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Hierarchical Modeling as Basis for an Optimal Shipyard Layout Design Methodology*

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In this article, a methodology for creating a preliminary optimal layout design of shipyard production areas is proposed. The methodology is based on the implementation of a specifically defined procedure which is composed of following actions: establishing the closeness relationships of the chosen production areas from the shipbuilding process technological point of view, based upon a survey of relevant experts; thereupon the generation and valuation of all possible production layout variants within the shipyard is performed using SLP method; after establishing a representative number of most competitive variants, the selection of optimal variant is performed by using the hierarchical modeling with AHP method; at the end the sensitivity analysis is made in order to check the stability of the chosen layout of production areas. Proposed methodology is applied on real problem of shipyard layout design optimization.

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Hijerarhijsko modeliranje kao osnova metodologije projektiranja optimalnog rasporeda proizvodnih površina brodogradilišta

Izvornoznanstveni članak

U radu je predložena metodologija za projektiranje optimalnog rasporeda proizvodnih površina brodogradilišta u preliminarnoj fazi. Predložena metodologija se temelji na provođenju točno definirane procedure gdje se redom utvrđuju odnosi bliskosti odabranih proizvodnih površina sa stajališta tehnologičnosti brodograđevnog procesa, a na temelju provedenog anketiranja relevantnih eksperata; zatim se vrši generiranje i procjena svih mogućih varijanti rasporeda odabranih proizvodnih površina SLP metodom; nadalje, nakon odabira reprezentativnog broja najizglednijih varijanti, AHP metodom se vrši izbor one varijante koja optimalno udovoljava svim postavljenim kriterijima; na kraju se vrši analiza osjetljivosti kako bi se ispitala stabilnost odabranog rješenja rasporeda proizvodnih površina. Nakon provedene predložene metodologije vrši se prikaz odabranog projektnog rješenja s pripadajućim proizvodnim tokovima. Predložena metodologija provjerena je na realnom problemu optimizacije rasporeda proizvodnih površina brodogradilišta.

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1. Introduction

Shipyard production processes is continuously technologically improving with a goal of achieving concurrent shipyard. For such mater a very complex decision making process is needed. Large number of different requirements and constraint has to be analyzed and valorised so to be able to find at least an acceptable solution. The process of finding the optimal solution requires additional analysis with use of appropriate scientific methods.

However, shipyard space expanding and technological improvement could be often conditioned by various objective constraints. Therefore, improvement of shipyard production processes often means conducting improvement only within shipyard boundaries.

Within the research, the author have perceived the lack of proper methodology for design, improvement and optimization of shipyard production areas layout and corresponding material flow. In current practice, shipyard management is often using a benchmarking method or automated tools which usually do not result with optimal design solutions.

Therefore, the new scientifically based methodology which will enable finding an optimal production areas layout, in efficient and fast manner, with respect to defined constraints is suggested. Further more, a special effort was conducted to make this methodology easy applicable by shipyard management, to whom this methodology is primarily intended.

Symbols/Oznake

AHP	- Analytic Hierarchy process - Analitički Hijerarhijski proces
A	- absolutely necessary closeness - isključivo potrebna bliskost
A_{1i}	- local priority of the i-class alternative regarding criteria 1. - lokalni prioritet i-te alternative s obzirom na 1. kriterij
A_{2i}	- local priority of the i -class alternative regarding criteria 2. - lokalni prioritet i-te alternative s obzirom na 2. kriterij
A_{3i}	- local priority of the i-class alternative regarding criteria 3. - lokalni prioritet i-te alternative s obzirom na 3. kriterij
A_{4i}	- local priority of the i-class alternative regarding criteria 4. - lokalni prioritet i-te alternative s obzirom na 4. kriterij
A_{5i}	- local priority of the i-class alternative regarding criteria 5. - lokalni prioritet i-te alternative s obzirom na 5. kriterij
a_{ij}	- Saaty's intensity of relative importance - numerički koeficijent Saat-ijeve skale
BIL	- locksmith and craft workshop - radionica s odjeljenjima za bravare i limare
E	- essential closeness - porebna bliskost
∂F	- goal function - ciljna funkcija
I	- important closeness - važna bliskost
$K_{1\text{-}5}$	- criteria - kriterij
m	- number of experts - broj eksperata
MOT	- engine workshop - radionica motorista
NAV	- berth - navoz
n_p	- number of production area - broj proizvodnih površina
O	- ordinary closeness - neunatno važna bliskost
$OD1$	- area for section assembling and finalizing - površina za odlaganje i ukrupnjivanje sekcija
$OD2$	- area for section finalizing - površina za odlaganje sekcija
PAN	- panel line - radionica za izradu panela
P_i	- overall priority of i-class - ukupni prioritet i-te alternative
RIC	- pipe cutting, forming and outfitting - radionica za rezanje i oblikovanje cijevi
r_{jk}	- closeness rating for i-th closeness form k-th expert - ocjena bliskostiua i-tu bliskost od k-tog eksperta
ROL	- plate cutting and forming - radionica za rezanje i oblikovanje limova
ROP	- profile cutting and forming - radionica za rezanje i oblikovanje profila
RPM	- subassembly - radionica prdmontaže
RRL	- plate cutting - radionica za rezanje limova
s	- SLP score - SLP ocjena
S_x^F	- sensitivity function - funkcija osjetljivosti
SEA	- sea - more
SKL	- steel stockyard - skladište čeličnog materijala
SLP	- Systematic Layout Planning - Sistematsko planiranje rasporeda površina
U	- unimportant closeness - nevažna bliskost
w_i	- weight factor for i-th closeness - težinski koeficijent i-tog elementa
X	- not desirable closeness - nepoželjna bliskost
Y_i	- number of closeness of i-class - broj bliskosti i-te površine
ZBO	- equipment blasting and painting - radionica za zrnčenje i bojenje opreme
ZIB	- section blasting and painting - radionica za zrnčenje i bojenje sekcija

2. Shipyard layout design

Generally, the production areas layout design process is geared towards seeking optimal solutions for different activities with corresponding components. This process understands finding spatial arrangement of such activities in a given space, satisfying given preferences and constraints, [1-2]. More specifically it is a complex and subjective problem which include evolving task dynamics, inadequate information availability, as well as uncertain and conflicting preferences [3-4].

It is obvious that production areas layout design process is based on designer's creativity and interaction between results of different contradictory disciplines, [5]. It is known fact that majority of software's and computerized techniques for layout design ignores creativity and talent of designer which understands complex interaction between production flow and production areas, [6]. Still, there is an approach which includes expert's knowledge for decision making and modeling such uncertain problems, [7]. Such Expert system approach is possible to apply for designing shipyard production area layout.

Production areas in shipbuilding are especially interesting problem due to specific characteristics of shipbuilding production process which involves large scale products requiring wide production areas. Need for investigating such specific problem arises from few basic reasons: 1) Size and shape of existing shipyards areas are often unchangeable because it is bounded with see from one side, and urban settlements and/or industries facilities, from the other side; 2) Layout of existing shipyard facilities if usually not subject to changes due to large scale structures and already established corresponding infrastructure; 3) Evolution of shipbuilding technology procedures caused a different demands and requirements for production areas in shipyards. Such demands are difficult to implement because of already specified constraints and limitations.

Due to mentioned reasons, technological modernization within the existing shipyards has to be oriented to improving efficiency of using existing production areas.

3. Methodology for shipyard production areas layout design

New methodology for designing shipyard production areas layout is based on conducting defined procedure with a goal to reach an optimal design solution. Such design solution is bases for further production flow analysis [8].

In the authors thesis the methodology is applied and verified for designing an optimal production areas layout within the project of technological modernization of existing shipyard. The procedure, methods and techniques of developed methodology are explained in this section. Furthermore, proposed methodology pattern of procedure is shown on Figure 1.

3.1. Identification of closeness ratings of selected shipyard production areas with expert survey method

The production areas which are directly participating in basic shipyard production process was selected and compared, [8].

Combination of these production areas directly changes basic production flow and therefore influence on shipyard production process. In that content it is necessarily to identify closeness ratings with corresponding weight factors for such areas. In this thesis the closeness ratings are described with numbers between 0 and 5, and letters *A, E, I, O, U* and *X* to be input data for next steps of the proposed methodology, table 1.

Table 1. Closeness ratings, [8]

Tablica 1. Pokazatelji odnosa bliskosti, [8]

Number code/ Brojčani kod	Closeness/Bliskost	Letter code/ Oznaka bliskosti
5	Absolutely necessary/Isključivo potrebna	*A*
4	Especially important/Posebno važna	*E*
3	Important/Važna	*I*
2	Ordinary/Neznatno važna	*O*
1	Unimportant/Nevažna	*U*
0	Not desirable/Nepoželjna	*X*

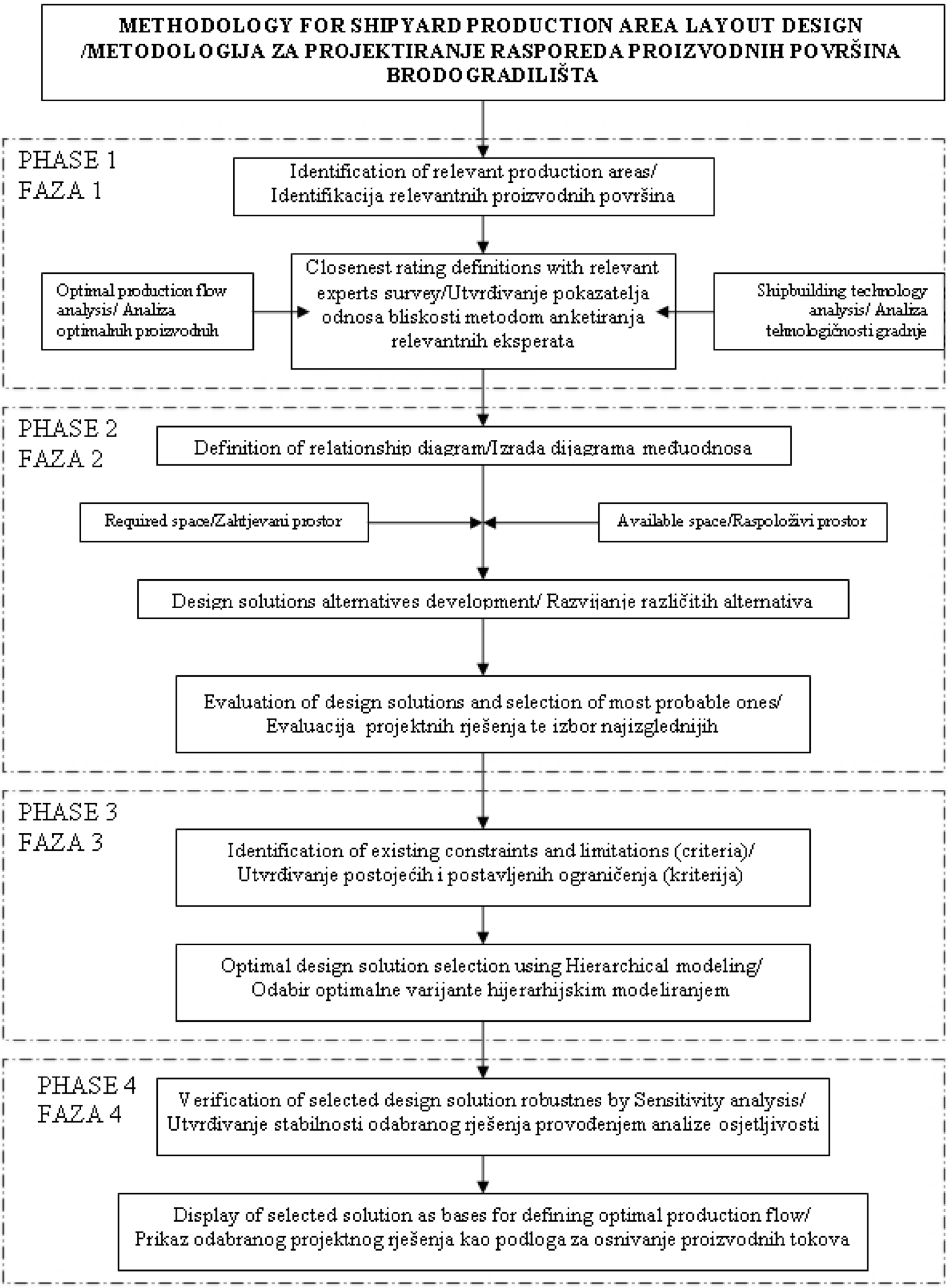

Figure 1. Proposed methodology Pattern of Procedures, [8]

Slika 1. Blok dijagram predložene metodologije, [8] Those closeness ratings between selected production areas are defined considering knowledge of optimal production flow and using survey method among large number of relevant experts from shipyards as well as from universities. With the same survey questioner weight factors were also defined.

Based on gathered information within survey, closeness ratings are calculated using following relation:

$$w_i = \frac{\sum_{k=1}^{m} \rho_{jk}}{m}. \tag{1}$$

Where is,

w_i – weight factor for *i-th* closeness,

r_{jk} – closeness rating for *i-th* closeness form *k-th* expert,

m – number of experts.

Using such data, the design solutions which are favourable regarding material flow will be highly scored using Systematic Layout Planning (*SLP*) score system, [9]. Closeness ratings of selected production areas are presented within relationship matrix as shown in Table 2.

Weight factors of corresponding closeness ratings are presented in Table 3.

Using data, shown in Table 2. and Table 3., within next phase all possible design solutions can be analyzed regarding optimal production flow using *SLP* method, [10].

3.2. Analysis of all possible design solutions of selected production areas and selection of probable ones by using *SLP* method

Generally, every shipyards layout includes: Relationship between selected shipyard production areas, Size and shape of particular production area, Spatial arrangement of production areas within shipyard layout, [8].

Within this phase of proposed methodology, by using *SLP* method and taking in consideration these elements, the goal is procedurally obtained. For faster generation of the results the specialized software was used [11].

The goal of this phase is selection of most feasible production areas layouts analyzing all possible combinations of shipyard production areas. There is very large number of such combinations, for example, for 20 production areas there is 2,4 x 10^{18} possible combinations.

All generated layouts as design solutions are evaluated by *SLP* score, calculated accordingly to closeness criteria as follows:

Table 2. Relationship matrix, [8]

Tablica 2. Matrica odnosa bliskosti, [8]

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
		SKL	*ROL*	*ROP*	*RRL*	*PAN*	*RPM*	*ZIB*	*RIC*	*BIL*	*MOT*	*ZBO*	*OD1*	*OD2*	*NAV*	*SEA*
1	*SKL*	◊	*A*	*A*	*A*	*O*	*O*	*U*	*E*	*O*	*O*	*O*	*U*	*U*	*U*	*I*
2	*ROL*			*I*	*I*	*I*	*E*	*U*	*U*	*U*	*U*	*U*	*O*	*U*	*O*	*U*
3	*ROP*			◊	*I*	*E*	*E*	*U*	*U*	*O*	*U*	*U*	*O*	*U*	*U*	*U*
4	*RRL*				◊	*A*	*E*	*U*	*U*	*O*	*U*	*U*	*O*	*U*	*O*	*U*
5	*PAN*					◊	*A*	*I*	*U*	*O*	*U*	*U*	*I*	*O*	*O*	*U*
6	*RPM*						◊	*A*	*I*	*I*	*I*	*O*	*E*	*E*	*I*	*O*
7	*ZIB*							◊	*U*	*U*	*O*	*O*	*E*	*E*	*E*	*U*
8	*RIC*								◊	*I*	*E*	*E*	*I*	*I*	*I*	*I*
9	*BIL*									◊	*E*	*E*	*I*	*O*	*I*	*O*
10	*MOT*										◊	*I*	*I*	*O*	*I*	*E*
11	*ZBO*											◊	*I*	*I*	*I*	*U*
12	*OD1*												◊	*I*	*A*	*O*
13	*OD2*													◊	*E*	*O*
14	*NAV*														◊	*A*
15	*SEA*															◊

Table 3. Closeness Weight factors

Tablica 3. Težinski faktori oznaka bliskosti

Closeness Letter code/ Oznaka bliskosti	A	E	I	O	U	X
Weight factor, w_i/ Težinski faktor, w_i	45	11	3	1	0	-45

$$s = \sum_{i=1}^{n_p} w_i \cdot Y_i . \qquad (2)$$

Where is,

Y_i - number of closeness of *i*-class,

w_i - weight factor for *i*-closness,

s - *SLP* score,

n_p - number of production areas.

One of the generated layouts will certainly be the best regarding *SLP* score, but it is not necessarily an optimal solution regarding shipyard requirements. Namely, beside requirements for optimal production flow, other important requirements and constraints has to be taken in consideration. Therefore, within this phase authors selected 20 best design alternatives regarding *SLP* score, because this is the sample where the design solution which optimally meats all constraints and limitations is most likely expected.

3.3. Hierarchical modeling with AHP method for optimal design solution selection

In this phase of proposed methodology, for optimal design solution selection, authors suggest using *Analytical Hierarchy Process* (*AHP*), [12]. The *AHP* method as one of multi-attribute decision making is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the *AHP* helps the decision makers find the one that best suits given constraints and limitations (criteria). Based on mathematics and psychology, it was developed by Thomas L. Saaty.

So, as to select the optimal design between previously selected 20 probable solutions it is necessarily to identify relevant constraints and limitations which this design has to satisfy optimally. The criterions are resulting from design requirements and shipyards spatial and technological limitations, [8]. Those criteria are included in hierarchical model development and based on them an optimal solution, as a method goal, will be found between chosen design solutions.

Detailed analysis of those 20 design solutions regarding selected criteria's was performed, [8].

Hierarchical model structurally consists of goal, criteria, sub-criteria and alternatives (solutions), figure 2.

Goal is placed on the highest hierarchical level and it is not compared to any other element of hierarchical structure. On the first level there are *k* criteria which are compared to each other in pairs regarding to directly superior element - goal. The $k \cdot (k - 1) / 2$ of comparisons is required. The same procedure is repeated for next hierarchical level, all the way down to the last *r* level, whiles all comparisons of all solutions regarding to superior criteria, down to *r-1* level, is completed.

Each comparison of two elements of hierarchical model is done by *Saaty*'s scale of relative importance [12].

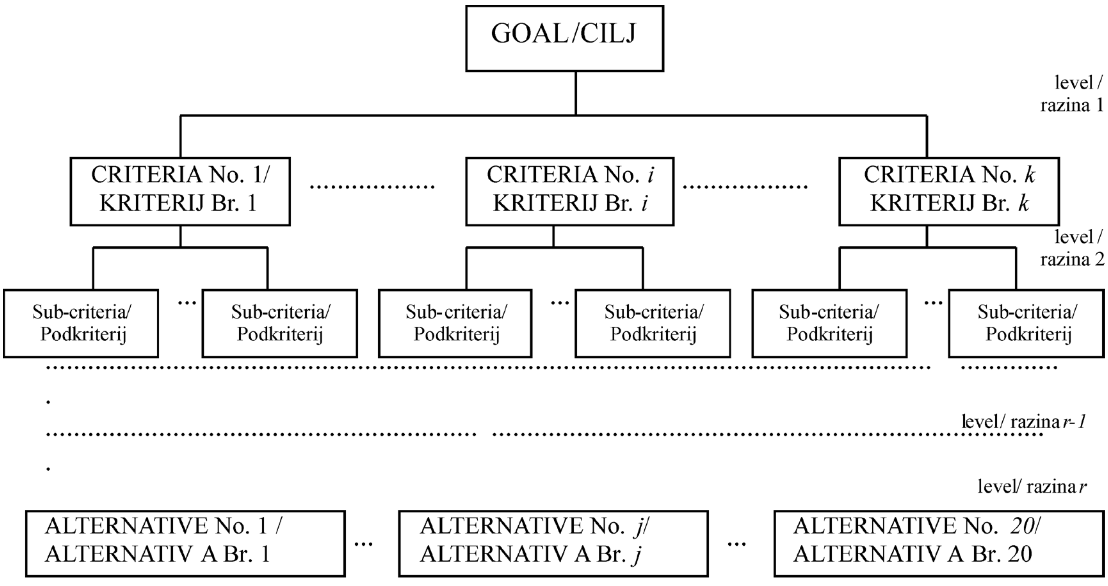

Figure 2. *AHP* hierarchical model

Slika 2. *AHP* hijerarhijski model

Results of element comparison on observed hierarchical level are organized in matrix as follows:

If n elements are compared to each other related to superior corresponding element on higher hierarchical level, then, when comparising i element to j element using *Saaty's* scale or relative importance, numerical coefficient a_{ij} is determined and placed in its adequate position in matrix A:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & \cdot & a_{2n} \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & & & \cdot \\ a_{n1} & a_{n2} & \cdot & \cdot & a_{nn} \end{bmatrix}. \quad (3)$$

Inverse result value is placed on position a_{ji} as to maintain consistency of decision making. Detailed description of *AHP* method procedure can be found in [13].

Within this research specialized software for hierarchical modeling has been developed and particularly adapted for use in shipyard production area layout design. Within this software the *AHP* method is used for finding relevant results organized as a ranking list of selected design alternatives. With *AHP* method local priorities are found and base on them overall priorities of design solutions are calculated with equation (4).

$$P_i = A_{1-i} \cdot K_1 + A_{2-i} \cdot K_2 + A_{3-i} \cdot K_3 + A_{4-i} \cdot \cdot K_4 + A_{5-i} \cdot K_5. \quad (4)$$

Finally based on determined priorities from P_1 to P_{20}, the solution with highest value is selected and such solution is considered to be optimal one.

3.4. Stability determination of selected design solution with sensitivity analysis

To conclude if suggested rank list of design solution is stable, the Sensitivity Analysis (*SA*) is conducted for various combinations of input data within this phase of suggested methodology. *SA* belongs to Operation Research methods within linear programming and is used for analyzing how changes of model parameters are influencing the optimal solution, [14].

The purpose and results of *SA* application are as follows: determining the stability of optimal design solution, Simplification of hierarchical model, Determination of new values for parameters of hierarchical model, based on experiments, Determination of critical parameters of hierarchical model, etc.

There are two types of *SA* as follows, [15]:

- **Analytical *SA*:**

1. for well defined systems,
2. solving problem using partial derivation, (5),

$$S_x^F = \frac{\partial F}{\partial x}. \quad (5)$$

Where S defines sensitivity function (change intensity) of goal function F related to changes of parameter x.

- **Empirical *S*A:**

1. influence of parameter values change on optimal solution is analyzed by experiments,
2. Such type of *SA* is more applicable to complex systems.

Within proposed methodology the empirical *SA* is suggested due to complexity of shipyard production process. For conducting *SA* within real problem the *Expert Choice* software was used, [16]. The following empirical *SA* types are used: Dynamic, Performance, Gradient, Head to Head.

Using *SA* within this final phase, the selected optimal design solution from previous phase can be confirmed as stable and therefore as final solution.

4. Selected design solution

With the proposed methodology, optimal design solution has been selected. This solution is presented in 3D model of particular shipyard, figure 3. Further more, based on such model, authors suggest using simulation modeling for analyzing the throughput of selected optimal design layout for defined production program.

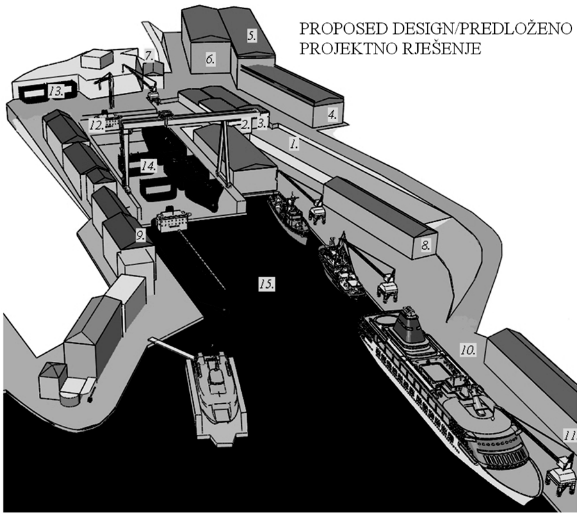

Figure 3. 3D model of proposed optimal design solution

Slika 3. 3D virtualni prikaz optimalnog projektnog rješenja rasporeda proizvodnih površina

Based on same model, the material flow chart has been defined as shown on Figure 4. Such material flow determined by proposed methodology is mostly straight forward and without backward characteristics. future research it is suggested to analyse the application of this methodology for designing optimal layouts within particular production areas of shipyard.

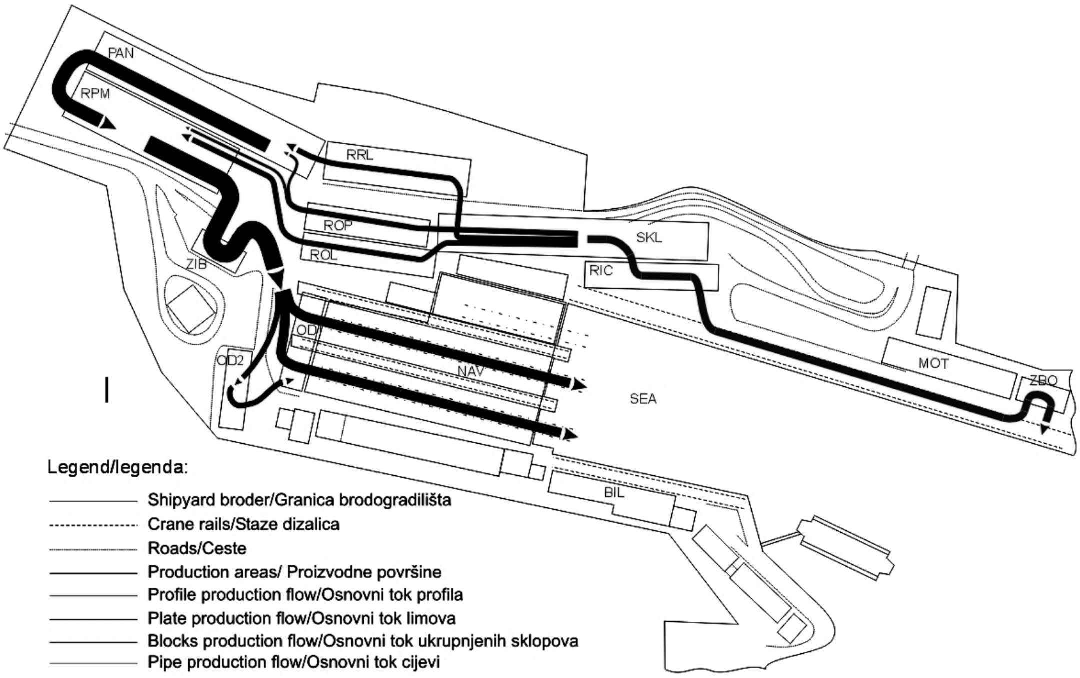

Figure 4. Material flow chart

Slika 4. Prikaz tokova materijala

5. Conclusions

The new methodology for shipyard production area layout design was developed because the lack of using modern scientific methods, techniques and tools for such designing was identified. Furthermore, additional effort was made to make this methodology more efficient and applicable especially for shipyard management. Developed methodology is realized through defined procedure with use of specially selected scientific methods and tools. This methodology was verified on real problem within project of technological modernization of existing shipyard. Application of developed methodology resulted with such design solution which improved shipyard production areas layout and in the same time optimally satisfy all given criteria's. Such design solution was basis for further detailed calculations. Furthermore, for

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