Adjacency-Based Facility Layout Optimisation for Shipyards: A Case Study

Salim Tamer[1]*(V), Baris Barlas[1](V), Sefer Anil Gunbeyaz[2](V), Rafet Emek Kurt[2](V), and Sukru Eren[3](V)
1. Faculty of Naval Architecture and Ocean Engineering, Istanbul Technical University, Istanbul, Turkey
2. Department of Naval Architecture Ocean and Marine Engineering, University of Strathclyde, Glasgow, United Kingdom
3. Tersan Shipyard, Yalova, Turkey

A shipyard located in Yalova, Turkey, with an annual processing capacity of 50,000 tons of steel, is studied to improve the layout to increase the production efficiency. The material and personnel traffic inside the shipyard is complex, considering the nature of the shipyards. Therefore, an adjacency-based optimisation procedure has been adopted in this study since this procedure allows quantitative evaluation of these aspects. Systematic Layout Planning (SLP) and graph-theoretic approach were used to generate twelve alternative layouts. Then, the best alternative layout was selected using the efficiency rate method. This study demonstrates the use of SLP and graphic theoretical approach in a maritime context and utilises the efficiency rate method to compare the alternative layouts, which are between 48.91% and 73.91% efficiencies, respectively. This study is a novel contribution to the literature in terms of demonstrating this methodology for shipbuilding applications, and practical applications for the industry can improve the industry to improve the efficiency of their operations.

KEYWORDS: Shipyard layout; facility layout; graph-theoretic approach; SLP; efficiency rate

NOMENCLATURE

N	Number of departments [-]
r_{ij}	Numerical value of closeness rating [-]
x_{ij}	Adjacency value [-]
AHP	Analytical Hierarchy Process
DWT	Deadweight tonnage
FGPM	Fuzzy Goal Programming Model
FSI	Fuzzy Similarity Index
SLP	Systematic Layout Planning

INTRODUCTION

In parallel with the increase in global economic growth and technological developments, new ships are needed for marine transportation, energy, security, fishing etc. This need triggers a globally competitive environment for the production of vessels in a cheap and efficient manner, which directly affects the shipbuilding industry and shipyards (Odabasi, 1993). The alignment of the production departments in the shipyard is critical for productivity. The shipyard should be optimised and designed as an efficient system to minimise unnecessary material and personnel traffic. On the other hand, the majority of shipyards are poorly designed. Facility layout deals with the placement of the production departments based on their relative relationship, and facility layout design aims to streamline the workflow and increase productivity (Muther and Hales, 2015). Dixit et al. (2020) describe the facility layout as a physical arrangement of departments with a focus on workflow across the system to achieve highest operational efficiency at the lowest cost. Facilities layout is fundamental to shipyard efficiency. In order to address this gap in the literature, this paper examines the application of SLP and graph theory approaches to the optimization of a specific facility layout.

LITERATURE REVIEW

Several researchers in the literature investigated the facility layout problem for shipyards. Chabane (2004) combined both shipbuilding and ship-repair yards' design in the same facility by depending on Muther (2015) SLP technique for small shipyards in the capacity of 1,000 and 5,000 DWT. An achievable result could be a combination of an appropriate product mix made of ships and convenient repair work activities. The methodology explains powerful and decisive since it can focus on circumstances where the feasible data are neither adequately comprehensive nor full-scale as it may be because of an early stage of a project. Shin et al. (2009) demonstrated a simulation-based shipyard layout design scheme, which was evolved on the assumption of the systems engineering approach. Their approach benefited from the SLP method and activity relationship chart. Shin et al.'s approach expected to contribute not only the improvement of the existing shipyard layout design but also to the construction of the new shipyard or shipyard advancement. Matulja et al. (2009) proposed a procedure for creating a preliminary optimal layout design of shipyard production areas based on the SLP method. After implementing a representative number of most competitive alternatives, optimal alternatives were selected by utilising the well-known Analytical Hierarchy Process (AHP) technique.

Song et al. (2010) also researched shipyard design using the simulation approach. The input/output details depend on the simulation of a ship production yard layout describing scheme and procedure. In this procedure, user demand and design data by

This is a peer-reviewed, accepted author manuscript of the following article: Tamer, S., Barlas, B., Gunbeyaz, S. A., Kurt, R. E., & Eren, S. (2023). Adjacency-based facility layout optimization for shipyards: a case study. Journal of Ship Production and Design, 39(1), 25-31. Advance online publication. https://doi.org/10.5957/JSPD.05210013

the steps were organised and established in the recommended layout design template form. Design elements were validated and optimised with a layout and machinery list demonstrating optimal process planning and arrangement impacts. Song and Woo (2013) also examined the layout of a new shipyard project in Venezuela before the construction with 19 departments. Commercial software(VIP Planopt) is used with actual shipbuilding data and actual operation time. Lee et al. (2013) described a method for determining the size and form of layout modules, as well as a heuristic location-allocation approach for the modules.The technique was carried out and was achieved utilising a smart internet application-based platform. Choi et al. (2017) studied the optimisation of a shipyard layout, comprising both topological and geometrical optimisations. The effect of addressing alignment restrictions on shipyard layout design was then shown in a case study to explain the two-stage approach in shipyard layout design.

Shablykova (2020) investigated the need for a revised layout plan in view of the decrease of land and assumption of the example shipyard, as well as the need to improve intralogistics and effectively assist the shipbuilding process of scheduled projects. The layout plan is evolved by adopting the SLP method with metaheuristic shipyard facility layout planning procedures. The material flow optimisation is achieved in agreement with the Intelligent Water Drop algorithm in combination with the shipyard material distribution optimisation method. Both optimisation techniques are conducted using Python programming. The proposed layout and material flow plan minimise the travel distances and maximise closeness importance factors for each link between the storage areas and the shipyard's core facilities. Dixit et al. (2020) introduced a novel two-stage layout optimisation concept applying the Fuzzy Similarity Index (FSI) and the Fuzzy Goal Programming Model (FGPM). Obtaining relationship charts and alternate layouts from practitioners is the first stage. The FSI of each alternative arrangement concerning the ideal design is considered, carrying out that the alternative layout with the highest FSI may not be feasible because of practical constraints. Accordingly, FGPM is developed to combine possible constraints accompanying site factors, harmful gases emission, environmental, and safety to produce an optimal layout selection.

Even though many researchers have been studying the facility layout problems, the extent of the shipyard layout is relatively narrow in the literature. Therefore, this study addresses this gap by focusing on the layout development of a medium-sized shipyard with an annual steel processing capacity of 50,000 tons to increase production efficiency and regulate the material flow. Initially, the relationship chart is filled to generate alternative layouts. Then in the second stage, alternative layouts are obtained using SLP and graph-theoretic approach methods by using the relationship chart filled by consensus of shipyard practitioners. At the last step, these alternative layouts are classified according to the efficiency rate's objective function, and the highest scored layout is selected and presented. The methods used in this study are SLP, graph-theoretic approach and efficiency rate, respectively. In the open literature, only Muthers' SLP is applied to shipyards; however, the graph theoretic approach and efficiency rate methods have not been tested for shipyards before. To quantify the benefits of a certain layout, it should be developed using a methodical approach (Bruce, 2020).silinebilir?

METHODOLOGY

Dixit et al., 2020 emphasised “an ideal shipyard layout is an arrangement of production and waterfront facilities aligned to achieve the operational objective at minimum cost and maximum efficiency.” Usually, a shipyard layout design depends on the experience of both naval architects and industrial engineers who have been working in the shipbuilding sector.

There are two main approaches to solving the facility layout problem: the distance-based approach and the adjacency-based approach. In this study, the adjacency-based approach is accepted, defined and utilised since the adjacency-based approach allows transforming qualitative data into quantitative data. The adjacency-based objective function for facility layout problem can be defined as (Tompkins et al., 2010);

$$max \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (r_{ij}) x_{ij}, \qquad (1)$$

where N is the Number of departments in the facility, $r_{ij}$is the numerical value of closeness rating between departments i and j, and x_{ij} equals to 1, if departments i and j are adjacent or else 0. Such an objective is based on the principle that material handling costs are reduced significantly when two departments are neighbouring. The adjacency-based approach involves the use of a relationship chart. As defined by Muther (2015), a relationship chart is a table that summarises estimates of the desirability of locating facilities next to each other. Designers often attempt to maximise the sum of the relationship chart scores of adjacent pairs of facilities in the layout. This approach is appropriate when it is difficult to estimate distances or traffic between facilities or important non-quantifiable considerations (Foulds et al., 1985).

According to the problem statement in the introduction, the purpose of this study is to re-develop the layout of a shipyard, which is chosen as a case study. The area”s of the departments in the current layout of the shipyard have not been re-calculated because due to problem definition, only the relative positions of the departments have been optimised. The layout of an existing shipyard is frequently dictated by existing facilities, and the development must be planned to make the most of these (Bruce, 2020). The list of departments and their corresponding areas defined in the shipyard are given in Table 1.

Table 1. List of departments and areas

No.	Department	Size (meter)
1	Steel Plate and Profile Stockyard	17 x 40
2	Profile Cutting Area	17 x 6
3	CNC Cutting Area	7 x 46
4	Pre-Assembly Area – 1	38 x 46

5	Pre-Assembly Area – 2	24 x 40
6	Pre-Assembly Area – 3	33 x 35
7	Panel Production Area	61 x 20
8	Block Production Area	272 x 123
9	Block Buffer Zone	52 x 24
10	Slipway	133 x 25
11	Warehouse – 1 (Cable and Pipe Stockyard)	22 x 40
12	Paint Workshop	29 x 27
13	Mechanical Workshop	23 x 32
14	Block Buffer Zone – 2 (open stockyard)	61 x 25
15	Piping Workshop	10 x 40
16	Piping Warehouse	42 x 12
17	Dining Hall	8 x 35
18	Design Office	8 x 35
19	Ventilation and Electricity shop	10 x 24
20	Woodshop	6 x 25
21	Trash and Waste Material Area	28 x 7

Systematic Layout Planning

Muther established the well-known SLP method in 1973. The SLP is a method for organizing a workplace in a factory by putting areas with high frequency and logical relationships in close to one another. The SLP method is used to optimise the location of facilities to minimise transportation, minimise cost, minimise travel time, and enhance safety (Muther and Hales, 2015).

The procedure allows for the most efficient material flow while processing the product at the lowest cost and with the least amount of handling. Additionally, SLP is a robust method that is very easy to use (Mohsen and Hassan, 2007). Improving the facility layout using the SLP method will decrease the material flow considerably (Wiyaratn et al., 2013). SLP and relationship charts are recently used to generate alternative shipyard layouts by Dixit et al. (2020). The SLP method is widely adopted for shipyard layout design and optimisation (Chanbe 2004, Shin et al. 2009, Matulja et al. 2009, Shablykova 2020).

A relationship chart is an essential element for Muthers' SLP method. The relationship chart determines the closeness ratio of departments. The closeness ration assignment is a rule of thumb, which is subjective. Layout planners not familiar with vowel-letter rating have a great tendency to over-assign A ratings. To avoid this, the increasing frequency of ratings is desirable, such as A through U – say, 2% to 5% A, 3% to 10% E, 5% to 15% I, 10% to 25% O. The nature of the project determines the occurrences of X's. Muther (2015) is presented these ratings, and the basis of the distribution of the ratings is to make it possible for the layout planner to generate alternative layouts correctly. The ratings of closeness relations in the relationship chart are given in Table 2. Every relationship must be accounted for later when adjusting the layout, or the layout becomes distorted. To check for total verification, the sum of all letter totals (Total) should equal the number of potential relationships on the chart,

$$Total = \frac{N * (N-1)}{2}, \quad (2)$$

Where N is the Number of departments enlisted.

Table 2. Ratings of closeness relations in relationship chart

Value	Closeness	Ratings
A	Absolutely Necessary	5
E	Especially Important	21
I	Important	31
O	Ordinary Closeness	42
U	Unimportant	105
X	Not Desirable	6
Total	N x (N-1) /2 =	210

Since the information in the relationship chart is vital in the optimisation process, the relationship chart is filled by the reasons stated given below by the consensus of shipyard practitioners (including the head of the shipyard-planning department with 10+ years of working experience.), the reasons also be defined as variables that generate different layouts.:

(1) Flow of materials
(2) Safety
(3) Need for personal contact
(4) Use the same equipment
(5) Use common records
(6) Share same personnel
(7) Supervision or control
(8) Frequency of contact
(9) Urgency of service
(10) Cost of utility distribution
(11) Use same utilities
(12) Degree of communicative or paperwork contact
(13) Specific management desires or personal convenience

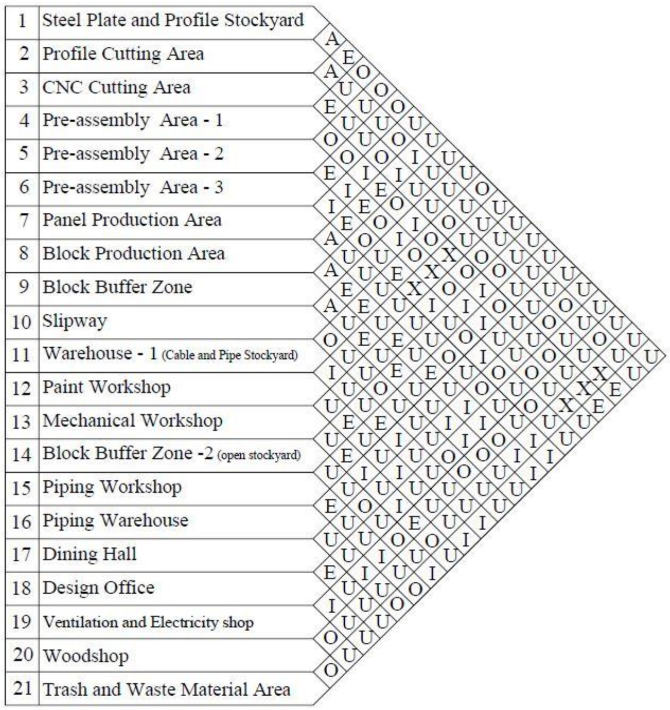

Fig. 1. Relationship chart for the shipyard layout

Twenty-one workshops displaying all pairs of activities in the shipyard are depicted in an activity relationship chart given in Fig.1. The relationship chart used in this optimisation study is filled by the common sense of the shipyard practitioners, titled production planning managers and other production planning staff. Because the vital element for the SLP procedure is the information in the relationship chart, the layout utilised will largely depend on the nature of the shipyard activities. The relationship diagram and the space relationship diagram are developed utilising a relationship chart; both are shown in Fig. 2 and 3, respectively. Relationship diagram is formed by placing the departments in order of importance first A's and X's then E's and I's. After that, space relationship drawn which includes dimensions of departments. Finally, seven different layouts have been generated that provide similarity to the space relationship diagram.

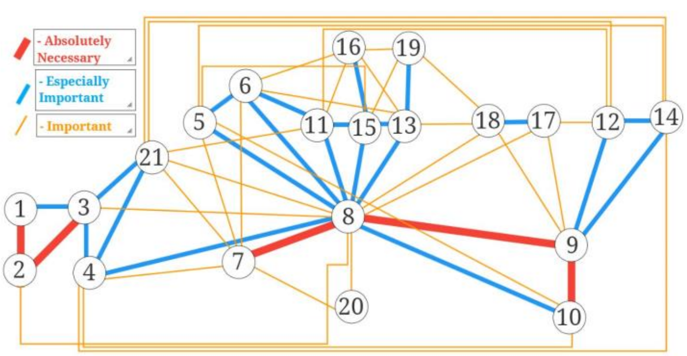

Fig. 2. Relationship Diagram

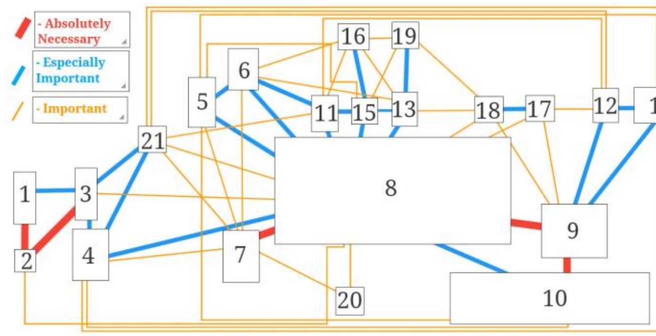

Fig. 3. Space Relationship Diagram

Summary of SLP

1- The list of departments is determined
2- Relationship chart is filled
3- A relationship diagram is drawn
4- Space relationship diagram is drawn
5- Seven different layouts are generated

Examples of the SLP can be found in Tompkins et al. (2010) and Heragu (2016).

Graph-Theoretic Approach

A facility layout problem's solution procedure presented by Foulds and Robinson in 1978, named as "deltahedron S construction solution method", was introduced as graph-theoretic approach or graph-based method in the literature in the following years by Tompkins et al. (2010) and Heragu (2016). In this study, graph-theoretic heuristics for the facility layout problem presented by Foulds and Robinson (1978) has been adopted, redefined and implemented for the shipyard design and layout problem.

The graph-theoretic approach begins by creating an adjacency graph that graphically shows the relationship between departments. To generate such a graph, first define the order in which vertices (departments) should be considered for placement in the graph, then identify the location of each vertex in the adjacency graph. Next, a block layout must be built from either the adjacency graph or its dual graph. (Mohsen and Hassan 2007). The graph-theoretic approach produces an adjacency graph that is a maximal planar weighted graph with a limited and known number of edges (adjacencies) equal to $3N-6$ (Seppanen and Moore, 1970). The criteria for the maximal number of edges may be represented mathematically as follows (Nozari and Enscore, 1981):

$$\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} x_{ij} = 3N-6, \qquad (3)$$

From this maximal planar graph, a designer presents a feasible layout in that space and shape necessities are accomplished and department couples, which have bigger weights, are adjacent. The graph-theoretic approach determines the pairs of departments that must be adjacent to maximise the sum of the profits (Heragu, 2016).

In this study, a relationship chart is generated for the SLP method is adopted to the graph-theoretic approach, considering the significance of adjacency is unchanging. Fig.4 represents the relationship chart converted to numbers. Graph-theoretic approach work with the relationship chart, which is converted to numerical values regarding the total closeness rating given in Table 3 is used to discover the most critical adjacency between departments and to control the algorithm's priority for selecting departments. Scores are usually powers of a base number, here in this study, chosen as a numerical value of 2.

Table 3. Ratings of closeness relations in relationship chart

Letter	A	E	I	O	U	X
Rating	8	4	2	1	0	-8

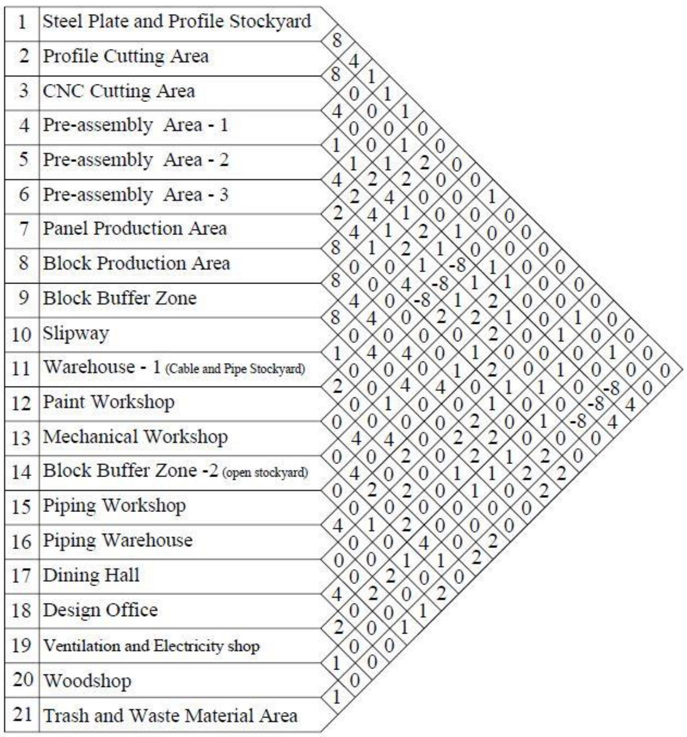

Fig. 4. Relationship chart converted to numerical ratings

The final maximal planar graph evaluated applying the graph-theoretic approach is demonstrated in Fig. 5. After calculating the maximal planar graph, the graph-theoretic approach generates five different layouts that provide similarity to the maximal planar graph. Although the graph-theoretic approach is a widely accepted method in the literature, the graph-theoretic approach has not been applied for generating alternative shipyard layouts.

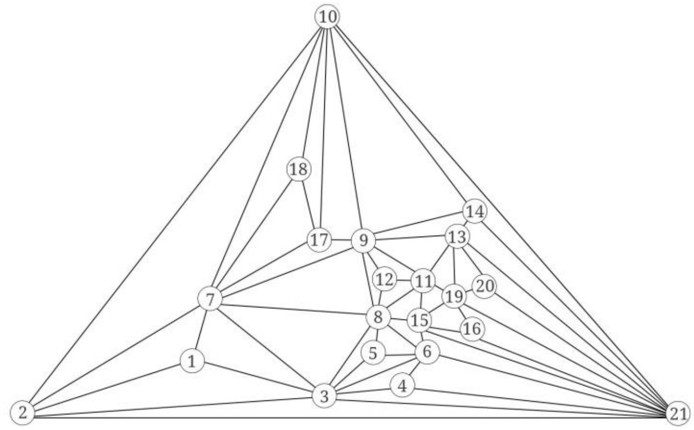

Fig. 5. Maximal planar adjacency graph

Summary of Graph-Theoretic Approach

1- Relationship chart is converted to numerical values
2- Maximal planar adjacency graph is drawn
3- Block layout is drawn
4- Five different layouts are generated

Examples of the graph-theoretic approach can be found in the Tompkins et al. (2010) and Heragu (2016).

RESULTS

This case study focuses on twelve different alternative shipyard layouts involving twenty-one departments using SLP and graph-theoretic approach methods. The crucial part of this study is selecting the best layout. A few techniques can be applied to choose the best layout out of alternatives, especially the previously adopted fuzzy logic-based designs (Matulja 2009, Dixit 2020). This study adopts the efficiency rate method to select the best layout among alternatives. Ojaghi et al. (2015) used the efficiency rate method recently. The efficiency rate is calculated by dividing the total relationship score for all departments in the layout by the projected relationship score for all departments. The following is the formula for calculating efficiency rate:

$$\text{Efficiency rate } = \frac{\sum department\ adjecency\ score}{\sum relationship\ score} \tag{4}$$

Note that the normalised adjacency score (which is also known as efficiency rate) is obtained simply by dividing the adjacency score obtained from Eq. (1) by the total flow in the facility (Tompkins et al. 2010). The efficiency rate formulation is modified in Eq. (5) since the negative numerical flow values are used in the relationship chart.

$$\text{Efficiency rate } = \frac{\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(r_{ij}^{+}x_{ij}) - \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(r_{ij}^{-}(1-x_{ij}))}{\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(r_{ij}^{+}) - \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(r_{ij}^{-})} \tag{5}$$

Where

$$x_{ij} = \begin{cases} 1, if \text{ department } i \text{ is adjacent to department } j \\ 0, otherwise \end{cases} \quad \forall i,j; i > j$$

r_{ij} is the numerical value of a closeness rating between departments i and j. Thus, for the numerical values of "-8" assigned for "X's" in the relationship chart is possible to calculate in efficiency rate calculation correctly. The efficiency rate scores for 12 alternative shipyard layouts and current layout are shown in Table 4. The layout alternative with the highest efficiency rate is chosen as the best layout, "SLP-3" is scored 73.91% efficiency rate is the best layout among alternatives.

Table 4. The efficiency rate scores

No	Efficiency rate	Calculation	Alternative
1	48.91%	135/276	Current Layout
2	73.91%	204/276	SLP – 3
3	71.37%	197/276	Graph-theoretic approach – 3
4	70.28%	194/276	SLP – 4
5	69.20%	191/276	Graph-theoretic approach – 4
6	67.75%	187/276	Graph-theoretic approach – 5
7	66.30%	183/276	SLP – 5
8	65.21%	180/276	SLP – 2
9	63.76%	176/276	SLP – 6
10	61.96%	171/276	Graph-theoretic approach – 1
11	60.14%	166/276	Graph-theoretic approach – 2
12	60.14%	166/276	SLP – 7
13	56.88%	157/276	SLP – 1

The efficiency rate is a percentage that compares the realisation rate of the relationship chart. While the efficiency rate of the current layout (Fig. 6) was 48.91%, this rate increased to 73.91% with the proposed layout (Fig. 7). Thus, we can say that the realisation rate of the detailed reasons for filling the relationship chart increased from 48.91% to 73.91%. Improvements have been made for parameters such as flow of materials, safety, need for personal contact, use of same equipment etc. The crossovers in the material and personnel flow have been eliminated. The shipyard layout has been converted from a poor flow pattern with excessive crossovers to an improved layout with a dendrite flow pattern. Improvements in shipyard performance are projected in cycle time reduction, productivity increase, reduction in travelling cost, and reduction in travelling distance; however, further research is required with the simulation tool.

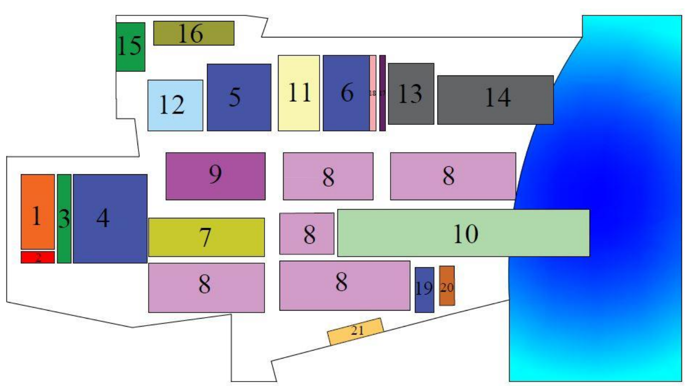

Fig. 6. Current layout

((1) Steel Plate and Profile Stockyard, (2) Profile Cutting Area, (3) CNC Cutting Area, (4) Pre-Assembly Area – 1, (5) Pre-Assembly Area – 2, (6) Pre-Assembly Area – 3, (7) Panel Production Area, (8) Block Production Area, (9) Block Buffer Zone, (10) Slipway, (11) Warehouse – 1, (12) Paint Workshop, (13) Mechanical Workshop, (14) Block Buffer Zone – 2, (15) Piping Workshop, (16) Piping Warehouse, (17) Dining Hall, (18) Design Office, (19) Ventilation and Electricity shop, (20) Woodshop, (21) Trash and Waste Material Area)

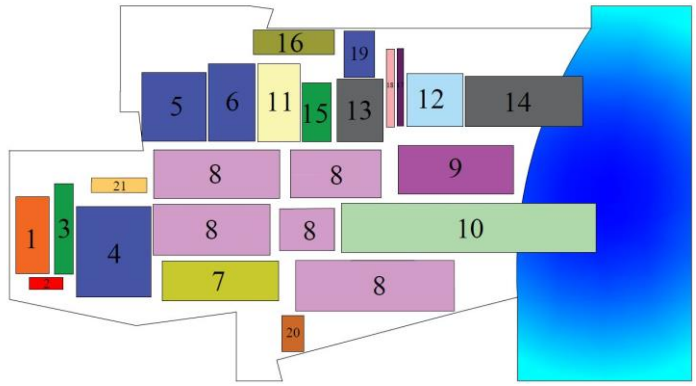

Fig. 7. Proposed layout (SLP-3 with 73.91%)

((1) Steel Plate and Profile Stockyard, (2) Profile Cutting Area, (3) CNC Cutting Area, (4) Pre-Assembly Area – 1, (5) Pre-Assembly Area – 2, (6) Pre-Assembly Area – 3, (7) Panel Production Area, (8) Block Production Area, (9) Block Buffer Zone, (10) Slipway, (11) Warehouse – 1, (12) Paint Workshop, (13) Mechanical Workshop, (14) Block Buffer Zone – 2, (15) Piping Workshop, (16) Piping Warehouse, (17) Dining Hall, (18) Design Office, (19) Ventilation and Electricity shop, (20) Woodshop, (21) Trash and Waste Material Area)

CONCLUSIONS

In this paper, 12 alternative layout plans were generated for the shipyard (seven alternative shipyard layouts were generated with SLP and five with graph-theoretic approach), selected as case studies. The purpose of creating alternative shipyard layouts is to regulate the flow of materials and personnel inside the shipyard and ensure effective use of the total shipyard area. The SLP and graph-theoretic approach techniques have been adopted for the shipyard layout problem for this purpose. In the literature, since SLP is widely used and applied for shipyards, the first time is the graph-theoretic approach. The alternative shipyard layouts generated are ranked according to the objective function of efficiency rate scores, and the highest score is SLP-3 with 73.91%. In other words, the compliance of SLP-3 to the relationship chart is 73.91%. By applying the SLP-3 facility layout to the shipyard, the estimation is that the material and personnel flow inside the shipyard will be carried on more efficiently. The annual throughput of the shipyard will increase by 5% to 10%, is estimated. Bruce, 2020 points out "a well-designed layout for the shipyard and careful analysis of movement requirements can reduce the costs."

In this study, every SLP analysis takes 1½-week time, and every graph-theoretic approach analysis takes 2-week time. Future studies suggest testing the current layout and the proposed (SLP-3) layout with simulation and measuring throughput to verify this prediction. Although the simulation process takes time and effort for both layouts, the simulation is a valuable tool to prove that SLP-3 will significantly contribute to the shipyard's throughput.

ACKNOWLEDGEMENTS

This study is partially supported by TUBITAK 2214-A International Doctoral Research Fellowship Program (Grant No:

1059B141800994).

REFERENCES

Bruce, G., 2020. Shipbuilding Management. Springer Nature, Singapore

Chabane, H., 2004. Design of a small shipyard facility layout optimized for production and repair. In Proceedings of Symposium International: Qualite et Maintenance au Service de l'Entreprise.

Choi, M., Kim, S. H., Chung, H., 2017. Optimal shipyard facility layout planning based on a genetic algorithm and stochastic growth algorithm. Ships and Offshore Structures, 12(4), 486-494.

Dixit, V., Verma, P., Raj, P., 2020. Leveraging tacit knowledge for shipyard facility layout selection using fuzzy set theory. Expert Systems with Applications, 113423.

Foulds, L. R., 1983. Techniques for facilities layout: deciding which pairs of activities should be adjacent. Management Science, 29(12), 1414-1426.

Foulds, L. R., Robinson, D. F., 1978. Graph theoretic heuristics for the plant layout problem. The International Journal of Production Research, 16(1), 27-37.

Foulds, L. R., Gibbons, P. B., Giffin, J. W., 1985. Facilities layout adjacency determination: An experimental comparison of three graph theoretic heuristics. Operations Research, 33(5), 1091-1106.

Heragu S. S., 20016. Facilities Design, fourth ed. CRC Press Taylor & Francis Group, Florida.

Lee, D. K., Jeong, Y. K., Shin, J. G., 2013. Study on a layout design method for leisure ship production factories using a heuristic location-allocation algorithm. Journal of the Korean Society of Marine Environment & Safety, 19(3), 277-284.

Matulja, T., Fafandjel, N., Zamarin, A., 2009. Methodology for shipyard production areas optimal layout design. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 60(4), 369-377.

Mohsen, Hassan M. D., 2007. Toward guiding the selection of a layout procedure. Journal of Manufacturing Technology Management, 18(3), 292-303.

Muther, R., Hales L., 2015 Systematic Layout Planning, fourth ed. Management & Industrial Research Publications, Georgia.

Nozari, A., Enscore Jr, E. E., 1981. Computerised facility layout with graph theory. Computers & Industrial Engineering, 5(3), 183-193

Odabasi, A. 1993. Development and evaluation of Marmara Shipyard's expansion program. Contract Report, Istanbul

Ojaghi, Y., Khademi, A., Yusof, N. M., Renani, N. G., bin Syed Hassan, S. A. H., 2015. Production layout optimisation for small and medium scale food industry. Procedia CIRP, 26, 247-251.

Seppänen, J., Moore, J. M., 1970. Facilities planning with graph theory. Management Science, 17(4), B-242.

Shablykova, V., 2020. Layout and material flow planning of a shipyard. Master's thesis, Helsinki Metropolia University of Applied Sciences, Helsinki.

Shin, J. G., Song, Y. J., Lee, D. K., Woo, J. H., 2009. A concept and framework for a shipyard layout design based on simulation. Journal of Ship production, 25(3), 126-135

Song, Y. J., & Woo, J. H., 2013. New shipyard layout design for the preliminary phase & case study for the green field project. International Journal of Naval Architecture and Ocean Engineering, 5(1), 132-146.

Song, Y. J., Lee, D. K., Woo, J. H., Shin, J. G., 2010. System development and applications of a shipyard layout design framework. Journal of Ship Production and Design, 26(2), 144-154.

Tompkins, J. A., White, J. A., Bozer, Y. A., Tanchoco, J. M. A., 2010. Facilities Planning, fourth ed. John Wiley and Sons, New Jersey.

Wiyaratn, W., Watanapa, A., Kajondecha, P., 2013. Improvement plant layout based on systematic layout planning. IACSIT International Journal of Engineering and Technology, 5(1), 76-79.