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Facility layout planning through the ALDEP Method in the wooden cable reels industry

Melike Nur İnce[a], **Çağatay Taşdemir**[b,c,*]

Abstract: Facility layout planning plays a pivotal role in manufacturing system design, impacting vital metrics such as lead time, handling costs, and space optimization. While a significant portion of research has been invested in refining existing facility layouts, there is a noticeable research gap in devising optimized layouts for new establishments, especially in the value-added wood products domain. Addressing this lacuna, this research focused on designing an efficient department-level layout for a wooden cable drums manufacturing facility in an area of 4150 m^2. This facility included both office and production areas. The investigative process was segmented into four distinct phases: Deciding the strategic positioning of the facility on the available plot, defining the functional and spatial requirements for each department, establishing the intricate relationship dynamics between these individual units, and rigorously documenting the most optimal department-level facility layout. For precision in layout creation, the ALDEP algorithm was employed, which was further visualized to offer a comprehensive three-dimensional representation. The final layout seamlessly organized seven departments within the 1st Floor Office Area, eight in the 2nd Floor Office Area, and thirteen within the Production Floor. Efficiency evaluation of these areas yielded scores of -811, 184, and -318, respectively. Conclusively, this research furnished actionable insights for manufacturers within the wood products sector and was expected to be an invaluable reference for academics delving into facility planning and value-added wood products manufacturing.
Keywords: Facility Layout Planning, Wood Products Industry, ALDEP Algorithm

Ahşap kablo makarası endüstrisinde ALDEP Yöntemi ile tesis yerleşim planlaması

Özet: Tesis yerleşimi planlaması, üretim sistemi tasarımında önemli bir rol oynamaktadır ve teslimat süresi, taşıma maliyetleri ve alan optimizasyonu gibi önemli metrikleri etkilemektedir. Mevcut tesis yerleşimlerini iyileştirmek için önemli sayıda araştırma yapılmış olsa da özellikle katma değerli orman ürünleri alanında yeni kuruluşlar için optimize edilmiş yerleşimler tasarlama konusunda belirgin bir araştırma açığı bulunmaktadır. Bu çalışma kapsamında 4150 m^2'lik bir alana sahip ahşap kablo makaraları üretim tesisinde bölümler düzeyinde verimli bir yerleşim planı tasarlanmasına odaklanılmıştır. Yerleşim planlaması gerçekleştirilen tesis hem ofis hem de üretim alanlarını içermektedir. İnceleme süreci dört farklı aşamaya ayrılmıştır: Tesise uygun arazi üzerinde stratejik konumun belirlenmesi, her bölüm için işlevsel ve mekânsal gereksinimlerin tanımlanması, bu ayrışık birimler arasındaki karmaşık ilişki dinamiklerinin oluşturulması ve en uygun tesis yerleşiminin bölüm düzeyinde titizlikle oluşturulması. Tesis yerleşim planının isabetli bir şekilde gerçekleştirilmesi için ALDEP algoritması kullanılmış olup, bu algoritma sonucunda elde edilen sonuçlar daha sonra kapsamlı üç boyutlu temsiller sunacak şekilde görselleştirilmiştir. Nihai tesis yerleşim planında 1. Kat Ofis Alanı'nda yedi departman, 2. Kat Ofis Alanı'nda sekiz departman ve Üretim Katı'nda on üç departman sorunsuz bir şekilde organize edilmiştir. Bu alanların verimlilik değerlendirmesi sırasıyla -811, 184 ve -318 skorlarını almıştır. Sonuç olarak, bu araştırma, orman ürünleri sektöründeki üreticiler için eyleme dönüştürülebilir içgörüler sunmuştur ve tesis planlaması ve katma değerli orman ürünleri üretimi alanlarında araştırma yapan akademisyenler için değerli bir referans olması beklenmektedir.
Anahtar kelimeler: Tesis Yerleşim Planlaması, Orman Ürünleri Endüstrisi, ALDEP Algoritması

1. Introduction

The rapid increase in world population implies increased consumers, demand, and potential labor force. These factors lead to further growth and development of businesses and allow them to seize market opportunities. The advent of Industry 4.0, which entails the digitization of manufacturing industries, has significantly shifted how manufacturing processes are perceived and executed. New productivity and efficiency policies and strategies have been implemented to improve business processes, reduce costs, and achieve a robust production flow. Greater productivity means companies could produce more goods or services and generate more income. On the other hand, such policies and strategies allow companies to optimize their production processes, enhance labor productivity, and ensure effective resource and area utilization. This results in lower costs and higher profit margins.

[a] Department of Industrial Engineering, Bursa Technical University, Bursa, Türkiye
[b] Department of Forest Industry Engineering, Bursa Technical University, Bursa, Türkiye
[c] Department of Industrial Engineering (Grad. School), Bursa Technical University, Bursa, Türkiye
@ * **Corresponding author** (İletişim yazarı): cagatay.tasdemir@btu.edu.tr
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One of the manufacturing sectors that the new industrial trends have impacted is the wood products industry, and there has been an increasing trend towards value-added manufacturing in the wood products industry, including the production of wooden cable drums. Value-added wood products, such as wooden cable drums, offer higher profit margins and create more jobs per unit of wood used compared to commodity-level products. The global cable drums market is expected to grow at a CAGR of 4.1% from 2019 to 2026, with wooden cable drums having the largest market share. The market's growth has been driven by the increasing demand for wooden cable drums in the oil and gas, construction, telecommunications, and manufacturing industries (Amar and Onkar, 2020). Wooden cable drums are a sustainable and cost-effective alternative to plastic and metal cable drums. In recent years, like any other manufacturing industry, the growth potential and global industrial trends have brought the industry into focus for facility layout planning research to adjust for the changing market conditions and become more flexible.

Facility layout planning is a strategic decision that could directly influence lead time, material handling costs, and effective space utilization; therefore, it is regarded as one of the most critical aspects of the manufacturing system design. The facility layout determines the arrangement of existing departments, the movement areas of machines, equipment, and workers within these departments, and the arrangement of individual work centers or stations. Arrangement of individual work centers or workstations within the departments involves ergonomics, work, and motion studies, and a layout plan is prepared based on the results of these studies (Eryiğit, 2000). Businesses with a good layout plan could effectively regulate operational flow, optimize business processes, increase worker productivity, and aim to increase efficiency by preventing unnecessary movements and associated costs. Ergonomically sound workstations and arrangements allow workers to perform tasks more efficiently and effectively. As a result, employee satisfaction increases, and productivity rises. Additionally, it may also have an impact on the quality of customer service of the company. A good layout plan enhances the ability to provide fast and effective service to customers.

On the other hand, businesses could face various problems when they disregard the layout plan. A poorly planned layout could affect the business's operations and negatively impact productivity. When workstations, warehouses, or office spaces are haphazardly arranged, business processes may become unclear and congested, which could cause a disrupted workflow. The natural result of such a disruption could be increased lost time, rework, and errors. In addition, a poorly planned layout hinders the effective use of space. Businesses could face additional costs due to unnecessary space requirements. An unplanned arrangement could also have adverse effects on worker productivity. Workstations without ergonomic adjustments or a disorganized work environment could reduce employee performance and affect employee satisfaction. Furthermore, from the perspective of customers, enduring long delivery times and the inability to easily access desired products could reduce customer satisfaction and even lead to customer loss.

Over the years, several methodologies have been proposed to address the facility layout problem, such as SLP (Systematic Layout Planning), CORELAP (Computerized Relationship Layout Planning), ALDEP (Automated Layout Design Program), CRAFT (Computerized Relative Allocation of Facilities) and BLOCPLAN (Computerized Block Layout Algorithm). Each method offers unique advantages and could be used in different contexts. In the next section of the study, evidence found in the literature regarding the theory and applications of facility layout planning methods was reviewed.

A review of previous scholarly articles revealed many articles on optimizing in-plant arrangement. Various methods related to such agreements have been adopted throughout the history of this academic pursuit. An overview of notable contributions to this field was provided as follows.

Turkmen and Ogulata's 2008 work capitalized on the LayOPT software to enhance layout plans, achieved through a detailed analysis of the flow and placement issues within a hospital context (Türkmen and Oğulata, 2008). Ak's 2009 study focused on assessing optimal and heuristic approaches to workplace arrangement, intending to compile a helpful reference source by applying a real-world problem (Ak, 2009). In 2013, Lee explored how Amazon's surging sales growth and expanded product range amplified the intricacy of warehouse storage management. Lee noted the lack of comprehensive data on warehouse storage type allocations as a factor contributing to inefficient allocations and escalated costs. Consequently, a cost model was constructed to suggest cost-efficient warehouse storage type allocations for Amazon's North American Shipping Center network and prospective centers (Lee, 2013).

Andryzio et al. (2014) underscored the importance of thoroughly evaluating factory layouts for seamless operations within a machine manufacturing and industrial equipment company. The evaluation procedure involved the ALDEP algorithm for developing new layout plans and comparing the material handling costs associated with the existing and proposed layouts (Andryzio et al., 2014). Prasad et al. (2014) designed an innovative plant layout utilizing the CRAFT method. The layout was specifically tailored for a typical manufacturing facility that needed to be interlinked with units, necessitating communication facilities in the era of modern industrial technology (Prasad et al., 2014).

The study of Deshpande et al. (2016) featured a case within the alloy steel industry, wherein the CRAFT and ALDEP methodologies were implemented for plant layout. Their findings showed a 0.10% improvement with the CRAFT technique over the existing layout, while the ALDEP technique resulted in a 23% enhancement of the layout, proving superior (Deshpande et al., 2016). In a 2017 study, Suhardini et al. strived to address the cross-traffic issue induced by unsuitable factory layouts to augment a company's production capacity. Their results highlighted a 37.5% increase in production capacity by adding machinery and operators and a 10.98% reduction in material handling cost through layout enhancement (Suhardini et al., 2017).

Tambunan et al. (2018) evaluated two layout planning algorithms, BLOCPLAN and ALDEP, to optimize the production floor layout of a company producing rubber and rubber compounds for retreading tires with hot and cold cooking systems. The paper aimed to discern the most efficient layout by comparing moment displacement and flow patterns. Both algorithms demonstrated their capacity to decrease moment displacement and enhance material flow patterns. Notably, ALDEP resulted in a smaller displacement value than the original layout, although it was larger than that achieved with BLOCPLAN (Tambunan et al., 2018). In their study, Gutta et al. (2018) presented a review of the plant layout design of Automated Guided Vehicles in a Flexible Manufacturing System. The article covered many topics, such as layout design, location of loading and delivery points, and flow path design. In addition, results obtained from different models and publications in the literature were classified (Gutta et al., 2018).

In another study, Suhardini and Rahmawati (2019) used computerized algorithms, CRAFT and ALDEP, to improve an existing layout and found that ALDEP provided 23% lower material handling cost than CRAFT. ALDEP was used to achieve an optimal arrangement, which was then improved with CRAFT. The improved layout outperformed the layout initially created by ALDEP by 6.24% in material handling cost and 15 minutes in processing time. This study demonstrated that combining computerized layout design algorithms could yield better results (Suhardini and Rahmawati, 2019). Tarigan et al. (2019) observed that the material flow was disrupted due to cross movements and distant stations in the production area layout of a rubber gasket manufacturer. This problem has been addressed by improving the production area layout using the CORELAP and ALDEP methods and simulating it with Flexsim software (Tarigan et al., 2019).

In a recent study, Budianto et al. (2020) optimized the layout for a furniture manufacturing company to avoid common project delays. Systematic Layout Planning (SLP) method and the Automated Layout Design Program (ALDEP) methods were comparatively evaluated in this context. The results indicated an improvement of 6.92% in material handling costs with SLP, whereas with the ALDEP method, a gain of 11.14% in material handling cost was achieved. The authors recommended implementing the layout plan developed with the ALDEP method. In addition, among this study's findings, evidence suggesting the applicability of the ALDEP method to the value-added wood products industry was present (Budianto et al., 2020). Burggräf et al. (2021) stated that identifying action fields is a pre-requirement for developing a functional and integrated system for automatic layout design that could be used in practice. For this purpose, they conducted a systematic literature review. They identified the need for actions in multicriteria optimization, the layout evaluation and selection process, the existing implemented algorithms, and the integration of the human planner (Burggräf et al., 2021).

As could be interpreted from the literature review outlined above, different facility layout optimization methods were effectively used to achieve better-performing facilities in manufacturing and service industries. However, most of the past studies primarily focused on improving an existing layout, and the studies aiming to develop an optimized layout plan for a new facility were scarce. Moreover, the facility layout optimization studies address the problem from the value-added wood products industry perspective was absent. Though niche, the wooden cable drum industry presents unique challenges for facility layout planning. The size and variety of wooden cable drums could necessitate a flexible yet efficient layout to ensure smooth, productive, safe, and cost-effective operations. The industry’s distinct features require a specialized approach to designing the facility layout. Therefore, this study explored using the ALDEP method for facility layout planning in a newly established wooden cable drum manufacturing facility. ALDEP was developed at IBM and presented by Seehof and Evans (Seehof et al., 1966). ALDEP was considered an ever-developing foundational algorithm and a program due to the evaluation process of accepting or rejecting a given layout plan. ALDEP could be used to design layouts from scratch without needing a layout plan prepared with preliminary programs. However, it also allows comparison of the solutions that arise, like the method used in a developmental algorithm (Özden, 2016). The ALDEP algorithm could accommodate up to 63 departments or activities in a layout that could cover up to 1 500 area units of 30x50 dimensions and could be used to develop multi-story layout plans up to 3 stories. In addition, it allows constraints to be imposed on the solution; for example, passages that need to be placed, elevator voids, staircase voids, and entrances could be designed around the existing departments. Such capabilities of the method made it suitable for the purposes of this study.

The study’s main objective was to develop an efficient and logical department-level facility layout that accounts for the significance of relationships among the departments and, therefore, would have the potential to enhance operational efficiency, reduce material handling and transportation costs, and ultimately contribute to improved company profitability.

2. Materials and method

2.1. Materials

The facility layout planning methodology was deployed onto a new wooden cable drums manufacturing plant planned to be established in Mudanya, Bursa. A wooden cable drum, also commonly known as a cable reel, is a round, drum-like object that carries various types of electrical wires, fiber optic cables, or other kinds of wire products. These drums make transporting and dispensing cable more manageable and efficient. The drum has two main parts: the flanges and the barrel. The flanges are the two circular flat parts at each end of the drum, and the barrel is the cylinder that connects the flanges and onto which the cable is wound (Sydor et al., 2017). Wooden cable drums are often preferred for their cost-effectiveness, ease of availability, and ability to be reused or recycled. After the cable has been used, the wooden drums can be returned to the cable manufacturer for reuse or recycled into other wooden products, thus reducing waste.

The company’s target annual production capacity was reported to be one hundred thousand wooden cable drums. The company owners required the production area to consist of 3 sections: the first- and second-floor office areas and the production floor. All three facility sections involved various departments with different functions and varying degrees of relationships. All units were also required to be interconnected with multiple access points. Company executives, the architectural team, and the researchers worked together to identify the name and area requirements of the departments required to form a complete manufacturing facility that would have the ability to produce the planned annual output.

The size of the selected plot, comprised of 4 parcels, for establishing the wooden cable drum manufacturing facility was approximately 14 800 m^2, and 3 895 m^2 of the total land size shown in Figure 1 was used for the manufacturing facility. Since the office area section of the facility had a two-story structure, the total floor area of the manufacturing facility added up to 4 150 m^2. The remaining land area was spared for other functional units required to conduct business and was deemed out of scope for the purposes of this study.

2.2. Methods

The study was completed in four phases. The definition of the phases, the objective, and the methods used in each phase were summarized in Table 1. In the first phase, the architectural team contoured the allowable construction boundaries of the plotted land size and identified the optimal positioning for the manufacturing facility based on the land characteristics of the four parcels forming the entire lot, especially considering the slope of the parcels. In the second phase, the name and the area requirements of the departments and other functional units to be placed within the facility were determined. In the third phase, the relationships of the departments and other functional units to be placed within the same facility section were identified. Finally, in the last phase of the study, the optimum layout of the departments and the other functional units were carried out consecutively, starting with the 1st Floor Office Area and ending with the Production Floor through the ALDEP algorithm. All 3D illustrations were created using SketchUp 3D Design Software.

2.2.1. ALDEP Method

Despite many different applications of ALDEP, the random selection method was used in this study. The basis of ALDEP and this method was the random selection of a department and the start of the design by placing it in the layout plan. Then, examining the relationship diagram (REL Chart), a department showing high proximity was placed in the plan. This process continued until all departments were placed or no departments were left suitable for placement with a high degree of proximity relationship with the previously placed departments. In such a case, one of the remaining departments or other functional units was randomly selected and placed in the layout. The selection process continued until all departments and other functional units were placed in the layout plan. While creating the placement order, the "E" relation was chosen as the cut-off point (Minimum Closeness Preference-MCP) in conjunction with the standard practice. The sweep width was set to 2 br^2 for the 1st Floor Office Area and three br^2 for the 2nd Floor Office Area, where 1 br equaled 5 m^2. For the Production Floor, the sweep width was three br^2, where 1 br equaled 10 m^2. Then, the total score of the layout was determined by adding the numerical values given according to the proximity degrees assigned for neighboring departments.

The numerical values of the proximity degrees in the ALDEP algorithm were as follows:

$A = 4^3 = 64$ $\quad$ $O = 4^0 = 1$

$E = 4^2 = 16$ $\quad$ $U = 0$

$I = 4^1 = 4$ $\quad$ $X = -4^5 = -1024$

Figure 1. Aerial view of the parceled land and drawing of the land boundaries.

Table 1. Flow diagram of study's phases.

Phase number	Phase definition	The objective	Method(s)
1	Positioning of the Manufacturing Facility	Proper and logical positioning of the facility based on the technical requirements.	The expert opinion provided by the architectural team.
2	Determination of the name and the area requirements of the departments and other functional units.	Developing the optimum department-level facility layout considering sectoral requirements and resource constraints.	Brainstorming among company executives, the architectural team, and the researchers.
3	Identification of the relationship degrees.		
4	Creation and documentation of the optimum department-level facility layout.		The ALDEP Algorithm

3. Results and discussion

In this study, the layout of a new wooden cable drums manufacturing facility to be established in Bursa was addressed. The total size of the plot for the new establishment was approximately 14 800 m^2, 4 150 m^2 of which was used for the manufacturing facility. The firm's architectural team concluded that the manufacturing facility was to be positioned on the third and fourth parcels of the plotted land due to the increasing slope in parcel two and insufficient land area in parcel one, as shown in Figure 2. The target manufacturing facility was designed to include 1st Floor Offices, 2nd Floor Offices, and Production Floor, as illustrated in Figure 2.

Firstly, the company managers, the architectural team, and the researchers determined the name and the area requirements of the departments and other functional units of the 1st- and 2nd-floor offices and the production floor. As for the 1st Floor Offices, the agreed-upon departments and other functional units with corresponding area requirements were R&D (40 m^2), Project Unit (55 m^2), Human Resources (30 m^2), Meeting Room (55 m^2), Restrooms (Female-Male) (20 m^2), Reception (25 m^2), and Customer Greeting Room (30 m^2). Afterward, the relationship diagram to determine the placement order of the departments and the other functional units was created, as given in Figure 3. Each proximity degree was assigned at the end of deliberate discussions moderated by one of the researchers.

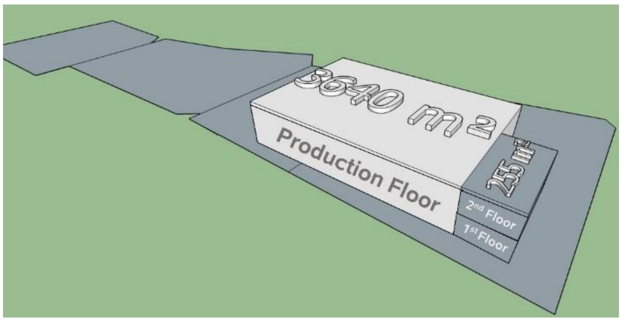

Figure 2. 3D illustration of the manufacturing facility positioned on the plotted land.

Number	Department OR Functional Unit	m²	1	2	3	4	5	6	7
1	R&D Unit	40		A	O	E	O	U	E
2	Project Unit	55			O	E	O	U	I
3	Human Resources	30				E	O	E	X
4	Meeting Room	55					E	E	E
5	Restrooms (Female-Male)	20						O	E
6	Reception	25							A
7	Customer Greeting Room	30							
	Total	255							

Figure 3. Relationship diagram of 1st floor office area.

According to the relationship diagram presented in Figure 3, a placement order was assigned for each department. To develop the determined placement order, a random initial selection was made for the first department to be placed (R&D Department), and the subsequent department was selected by looking at its relationship with the department chosen initially. The priority was on the A relationship; if there was no department or other functional units with an A relationship with the previous department, a department with an E relationship was chosen. If a department with an E relationship could not be found, a random department was selected again, and the process was repeated until all the departments were placed in the 1st Floor Office Area. Such a repetitive iteration resulted in the placement order documented in Table 2.

Based on the determined relationship diagram, sweep width of 2 br^2, and the department placement order for the 1st Floor Office Area, the optimum layout for seven departments and other functional units covering an area of 255 m^2 was created. Subsequently, the rough layout plan was smoothened to adjust the indentations and protrusions of the placed departments, resulting in the final layout of the 1st Floor Office Area as given in Figure 4. Before moving on to the next section of the facility, the created layout plan was transferred to the facility's 3D model to double-check whether or not it contained any boundary violations, as illustrated in Figure 5. For the 1st Floor Office area, a total layout score of -811 was calculated based on the relationship degrees and corresponding numerical values of these degrees. The main decisive factor of the negative score obtained is the X (-1024) relationship defined for the Human Resources and Customer Greeting Room department pair. The negative total score does not hinder the validity of the created layout plan but is used for comparative evaluation when multiple plans are created for the same area.

Table 2. Department placement order for the 1st floor office area.

Order	Department OR Functional Unit	Selection Reason
1	R&D Unit	Random
2	Project Unit	A Relationship with 1
3	Meeting Room	E Relationship with 2
4	Reception Area	E Relationship with 4
5	Customer Greeting Room	A Relationship with 6
6	Restrooms (Women-Men)	E Relationship with 7
7	Human Resources	The Last Department

1	1	4	4	4	4		
1	1	4	4	6	6		
1	1	4	4	6	6		3
1	1	4	4	6	7	3	3
2	2	2	4	7	7	3	3
2	2	2	2	7	7	3	5
2	2	2	2	7	5	5	5

Figure 4. Department placement of 1st floor office area.

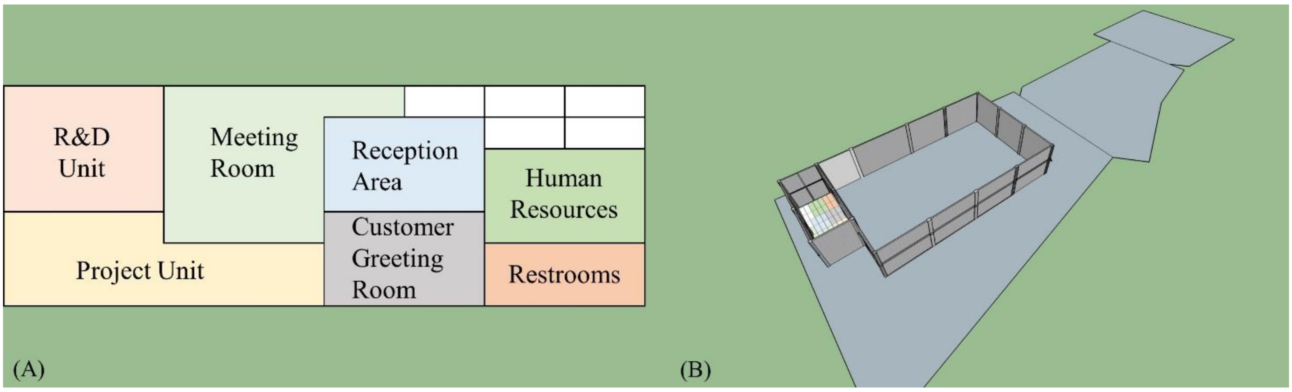

Figure 5. (A) Arranged department placement for the 1st floor office area. (B) Placement of the 1st floor office area layout into the 3D model of the facility.

As for the 2nd Floor Office Area, the name and area requirements of the departments and other functional units were Purchasing (25 m^2), Marketing (25 m^2), Secretariat (15 m^2), Executive Offices (65 m^2), Executive Meeting Room (55 m^2), Accounting (25 m^2), Restrooms (Male and Female-15 m^2), and Production Planning and Quality Control (30 m^2). Starting from the Purchasing Department, the relationship degrees of all departments and other functional units with each other were determined, and the relationship diagram shown in Figure 6 was constructed.

Once the department placement order for the 2nd Floor Office Area was created, the first department to be chosen for creating the department placement order was randomly selected using the MCP value of the "E" relationship. The random selection of the first department resulted in Executive Offices. Afterward, the following department to put in the placement order was identified as the Secretariat since it had an "A" relationship with the Executive Offices, as shown in Figure 6. The department to be chosen was expected to primarily have an "A" relationship with the previously chosen one. If not, a department with the "E" relationship, the cut-off point, was chosen. A random department was selected if no department had these two relationships. Following these rules, consecutive selections of the 2nd Floor Office Area departments have occurred in the order of Purchasing Department, Accounting, Production Planning and Quality Control, Marketing, Executive Meeting Room, and Restrooms. The result of the department placement order process with corresponding selection reasons was given in Table 3.

Number	Department OR Functional Unit	m^2	1	2	3	4	5	6	7	8
1	Purchasing	25		E	E	E	U	A	I	E
2	Marketing	25			E	E	U	I	O	E
3	Secretariat	15				A	U	I	O	I
4	Executive Offices	65					E	E	E	E
5	Executive Meeting Room	55						I	O	E
6	Accounting	25							O	O
7	Restrooms (Male and Female)	15								O
8	Production Planning and Quality Control	30								
	Total	255								

Figure 6. Department relationship diagram for 2nd floor office area.

Using the department placement order, area requirements, and sweep width of 3 br^2 for the 2nd Floor Office Section, the department placement process was conducted, and the final layout was created, as shown in Figure 6. As can be seen in the same figure, the last sweep of the placement process consisted of 2br^2 since it coincided with the boundaries of the construction design. The total layout score of the 2nd Floor Office Area was 184 without any X relationship.

The department placement given in Figure 7 was placed within the walls of the second-floor office area of the 3D model of the manufacturing facility for the final confirmation and was shown in Figure 8.

Table 3. Department placement order for the 2nd floor office area.

Order	Department OR Functional Unit	Selection Reason
1	Executive Offices	Random
2	Secretariat	A Relationship with 4
3	Purchasing Department	E Relationship with 3
4	Accounting Department	A Relationship with 1
5	Production Planning and Quality Control Dept.	Random
6	Marketing Department	E Relationship with 8
7	Executive Meeting Room	Random
8	Restrooms (Women-Men)	The Last Department

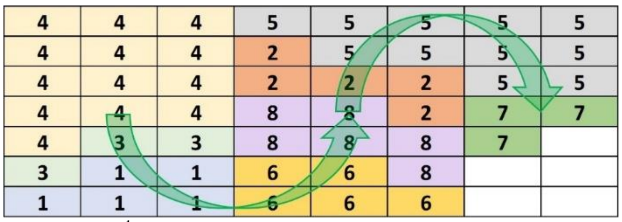

Figure 7. 2nd floor office area layout.

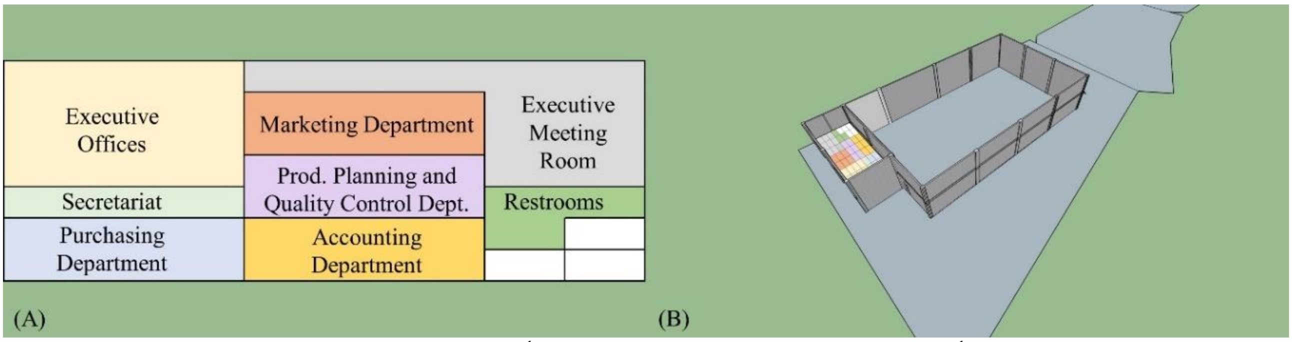

Figure 8. (A) Arranged department layout of the 2nd floor office area. (B) Placement of the 2nd floor office area layout into the 3D model of the facility.

After the optimum layout planning of the office sections of the facility was completed, the process moved on to creating the optimum layout plan for the Production Floor. The departments and other functional units to be placed on the Production Floor were decided to be the Asakai Meeting Room (50 m^2), Restrooms (Female and Male - 30 m^2), Dressing Room (60 m^2), Cafeteria and Dining Hall (100 m^2), Accessories Warehouse (100 m^2), Maintenance Room (30 m2), Tools and Equipment Room (30 m^2), Raw Materials Warehouse (1000 m^2), Heat Treatment Oven (40 m^2), Production Line (1 500 m^2), Assembly (300 m^2), Sanding-Finishing Workshop (100 m^2) and Shipping and Finished Goods Warehouse (300 m^2), resulting in a total of 13 departments and adding up to 3640 m^2 of coverage area.

To place the thirteen departments and other functional units that needed to be on the Production Floor within the designated area, a relationship diagram highlighting the degrees of relationship between the job functions of those departments was created and documented in Figure 9.

Following the assignment of relationship degrees, the department placement order for the Production Floor was conducted using the MCP value of the "E" relationship. Accordingly, the first department placed in the area was randomly selected. This random selection pointed out the Finished Good Warehouse and Shipping department. The following department was identified as the Sanding-Finishing Workshop since it had an "A" relationship with the previously selected department. The second selection was followed by the sequential selection of the departments of Assembly, Production Line, Maintenance Room, and Tools and Equipment Room, all having "A" relationships with those selected before them. As the seventh selection, Accessories Warehouse made its way to the list based on its "E" relationship with the Tools and Equipment Room. The process was continued with two random selections, resulting in Restrooms and Dressing Rooms. Even though random selections are independent of the relationship diagram, these selections were also the products of some logic based on the judgment of the experts trying to achieve practicality and feasibility. The tenth and eleventh orders were determined as Heat Treatment Oven and Raw Material Warehouse as a function of their "A" relationships with Dressing Rooms and Heat Treatment Oven, respectively. The twelfth selection was again made randomly, resulting in the Asakai Meeting Room. At the same time, the only remaining functional unit, the Cafeteria and Dining Hall, had the thirteenth order on the list. The complete list of department placement orders for the Production Floor was documented in Table 4.

The sweep width used in placing the Production Floor departments was three br^2, and the area corresponding to each unit cell was determined to be 10 m^2. According to these parameters, the departments and other functional units were laid out over the space allocated for the Production Floor, as depicted in Figure 10. The developed layout plan of the production floor had a total layout score of -318.

As performed for the 1st and 2nd Floor Office Areas, the arranged and adjusted version of the Production Floor department layout plan was transferred into the 3D modeling software for final confirmatory controls, as shown in Figure 11.

Number	Department OR Functional Unit	m^2	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Asakai Meeting Room	50		E	X	U	X	I	X	U	X	A	E	I	I
2	Restrooms (Female and Male)	30			I	I	I	I	I	I	I	I	I	I	I
3	Dressing Room	60				U	I	A	O	U	A	A	A	A	E
4	Cafeteria and Dining Hall	100					X	X	X	X	X	X	X	X	X
5	Accessories Warehouse	100						E	E	O	U	A	A	A	U
6	Maintenance Room	30							A	O	E	A	A	E	U
7	Tools and Equipment Room	30								U	O	A	A	E	O
8	Raw Materials Warehouse	1000									A	A	E	E	X
9	Heat Treatment Oven	40										E	I	O	U
10	Production Line	1500											A	A	E
11	Assembly	300												A	E
12	Sanding-Finishing Workshop	100													A
13	Shipping and Finished Goods Warehouse	300													
	Total	3640													

Figure 9. Production floor relationship diagram.

Table 4. Department placement order for the production floor

Order	Department OR Functional Unit	Selection Reason
1	Shipping and Finished Goods Warehouse	Random
2	Sanding-Finishing Workshop	A Relationship with 13
3	Assembly Department	A Relationship with 12
4	Production Line	A Relationship with 11
5	Maintenance Room	A Relationship with 10
6	Tools and Equipment Room	A Relationship with 6
7	Accessories Warehouse	E Relationship with 7
8	Restrooms (Women-Men)	Random
9	Dressing Room	Random
10	Heat Treatment Oven	A Relationship with 3
11	Raw Materials Warehouse	A Relationship with 9
12	Asakai Meeting Room	Random
13	Cafeteria and Dining Hall	The Last Department

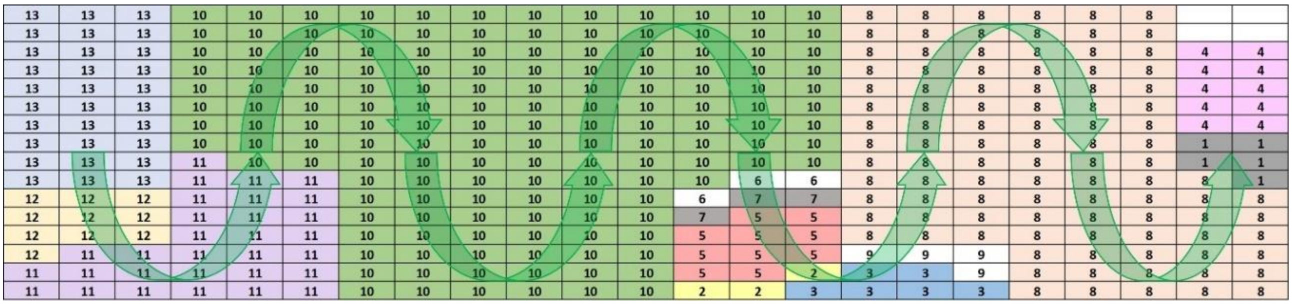

Figure 10. Department layout for the production floor.

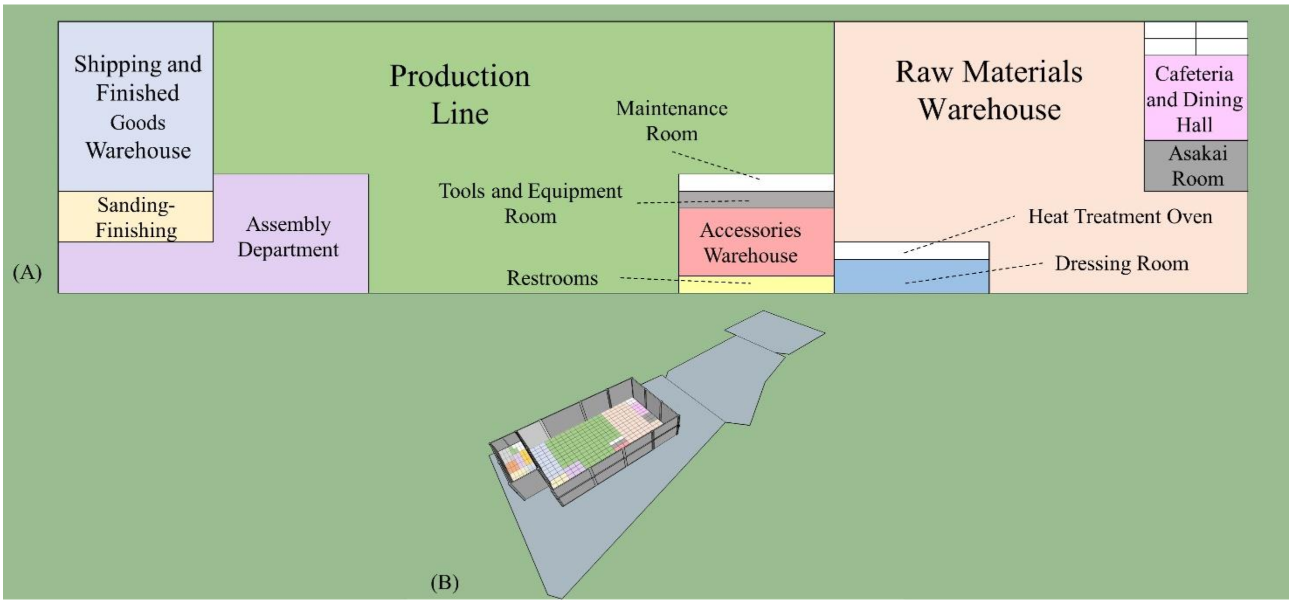

Figure 11. (A) Arranged department layout of the production floor. (B) Placement of the production floor layout into the 3D model of the facility.

As can be interpreted from the detailed documentation of the study results, facility layout optimization could significantly improve any manufacturing process, including wooden cable drum manufacturers. Optimizing the facility layout using methods such as ALDEP could have numerous benefits and implications. In this study, the ALDEP method was employed to determine the layout of a newly established facility for a company producing wooden cable drums. When simultaneously evaluated with the findings of previous studies, the ALDEP method was proven effective and functional in developing a layout plan for a newly established facility. A Review of earlier publications in the field showed that the ALDEP method was a commonly preferred method for studies with similar objectives. Andryzio et al. (2014) created a new facility layout using the ALDEP method in their research, resulting in 1098 proximity degrees and 245.526 Rp material handling costs. This resulted in a 32.74% improvement over the existing layout (Andryzio et al., 2014). Deshpande et al. (2016) observed a 0.10% improvement with the CRAFT method and a 23% improvement with the ALDEP method compared to the existing layout. Therefore, they have concluded that the layout created with the ALDEP method was better (Deshpande et al., 2016). In their study, Tambunan et al. (2018) calculated material handling costs in the rearrangement of the XYZ company using BLOCPLAN and ALDEP methods. Even though the layout created with BLOCPLAN yielded better results than that developed with the ALDEP method, the authors recommended the use of the layout made with the ALDEP method since it did not require a change in the architectural design of the building and was able to maintain a straight-line production flow (Tambunan et al., 2018). As can be interpreted from the findings of this study and the studies mentioned above, the results of the previous studies and our study are parallel and complementary to each other.

On the other hand, Suhardini and Rahmawati (2019) used ALDEP and CRAFT techniques to arrange a newly established facility. It was found that ALDEP provided a 23% lower material handling cost compared to CRAFT. Then, the layout created with the ALDEP method was further improved through an optimization stage involving the CRAFT method. (Suhardini and Rahmawati, 2019). Tarigan et al. (2019) compared CORELAP and ALDEP methods in their study. They increased the distance efficiency within the company from 53.67% to 93.74% using the CORELAP algorithm and to 78.18% using the ALDEP algorithm. After simulation to find the best method, the recommended layout, covering 1.9 km/day, resulted from the CORELAP algorithm (Tarigan et al., 2019). It was also evident in the previous studies that the ALDEP method has not always provided the best or optimal internal facility layout results. However, it has never fallen extremely short of the other alternatives and was able to populate acceptable and satisfactory layout plans. Although, due to some sector and case-specific factors, the ALDEP method could be outperformed by other algorithms in some previous studies, within the facility layout planning research stream, the ALDEP method has been accepted as a foundational algorithm and known as one of the best methods for determining the internal layout of newly established facilities. Since this study focused on the internal layout of a newly established facility, using the ALDEP method was logical, suitable, and practical.

Furthermore, discussing the potential cost savings associated with such systematic layout plan development activities is essential. Suhardini and Rahmawati (2019) found that the improvement provided by ALDEP compared to the CRAFT technique reduced annual material handling costs by 23%. Their study aimed to obtain the optimal layout plan for CV Aji Jaya Mandiri using ALDEP and then to improve it with CRAFT. The new layout obtained with ALDEP was compared with the final layout improved with CRAFT by using material handling cost taken from the MHES (material handling evaluation sheet) and the production provision time or processing time using Promodel simulation. The layout plan obtained with CRAFT reduced material handling costs by 6.24%, meaning CRAFT effectively improved the layout plan. The simulation results also showed that the improved layout plan reduced the production delivery time by 23 minutes. The layout evaluation using Adjacency Based Scoring for the CRAFT layout showed a 15% increase compared to the original layout. Therefore, it was selected as the best layout (Suhardini and Rahmawati, 2019). In another study, Suhardini et al. (2017) produced four layout alternatives, and each alternative was to be evaluated based on two criteria: material handling cost and simulation-based processing time. The results showed that with the addition of machines and operators, production capacity increased by up to 37.5%, and material handling costs decreased with the improvement of the layout plan. The systematic layout planning method reduced material handling costs by 10.98%, equivalent to 1229813.34 Rp, compared to the initial layout plan (Suhardini et al., 2017). Moreover, Andryzio et al. (2014) found that the layout design created using the ALDEP method resulted in an alternative with a total of 1098 proximity degrees and a material handling cost of 245.526 Rp. The developed layout plan had a 32.74% lower material handling cost than the existing one (Andryzio et al., 2014). As can be interpreted from the findings of the previous studies focusing on developing facility layouts through the employment of the ALDEP method, material handling cost savings could vary in the range of 6 to 32%, with an average value of 16.65%. Since this study dealt with a facility design problem of a wooden cable reel manufacturing facility that is yet to be built, it was not possible to calculate the material handling cost savings associated with the developed plan. However, the developed plan is expected to meet the ALDEP-method-enabled historical average of material handling cost savings (16.65%) reported in the previous studies based on empirical evidence.

The context of the study's implications could be summarized under three main themes: scientific, practical, and social, as detailed in the following paragraphs.

Scientific implications of the study could be summarized as advancements in layout optimization, cross-industry applicability, and efficiency modeling and algorithms. The study contributed to the body of knowledge in layout optimization, particularly in the wooden cable drum manufacturing sector. ALDEP has been a popular algorithm used in many manufacturing setups, but its application has varied widely in different industries. By focusing on this specific industry, the study set a particular example of ALDEP's applications and revealed unique opportunities for optimization. In the means of cross-industry applicability, the scientific community could potentially apply the findings and methodologies from this study to other similar industries or scenarios, paving the way for broader research. Moreover, this and similar studies could also lead to the development of new models or algorithms for improving efficiency, contributing to the scientific understanding of production efficiency since the deployment of each optimization algorithm onto a sector-specific case had pieces of evidence about the method's ability and competency to conform sectoral dynamics and requirements.

The study's practical implications could be explained under three main frames: operational efficiency, space utilization, and inventory management. First, an optimized facility layout such as the one created in this study could reduce the time taken for the manufacturing process, minimize material handling, improve worker safety, and increase overall productivity. Moreover, efficient use of available space is crucial in manufacturing. An optimized layout would better utilize space, potentially reducing the need for expensive expansion or relocation. Furthermore, optimizing the facility layout could improve storage and retrieval efficiency, leading to better inventory management and reduced warehousing costs.

Social implications of the study were expected to be seen in the long term in the areas of employment, environment, and local economy. An increase in efficiency might result in the need for fewer workers to produce the same output. However, it could also lead to upskilling opportunities, where workers learn to operate new, more sophisticated machinery or learn new, more efficient processes. Optimized layouts often mean less waste in terms of materials, energy, movement, and transportation. The current focus on sustainability and climate change could result in a lower carbon footprint, a significant social benefit. As for the local economy, if the wooden cable drum manufacturer becomes more efficient and profitable, it could positively impact the local economy in Türkiye. Increased profitability could lead to more taxes paid, more local supplies purchased, and potential job creation in the area.

Regarding future research directions in this research area, it could be elaborated into countless possibilities. While ALDEP is a powerful tool, other layout optimization algorithms exist, such as CORELAP (Computerized Relationship Layout Planning) and CRAFT (Computerized Relative Allocation of Facilities Technique). Future research could focus on a comparative study of these techniques in the specific context of wooden cable drum manufacturing or different manufacturing sectors. Moreover, this study focused on department-level layout optimization. Future research could be channeled into more micro-level optimization issues, such as machinery and equipment layout optimization within the production line. In addition, as technologies like artificial intelligence, machine learning, and the Internet of Things (IoT) continue to advance, studies could investigate how these tools could be integrated with ALDEP to enhance layout optimization. This study was designed to tackle a wooden cable manufacturer's initial facility layout planning problem. Future studies could investigate layout optimization's long-term impacts and benefits using ALDEP in the wooden cable drum manufacturing sector. These analyses could include effects on worker satisfaction, business profitability, environmental footprint, and supply chain robustness.

4. Conclusions

Although facility layout studies may seem simple, and even in some cases, one could mistakenly think that if the arrangement was done wrong, it may seem like it would not pose a problem. However, one small mistake made out of lack of experience, not thoroughly following the methodology, or a moment of inattention could lead to significant, irreversible, and expensive consequences. Facility layout studies have proven beneficial for businesses and employees when done correctly. A diligently and precisely created facility layout could aid enterprises in preventing the costs arising from unnecessary movements and transportation of material and personnel and increase efficiency. At the same time, it could contribute to creating safer and leaner workplaces.

This study aimed to develop the optimum department-level facility layout of a newly established wooden cable drums manufacturing facility and successfully met the objectives with documented results. The company had purchased 14800 m^2 of land in Bursa, Türkiye, and approximately 4150 m^2 of the total land area was reserved for the manufacturing facility. The optimum layout plan was successfully achieved by systematically arranging seven departments within the 1st Floor Office Area, eight departments within the 2nd Floor Office Area, and thirteen departments within the Production Floor of the manufacturing facility through the ALDEP algorithm. The results also indicated that the ALDEP algorithm could be effectively used for optimized layout planning of hybrid buildings involving interconnected single- and multi-story sections. The total layout scores of the 1st and 2nd Floor Office Areas and the Production Floor were determined to be -811, 184, and -318, respectively.

The results of the study depicted a successful example of developing an efficient and logical layout that would have the potential to enhance operational efficiency, reduce material handling and transportation costs, and ultimately improve profitability in the wooden cable drums manufacturing process. While this study focuses on the plant layout optimization of a wooden cable reel manufacturer in Türkiye, it can have far-reaching implications beyond the company's immediate benefits. It can also serve as a case study for similar industries looking to optimize their production processes. It could also be a good reference for academics researching facilities planning and value-added wood product manufacturing processes.

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