regarding size

Figure 2. Production line with one working station and two exits.

5. VREDNOVANJE ODABRANOG PROJEKTA PROCESA SIMULACIJSKIM MODELIRANJEM

U svrhu analize i vrednovanja odabranog projekta nove proizvodne linije autori su osnovali simulacijski model konfiguracije robotizirane linije za rezanje ravnih profila. Model simulira buduću liniju za rezanje profila te na razini računalnog programa omogućava variranje niza parametara, odnosno analizu većeg broja različitih proizvodnih scenarija. Stoga takav bi model poslužio i preciznijem definiranju i optimiranju parametara opreme linije te kontinuiranom planiranju i optimiranju proizvodnje tijekom njezine eksploatacije. Prema priloženoj dokumentaciji izvršena je analiza asortimana profila i traka te je definirana i prihvaćena konfiguracija ulaznog materijala temeljem prethodno izvršenog projekta simulacijskog modeliranja robotske linije za rezanje profila sa dvije radne stanice za rezanje, [5]. Secifikacija ulaznog materijala prikazana je u tablici 1.

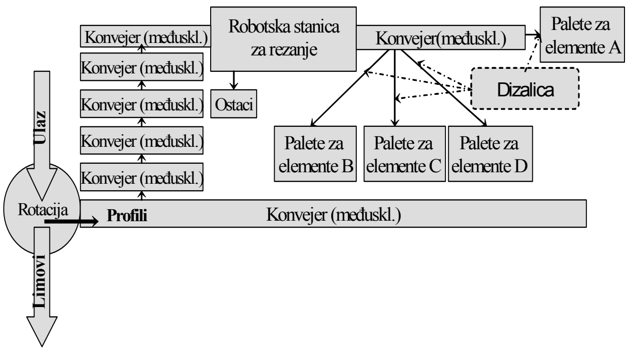
5. SELECTED PROCESS DESIGN EVALUATION BY SIMULATION MODELLING

For evaluation purposes of the selected new production line design, the authors created a simulation model of the robotized production line for profile cutting. The model presents and simulates a future production line and as such, it allows the designer to vary the production line parameters using different production scenarios. Therefore, such a model is used for more precise definition and optimization of production line parameters and for day-to-day scheduling of line exploitation. According to the documentation profile assortment analysis provided, a profile assortment analysis has been conducted and input material configuration has been accepted as in the previously conducted research project of modelling and simulating a robotised profile cutting production line for two cutting stations, [5]. Material input specification is presented in Table 1.

Tablica 1. Prihvaćena specifikacija ulaznog materijala

Grupa dvodna			
Naziv	Visina, h mm	Debljina, δ mm	Broj komada
HP 220 x 11,5	220	11,5	26
HP 240 x 10	240	10	12
HP 280 x 11	280	11	2
HP 340 x 12	340	12	20
HP 340 x 14	340	14	56
HP 370 x 13	370	13	48
HP 370 x 15	370	15	4
HP 400 x 14	400	14	2
TR 80 x 15	80	15	12
TR 120 x 13	120	13	2
TR 130 x 12	130	12	92
TR 150 x 12	150	12	84
TR 150 x 13	150	13	427
TR 150 x 15	150	15	714
TR 200 x 10	200	10	4
TR 200 x 15	200	15	5
TR 200 x 20	200	20	12

Na temelju definiranoga koncepta konfiguracije linije za rezanje profila, te njegove detaljne razrade utvrđen je grafički prikaz toka procesa, slika 3.



Slika 3 Dijagram toka procesa

Model linije je temelj i osnovni element računalne simulacije, te ga je potrebno definirati tako da na odgovarajući način predstavlja stvarni proizvodni proces. Nužno je modelirati samo one aspekte stvarnog sustava koji utječu na problem koji se istražuje. Stoga model mora istodobno biti jednostavan i dovoljno detaljan kako bi se mogli izvući valjani zaključci. Uspješna pomirba tih dvaju zahtjeva, detaljnosti i jednostavnosti, te izrade modela u razumnom roku vrlo je značajna za izradu kvalitetnog modela [6].

Za izradu modela procesa potrebno je:

- Utvrditi što sve treba biti uključeno u model;
- Utvrditi razinu detaljiziranosti modela;
- Razlučiti osnovne resurse i operacije u procesu;
- Definirati proizvodni plan linije za rezanje profila;

Table 1. Adopted input material specification

Double bottom group			
Mark	height, h mm	Thickness, δ mm	Number of pieces
HP 220 x 11,5	220	11,5	26
HP 240 x 10	240	10	12
HP 280 x 11	280	11	2
HP 340 x 12	340	12	20
HP 340 x 14	340	14	56
HP 370 x 13	370	13	48
HP 370 x 15	370	15	4
HP 400 x 14	400	14	2
TR 80 x 15	80	15	12
TR 120 x 13	120	13	2
TR 130 x 12	130	12	92
TR 150 x 12	150	12	84
TR 150 x 13	150	13	427
TR 150 x 15	150	15	714
TR 200 x 10	200	10	4
TR 200 x 15	200	15	5
TR 200 x 20	200	20	12

Based on the chosen production line configuration and its detailed drawings, the production flow chart has been defined as in Figure 3.

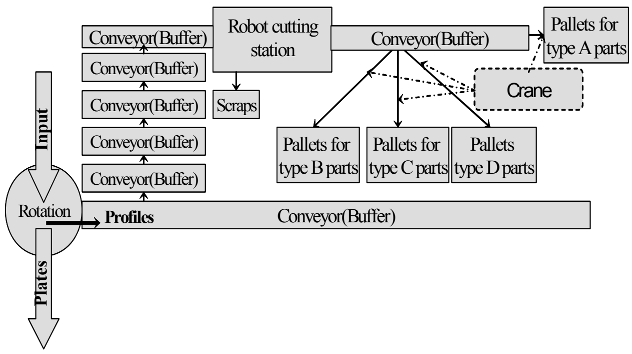


Figure 3 Process flow chart

The computer model of the real production line is the basis for computer simulation therefore, it should properly represent a real production line. While modelling, it is necessary to model only relevant production line parameters, which are relevant to the project. Therefore, the model should be simple and adequately detailed to provide valid conclusions.

Successfully balancing those demands is important for making a good model, [6].

Therefore, in the development of a model it is important to determine the following:

- What has to be included in the model;
- Determine the level of detail of the model;
- Distinguish the basic process resources and operations;
- Define the production assortment fabricated on

• Uključiti prostorna i vremenska ograničenja sustava;
• Prikupiti ostale relevantne podatke;
• Definirati uvjete i način provjere modela;
• Utvrditi koji se izlazni podaci očekuju;
• Definirati rokove.

Slijedom definiranog toka procesa i njegovih parametara razvijen je računalni simulacijski model linije za rezanje ravnih profila i traka.
Nadalje, proveden je niz simulacija procesa te analizirani proizvodni scenariji s ciljem utvrđivanja da odabrana konfiguracija proizvodne linije udovoljava sljedećim zahtjevima brodogradilišta:

- da ukupno vrijeme rezanja za odabranu grupu elemenata trupa udovoljava zahtjevima dinamike proizvodnje,
- da iskoristivost stanice za rezanje iznosi najmanje 70%,
- da nema *uskih grla* u proizvodnji.

Vrednovanjem procesa pomoću simulacijskog modela utvrđeno je da odabrana konfiguracija udovoljava postavljenim zahtjevima. Dobiveni rezultati za ukupno vrijeme rezanja i zauzetosti robotske stanice za rezanje su:

t_u – ukupno vrijeme rezanja = 8600 min
R_u – zauzetost stanice za rezanje = 97.5 %

Međutim treba napomenuti da temeljem iskustva nije relano očekivati neprekidan rad stanice za rezanje posebice pod zauzetosti većoj od 95%. Stoga se, predlažu daljnja istraživanja u kojima bi se model testirao s maksimalnom zauzetosti stanice od 75%. Također, procijenilo bi se ispunjava li odabrana konfiguracija linije i u tom slučaju postavljene zahtjeve brodogradilišta.

6. ZAKLJUČAK

Prethodno je predložen nov pristup za definiranje nove proizvodne linije za obradu elemenata trupa za uvjete i ograničenja postojećega brodogradilišta, nastojeći pritom angažirati što manja potrebna financijska sredstva i umanjujući rizik od pogreške. Ovdje je pristup provjeren korištenjem simulacijske metode, a vrednovan nakon što je nova linija izgrađena i stavljena u funkciju. Cilj je vrednovanja da se uz ostale poznate karakteristike proizvodnog procesa propusnost nužno afirmira kao odrednica za projektiranje uravnoteženoga proizvodnog procesa uz zadana ograničenja okruženja.
Provjera simulacijskim modeliranjem potvrdila je da rezultati novog pristupa pridonose optimizaciji proizvodnih procesa, skraćenju trajanja izrade i rokova

the production line;
• Define the process limitations in terms of available space, time limits, etc.;
• Gather other relevant data;
• Define and determine conditions and terms for model evaluation and testing;
• Determine what output data are expected;
• Define the time schedule.

Determining the previous and defining production line basic parameters and process flow chart is followed by the building of the production line simulation computer model. After finishing the simulation model, conduction of different production scenario proceeds with the goal of defining if the suggested production line concept will meet shipyard requirements, particularly regarding:

- The total cutting time for chosen hull elements assortment should comply with production dynamics requirements;
- Cutting station usage should be min. 70%;
- Avoid production bottlenecks.

After conducting scenarios on a simulation model and analyzing results, it is concluded that the suggested concept for a robotized production line for profile cutting accomplishes the shipyards requirements. The results for total cutting time and cutting station usage are as follows:

t_u – total cutting time = 8600 min
R_u – cutting station usage = 97.5 %

However, from experience it is not likely to expect non-stop working hours of a robotic station especially with over 95 % usage. Therefore, in further research, the model will be configured and analyzed with station usage set at no more than 75%, to see if shipyards requirements will still be meet.

6. CONCLUSION

Previously, a new approach has been suggested for designing new production line hull elements fabrication, respecting known shipyard limitations, and involving optimal financial recourses and minimizing risk.
Here, this approach is tested using a simulation method and evaluated after the new line has been built and made operational.
The objective of evaluation is to promote throughput of the production process, among other known characteristics, as one of the major characteristics of a balanced production process within defined limitations.
Verification by simulation modelling has confirmed that the results of the suggested new approach contribute to the optimisation of production processes, a decrease in

isporuke gotovih proizvoda te smanjenju angažmana radne snage i materijalnih sredstava.
Nadalje, utvrđeno je da se ovim pristupom mogu već u fazi projektiranja proizvodnog procesa predvidjeti i riješiti potencijalna uska grla te racionalizirati proizvodni proces u segmentima gdje se uoči da je to moguće.
Ujedno, ovaj pristup omogućava prikladnije određivanje i uspoređivanje odzivnih moći stare i nove tehnologije te optimalno definiranje potrebne nove opreme.
Projektno rješenje u odnosu na konvencionalan pristup sadrži nižu razinu rizika u odlučivanju i osigurava nužno i dovoljno rješenje sa stajališta angažiranih resursa i financijskih sredstava.
Predlaže se primjena pristupa kako za projektiranje novih proizvodnih procesa tako i za restrukturiranje i unapređenje postojećih.

production time and delivery intervals for new buildings, and more efficient usage of labour and material resources.
Furthermore, it has confirmed that with such an approach it is possible already in the stage of concept design, to identify and solve potential problems and bottlenecks and to rationalize the production process.
In addition, this approach enables a more appropriate definition and comparison of response characteristics between old and new technologies and optimally defines the requirement of new equipment.
Such solutions, compared to the conventional approach, constitute a lower risk level in decision-making and ensure effective allocation of involved recourses and financial funds.
It is suggested that this approach be applied, not only for new production process designs, but also for the refitting and improvement of existing ones.

7. POPIS OZNAKA / 7. LIST OF SYMBOLS

propusnost	t_{pr},	min	throughput
trajanje sljedećeg procesa	t_{i+1},	min	duration of next process
trajanje promatranog procesa	t_{pi},	min	duration of observed process
trajanje prethodnog procesa	t_{pi-1},	min	duration of preceding process
međuvrijeme čekanja	Δt_i,	min	interval of time for waiting next process

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Adresa autora / Authors' address
Red. prof. dr. sc. Nikša Fafandjel
Asist. Marko Hadjina, dipl. ing.
Asist. Tin Matulja, dipl. ing.
Tehnički fakultet Sveučilišta u Rijeci
Vukovarska 58
51000 Rijeka
HRVATSKA
niksaf@riteh.hr
hadjina@riteh.hr
tmatulja@riteh.hr

Rajko Rubeša
Brodogradilište "3. maj" d.d.
Liburnijska 3
51000 Rijeka
HRVATSKA
rajko.rubesa@ri.t-com.hr