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Improvement of Industrial Production Process Design Using *Systematic Layout Planning*

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Modern industrial production processes, including also shipbuilding processes, are expected to deliver products or interim products on time with acceptable price and required quality. For instance, production of pipe units in shipbuilding industry that use conventional methods, characterized by high content of human work per pipe unit, cannot satisfy these requirements. To increase productivity it is necessary to introduce CNC machines and robotized lines that will also enhance production process capacity. Accordingly, optimal machines layout to ensure production and technological process with maximal capacity potential should be defined. Therefore, for production process design improvement, the employment of Systematic layout planning procedure is proposed. SLP procedure is used for defining optimal machines and jobs layout within the production process. Improvement of production process design using proposed procedure has been tested through basic design for new pipe production workshop within a particular shipyard.

Unapređenje projektiranja industrijskog proizvodnog procesa primjenom *Sistematskog planiranja layouta*

Izvornoznanstveni članak

Suvremeni industrijski proizvodni procesi, pa tako i brodograđevni, moraju biti takvi da osiguraju isporuku proizvoda ili međuproizvoda na vrijeme uz prihvatljivu cijenu i pritom uz zahtijevanu kvalitetu. Primjerice, proces izradbe cijevi u brodograđevnoj industriji primjenom konvencionalnih metoda temelji se na velikom udjelu ručne obradbe, što rezultira nedovoljnom proizvodnošću po jedinici cijevi. Za povećanje proizvodnosti nužno je uvoditi CNC strojeve i robotizirane linije koje će doprinijeti povećanju propusne moći proizvodnog procesa. Pri tome treba definirati optimalan razmještaj strojeva, odnosno *layout*, koji osigurava proizvodno-tehnološki proces obradbe s maksimalnom propusnom moći. Stoga se, za unapređenje projektiranja proizvodnog procesa predlaže primjena procedure Sistematskog planiranja layout-a. SLP procedura koristi se za utvrđivanje optimalnoga razmještaja strojeva i radnih mjesta unutar proizvodnog procesa. Unapređenje projektiranja proizvodnoga procesa korištenjem predložene procedure provjereno je na temeljnom projektu nove cjevarske radionice realnog brodogradilišta.

1. Introduction

From present industries, focusing on shipbuilding is expected to deliver to owners a quality product i.e. ship, on time and at the market price. To obtain these requirements, existing shipyards need to improve productivity and efficiency through implementation of new technologies and reorganization. It can be achieved by using new methodologies and approaches to design particular shipbuilding process segments with the objective to reach acceptable solutions.

Symbols/Oznake

SLP	- systematic layout planning - sistematsko planiranje layout-a
P	- product - proizvod
Q	- quantity - količina
R	- routing - proces
S	- supporting service - podrška
T	- timing - tajming
A	- absolutely essential - apsolutno potrebno
E	- essential - potrebno
I	- important - važno
O	- ordinary importance - prosječno važno
U	- unimportant - nevažno
X	- undesirable - neželjeno
DN	- nominal diameter - nazivni promjer
s	- layout adjacency score - vrijednost graničnosti layout-a
Y_i	- the number of adjacencies in class i - broj graničenja i-tog elementa
w_i	- the code score for class i - odnos bliskosti i-tog elementa
s	- layout score - ocjena layout-a
n	- number of workstations - broj radnih stanica

There are several ways to improve production: eliminate waste, improve flow, reduce material handling, plan for growth and expansion, built-in flexibility [1].

Production of pipe units in shipbuilding industry using conventional methods characterized by high content of human work per pipe unit cannot give good results towards the objectives of increasing productivity and obtaining higher production quality levels. In this respect, every shipyard, which has the intention to remain present in the world market, considers various possibilities for decreasing the content of human work per unit of the final product.

One of the possibilities in this way of increasing productivity and shortening production time within a shipyard is the introduction of modern robotized lines for pipe units production i.e. modernization and reorganization of present state [2].

Shipyards equipped with machines and tools with high content of manual work will be faced with problems during the process of changing type of production from conventional to modern pipe unit production line. It can be related to the fact that the complete technological process should be changed, starting from the design stage, work based breakdown structure, production planning and production itself [3].

Complexity of building a ship-piping system can be solved through a variety of potential solutions depending on the level of development for piping design and production [4].

While designing a particular modern production process within shipyards, space limitations appear, because new spaces have to be found or the old ones have to be technologically rearranged, which is usually difficult to realize. That is the reason why the best solution might be to design a completely new production line if possible.

The layout design has a significant impact on the performance of a production process [5]. Layout design has been an active research area in the past few decades [6]. However, design algorithms for production lines and/or workshops are rare and/or may not be adequate to solve a real design problem [7].

Existing research in production design layout problems often fall into two major categories, such as algorithmic and procedural ones. Algorithmic approaches usually simplify both design constraints and objectives in order to reach a surrogate objective function whose solution can then be obtained [8-9]. These approaches usually only involve quantitative input data [10]. Their design solutions are easier to evaluate by comparing their objective function values.

Procedural approaches can incorporate both, qualitative and quantitative, objectives in the design process [11-12]. For these approaches, the design process is divided into several steps that are then solved sequentially. The success of a procedural approach implementation is dependent on the generation of quality design alternatives that are often from the output of an experienced designer. Thus, the input from area experts during the design process is considered to be a must towards an effective workshop layout design. It is often the last step for a procedural approach to evaluate the design alternatives. The choice of the final design is often difficult when multiple objectives are considered.

A workshop layout design problem exposes the strong properties of a multiple objective decision problem. For this instance, an algorithmic approach may not be adequate in providing a quality solution. Alternatively, the use of a sound procedural approach with the aid of a proven tool as design evaluation function would be a viable approach for a workshop layout design problem.

The authors suggest using a Systematic layout planning (SLP) procedural approach for production process design improvement, because it features both the simplicity of the design process and the objectivity of the multiple-criteria evaluation process as opposed to existing algorithmic approaches, which are ineffective in solving qualitative objective problems, and regular procedural approaches that lack a structural multiple-criteria evaluation approach.

While the authors were involved in the R&D project of technological modernization of one real shipyard, as a separate project they had to design a new pipe production workshop, where a proposed novel approach was implemented and tested.

2. Outline of systematic layout planning

This section aims at providing a brief review of the SLP procedure as shown in Figure 1. The SLP begins with PQRST analysis (step 1) for the overall production activities. The data collection fields including P (product), Q (quantity), R (routing), S (supporting), and T (time) should be scrutinized in order to assure the validity of the input data at the design stage.

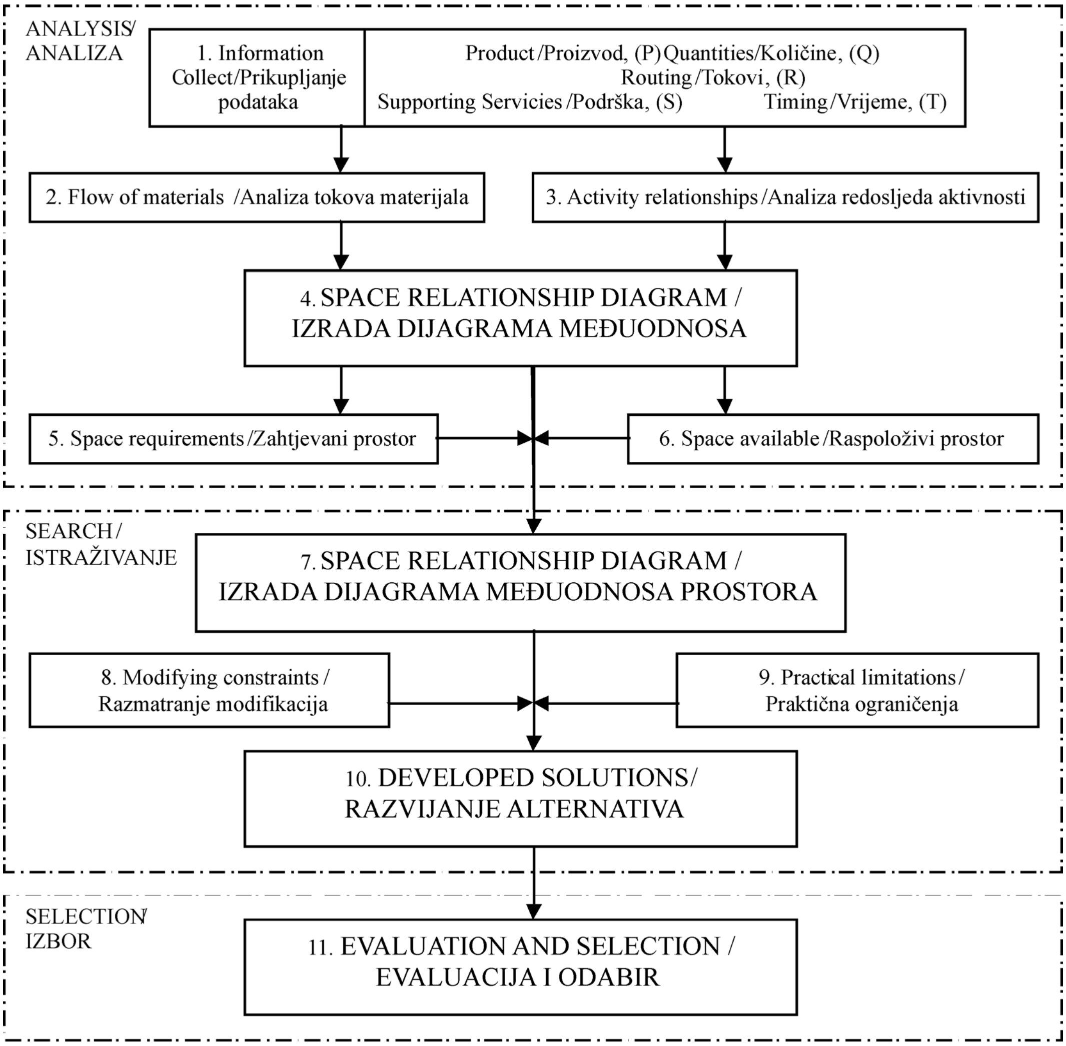

Figure 1. SLP Procedure
Slika 1. SLP procedura

In the flow of material analysis (step 2), all material flows from the whole production line are aggregated into a from-to chart that represents the flow intensity among different tool sets or work positions. The step of “activity relationships” (step 3) performs qualitative analysis towards the close relationship decision among different work positions.

The step of “relationship diagram” (step 4) positions areas spatially. For those work positions (areas) that have strong interactions and/or close relationships are placed in proximity.

The steps of “space requirements” and “space available” (steps 5 and 6) determine the amount of floor space to be allocated to each work position. This decision is particularly critical to a workshop design problem due to the costly clean room floor space and the difficulty in future expansion.

The step of “space relationship diagram” (step 7) adds area size information into the relationship diagram from step 4. Additional design constraints and limitations are considered before the start of block layout generation in steps 8 and 9. Step 10 then develops layout alternatives as design candidates. Step 11 chooses the final design from these design candidates.

3. Analysis of pipe production process

Before starting with the suggested procedure appropriate analysis regarding what is going to be designed, or redesigned, should be performed. The existing pipe workshop within the observed shipyard has insufficient capacity and insufficient space available to satisfy planned product mix of four various types of ships, which is given in Table 1. So it is decided to design a new pipe workshop, which will be moved to the new area, as defined within the R&D project of technological modernization of the related shipyard done previously. Further more, the new CNC tools will be inserted in the process.

The main goals of the new pipe workshop are:

- to improve pipe production efficiency and productivity,
- to modernize pipe production process,
- to replace old existing equipment with new, modern and effective ones,
- to achieve scheduled pipe production capacity with reductions in cost while maintaining required quality,
- to use the existing machines where necessary, or possible.

This product mix requires approximately 50 000 m of pipes per year i.e. production of 25 000 pieces per year in range from 15 mm to 400 mm of nominal diameter. Further constraints and limitations are in dimensions and location of the workshop and associated areas as defined in the R&D project of related shipyard and also in production capacity, which should be flexible for introducing new ship types into the product mix and also for ship repair purpose.

The new, designed, pipe production process should be a modern one with the following activities: steel pipe input buffer; steel pipe tracing and marking for cutting by CNC band saw; small and precise steel pipe tracing and marking for cutting by conventional saw (DN 15 – DN 32); steel pipe cutting DN 25 – DN 400 by CNC band saw; steel small and precise pipe cutting by conventional saw (DN 15 – DN 32); automatic flange welding on the straight steel pipe DN 25 – DN 350; manual flange welding on the welding station; steel pipe drilling by CNC hole and saddle cutter DN 80 – DN 400; manual pipe drilling on the fitting station; steel pipe bending by CNC bending machine DN 20 – DN 125; small and precise steel pipe bending by bending machine without mandrel DN 15 – DN 32; curved steel pipe made by elbow; automatic groove pipe end preparation by CNC hole and saddle cutter DN 80 – DN 400; groove pipe end

Table 1. Product mix, four newbuildings per year

Tablica 1. Proizvodni asortiman, četiri novogradnje godišnje

Ship/Brod	No./ y. Br./g.	Net steel mass/ ship Neto masa čelika/brod t	Length/ Duljina m	Breadth/ Širina m	Depth/ Visina m
Asphalt carrier/ za prijevoz asfalta	1	2600	108	18,6	10,6
Car carrier/ za prijevoz automobila	1	2000	125	20	15,7
Ferry/ Trajekt	1	1100	87	17,5	3,7
Crude oil tanker/ za prijevoz sirove nafte	1	3000	130	22	12

preparation by lathe; steel pipe fitting on the fitting table; steel pipe welding; steel pipe grinding; pipe testing; steel pipe coating; steel pipe shipping. Schematic diagram of designed pipe production process with their mutual relationships is presented in Figure 2.

The results of proposed designed production process will be observable in:

- modernization of pipe production process
- improvement of shipbuilding and ship repair pipe production methodology
- increase of pipe production capacity, which will reduce production time and costs.

Modernization should also take into account budget limitations and practicability of implementation without interrupting the production in process.

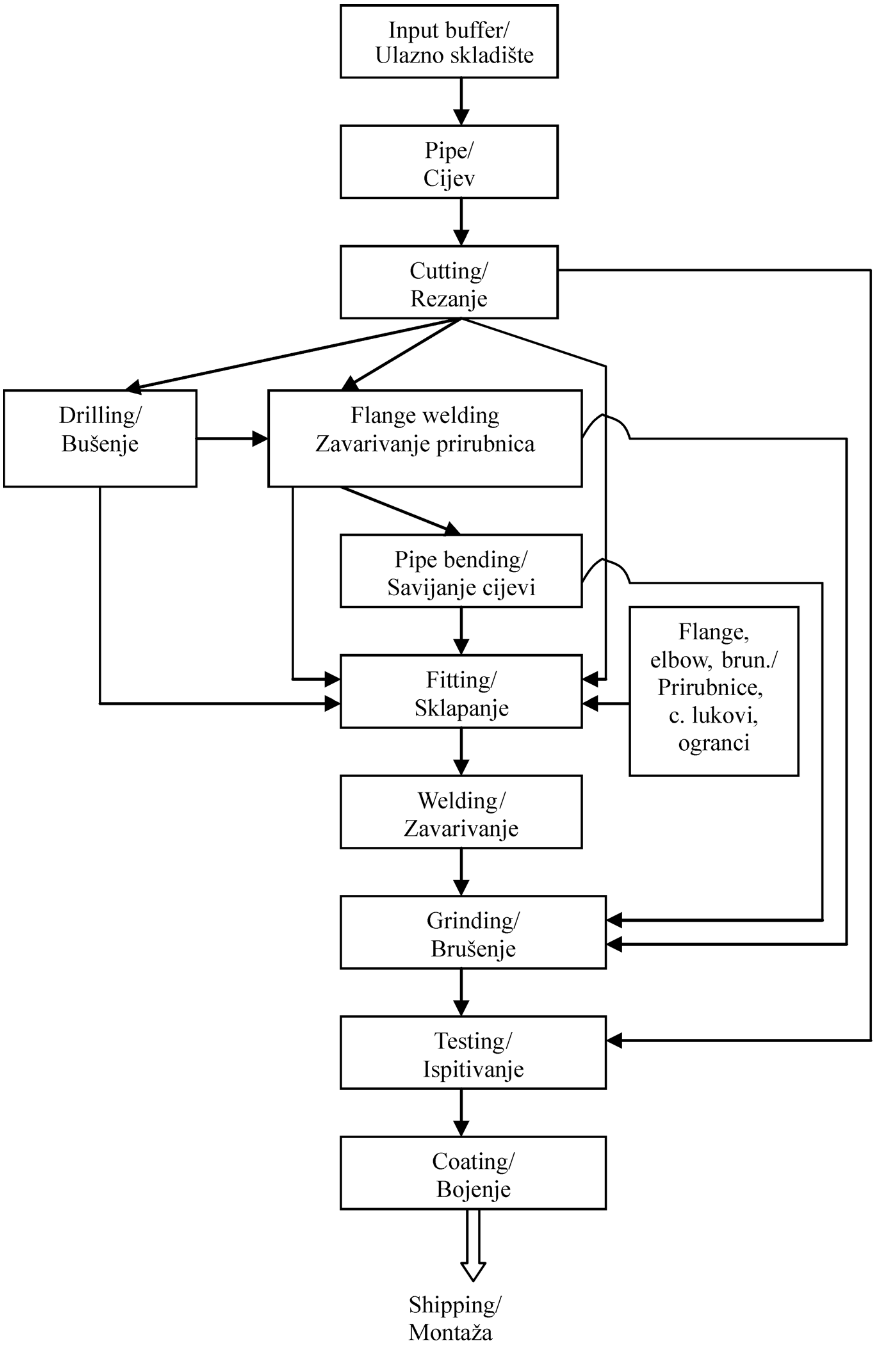

Figure 2. Schematic diagram of designed pipe production process of new pipe workshop
Slika 2. Shematski prikaz projektiranog proizvodnog procesa izrade cijevi nove cjevarske radionice

The following workstations are needed to satisfy the designed pipe production process: steel pipe input buffer; pipe tracing and cutting station; automatic flange welding station; CNC pipe bending station; pipe fitting station; orbital pipe welding station; pipe welding station; pipe grinding station; small and precise pipe cutting and fitting station (DN 15 – DN 32); transport route through the workshop.

4. Design improvement with SLP procedure

To improve industrial production process design, the authors suggest a novel approach based on Systematic layout planning procedure, introduced as an initial design step. The suggested approach has proved to be a reliable basis for following steps towards reaching an optimal final design. SLP enable designers with the opportunity to analyse a larger number of alternatives and to choose the optimal one followed by further elaboration and detailed design. In this article the suggested procedure for real problem was supported with BlockPlan software [13].

The SLP as a procedure starts by collecting the input data. The most important workstations within the workshop should be defined followed by the required area for each one, as shown in Table 2. In observed real design problem, targeted ten workstations need to be placed within the workshop area of defined length and breadth.

Table 2. Workstations input data

Tablica 2. Ulazni podaci o radnim stanicama

No./ Br.	**Workstation/Radna stanica**	**Abbrev./ Kratica**	**Površ./ Area, m^2**
1	Steel pipe input buffer/ Ulazno skladište čeličnih cijevi	INB	45
2	Pipe tracing and cutting station/ Platforma za trasiranje i rezanje cijevi	LAC	60
3	Automatic flange welding station/ Platforma za automatsko zavarivanje prirubnica	FAW	78
4	CNC pipe bending station Platforma za CNC savijanje cijevi	BND	132
5	Pipe fitting station/ Platforma za oblikovanje (sklapanje) cijevi	FRM	150
6	Orbital pipe welding station/ Platforma za orbitalno zavarivanje	ORW	60
7	Pipe welding station/ Platforma za zavarivanje cijevi	PIW	56
8	Pipe grinding station/ Platforma za brušenje cijevi	PGR	55
9	Small and precise pipe cutting and fitting station/ Platforma za izradu tankih i preciznih cijevi	CAF	78
10	Transport route through the workshop/ Transportni pravac kroz radionicu	TRS	120
			∑ 834

Table 3. Relationship chart

Tablica 3. Matrica odnosa bliskosti

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		INB	***LAC***	***FAW***	***BND***	***FRM***	***ORW***	***PIW***	***PGR***	***CAF***	***TRS***
1	***INB***	-	*A*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
2	***LAC***	*A*	-	*E*	*I*	*U*	*U*	*X*	*X*	*U*	*A*
3	***FAW***	*U*	*E*	-	*A*	*E*	*U*	*O*	*E*	*U*	*A*
4	***BND***	*U*	*I*	*A*	-	*E*	*E*	*X*	*I*	*U*	*A*
5	***FRM***	*U*	*U*	*E*	*E*	-	*I*	*I*	*X*	*U*	*A*
6	***ORW***	*U*	*U*	*U*	*E*	*I*	-	*O*	*I*	*U*	*A*
7	***PIW***	*U*	*X*	*O*	*X*	*I*	*O*	-	*I*	*U*	*A*
8	***PGR***	*U*	*X*	*E*	*I*	*X*	*I*	*I*	-	*U*	*A*
9	***CAF***	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	-	*A*
10	***TRS***	*U*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	-

Calculated workstation average area is 83,40 m^2. All process flows are aggregated among different functional areas in order to determine the departmental relationships. The resulting relationship chart is shown in Table 3. Every workstation area is put in relation to every other one by assigned relationship codes as follows: Absolutely Essential, *A*; Essential, *E*; Important, *I*; Ordinary Importance, *O*; Unimportant, *U*; and Undesirable, *X*, as shown in Table 4.

The assigned numerical values of each of these codes are shown in Table 4.

Table 4. Relationship code scores

Tablica 4. Pokazatelj odnosa bliskosti

	Code/ Kod	**Code Score/ Vrijednost koda**
Absolutely Essential / Isključivo potrebno	*A*	15
Essential / Posebno važno	*E*	5
Important / Važno	*I*	2
Ordinary Importance / Neznatno važno	*O*	1
Unimportant / Nevažno	*U*	0
Undesirable / Nepoželjno	*X*	-10

Further more, the numerical value of each workstation is calculated by summing all code scores associated with the particular workstation. These values for all workstations are shown in Table 5.

Table 5. Numerical value of each workstation

Tablica 5. Numeričke vrijednosti pojedinih radnih stanica

Workstation Radna stan.		**Code scores/ Vrijednosti koda**									**No. val./ Br. vrij.**
1	***INB***	15	0	0	0	0	0	0	0	0	**15**
2	***LAC***	15	5	2	0	0	-10	-10	0	15	**17**
3	***FAW***	0	5	15	5	0	0	5	0	15	**46**
4	***BND***	0	2	15	5	5	-10	2	0	15	**34**
5	***FRM***	0	0	5	5	2	2	-10	0	15	**34**
6	***ORW***	0	0	0	5	2	0	2	0	15	**25**
7	***PIW***	0	-10	0	-10	2	0	2	0	15	**1**
8	***PGR***	0	-10	5	2	-10	2	2	0	15	**6**
9	***CAF***	0	0	0	0	0	0	0	0	15	**15**
10	***TRS***	0	15	15	15	15	15	15	15	15	**120**

The next steps convert the space relationship diagram into block layout alternatives by incorporating practical limitations and constraints. If there are no limitations and constraints, there are more then 3,6×10^6 different layout alternatives to be analysed.

The authors enforce shape constraints according to R&D project of technological modernization of the observed shipyard. In addition, there are few practical limitations for observed layout design as follows. First, the overall dimensions of the whole workshop are 60 m in length and 15 m in breadth, which means 4:1 ratio. Second, the input buffer for all steel pipes has fixed position. Third, the workshop should be divided into two parts in longitudinal way with transport route 2 m wide, called central spine. Fourth, some of the areas must be located in such way to have connection to the roller conveyor also with fixed position. Taking into account the practical limitations and constraints, the layout generation commences with the space relationship diagram. When two workstations are preferred to be in proximity, they are either placed close on the same side of the central spine or on opposite sides of the central spine. The layout design process continues to place workstations on the workshop floor in this manner and consider necessary limitations and constraints until all departments are on the workshop floor. The area expert's opinions are part of the inputs towards the layout generation.

Finally, evaluation and selection are performed. The evaluation of layout alternatives is difficult in that multiple objectives including quantitative and qualitative ones are involved. In addition, many of those objectives are subjective in nature.

In the original case study, eight categories were used for layout evaluation i.e.:

A) maximize process quality;

B) maximize productivity;

C) maximize capacity;

D) maximize layout flexibility;

E) maximize work in process flow;

F) maximize human factors;

G) maximize maintenance; and

H) minimize cost impact.

Twenty possible alternatives were taken into consideration. These alternatives were evaluated by the score calculated using adjacency criterion regarding input parameters. Higher score means that constraints are satisfied better i.e. better alternative. A score 1,0 would be the highest possible normalized adjacency score.

The layout score is computed as:

$$s = \sum_{i=1}^{n} w_i \cdot Y_i , \qquad (1)$$

where:

Y_i is the number of adjacencies in class i,
w_i is the code score for class i,
s is the layout score, and
n is the number of workstations.

Regarding the requirements from relationship chart the highest theoretical layout value calculated with adjacency criterion is 149. Due to some practical limitations and constraints this value is not possible to achieve. The best adjacency score value for related problem is obtained to be 131. The normalized value of adjacency score is 0,88. This obtained alternative is chosen as the final solution, and as a basis for further design steps. The schematic view of selected layout is shown in Figure 3.

The obtained alternative is then further analysed using statistical methods of processing the evaluation data received by the shipyard management and area experts [14]. Furthermore, this alternative was then used as the basis for following detailed design and optimisation procedures [15-16]. The final design of pipe production workshop in observed shipyard is shown in Figure 4. The positions shown in this figure are given in Table 6.

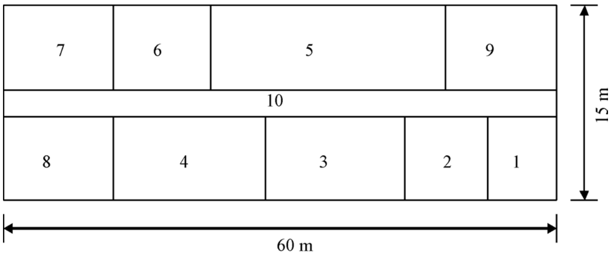

Figure 3. Obtained alternative
Slika 3. Odabrana varijanta

5. Conclusion

The Systematic layout planning procedure has been proposed to improve an industrial production process design, and in particular to successfully solve a pipe workshop layout design which embodies the nature of a multiple-objective decision problem with many qualitative design constraints. As used algorithmic approaches are usually more effective for solving quantitative problems, Systematic layout planning was here suggested as more suitable for solving qualitative problems to support the design process, especially during the first phase of preliminary design. This procedural approach features the simplicity of the design process and the objectivity of the multiple-criteria evaluation process. The proposed approach, as an additional tool for design methodology, is valuable as a design tool for supporting design process so as to become more effective in solving real-world industrial problems.

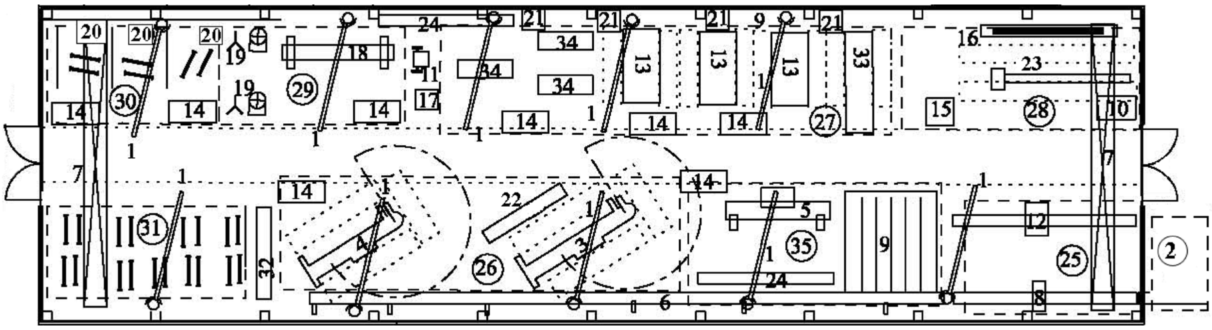

Figure 4. Layout of new pipe production workshop
Slika 4. Oprema nove cjevarske radionice

Table 6. Positions list from Figure 9.

Tablica 6. Popis pozicija iz slike 9.

No. / Pos.	**Position name / Naziv pozicije**	**No. / Pos.**	**Position name / Naziv pozicije**
1	Console revolving crane / Konzolna dizalica	**19**	Semiautomatic tool for orbital welding / Poluautomatski alat za orbitalno zavarivanje
2	Input buffer for steel pipes, DN 32-400 / Ulazno skladište čeličnih cijevi, DN 32-400	**20**	MAG wlding equipment / Ispravljač za MAG zavarivanje /
3	CNC bending machine with manderl, pipes DN 20 -100 / CNC savijačica cijevi s trnom za cijev, DN I0-100	**21**	ARC welding equipment / Ispravljač za REL zavarivanje
4	CNC bending machine with manderl, pipes DN 32-125 / CNC savijačica cijevi s trnom za cijev, DN 32 –125	**2I**	Shelves for radius die / Police za odlaganje za kalupe
5	Automatic flange welding machine, DN 25-350 / Stroj za automatsko zavar. prirubnica, DN 25-350	**23**	Abrasive cutting wheel up to DN 32 / Abrazivni cirkular za rezanje cijevi, do DN 32
6	Roler conveyor for steel pipes, DN 40 - 400 / Transportni valjci za čelične cijevi, DN 40 -400	**24**	Inerim flange buffer / Priručno međuskladište prirubnica
7	Gantry crane / Mostna dizalica	**25**	Steel pipe tracing and cut. station, DN 15 - 400 / Platforma za trasiranje i rezanje cijevi, DN 15 -400
8	CNC band saw, pipes DN 32 - 350 / CNC tračna pila za rezanje cijevi, DN 32 - 350	**26**	Steel pipe bending pipes station, DN 25 -100 / Platforma za savijanje cijevi, DN 25 - 100
9	Process pipe fitter / Rešetkasti transportni stol za odlaganje cijevi	**27**	Steel pipe bending pipes station, DN 15 - 400 / Platforma za oblikovanje cijevi, DN 15 - 400
10	Lathe machine / Tokarski stroj	**28**	Pipe cutting and fitting station, up to DN 32 / Platforma za rezanje i oblikovanje cijevi, do DN 32
11	Two-side grinding machine / Dvostrana brusilica	**29**	Orbital welding station / Platforma za orbitalno zavarivanje
12	CNC hole and saddle cutter, DN 80 - 400 / CNC stroj za rezanje cijevi i prodora, DN 80 -400	**30**	Steel pipe welding station, DN 15 - 400 / Platforma za zavarivanje cijevi, DN 15 - 400
13	Pipe fitting table / Radni stol za izradu cijevi	**31**	Steel pipe gringing station, DN 15 - 400 / Platforma za brušenje cijevi, DN 15 - 400
14	Pallets for pipe sorting / Palete za slaganje cijevi	**32**	Shelves for mandrel storage / Nosač za skladištenje trnova
15	Bending machine without mandrel / Savijačica bez trna za cijevi DN 15 - 32	**33**	Working table for smal pipe fitting / Radni stol za izradu tankih cijevi
16	Vertical interim pipe buffer, up to DN 32 / Vertikalno međuskladište cijevi, do DN 32	**34**	Working table for pipe fitting / Radni stol
17	Drilling machine / Bušilica	**35**	Automatic flange welding station / Platforma za automatsko zavar. prirubnica
18	Orbital machine welding / Stroj za orbitalno zavarivanje		

Although the proposed methodology is proven to be viable for solving described design problems, its solution quality is dependent on expert input provided during the design process. Therefore, for future research it is suggested that expert knowledge be collected during the design process so as to develop a knowledge data base to facilitate the design process and to serve for justification of design solutions.

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