Facility Location Selection and Layout Planning through AHP, PROMETHEE, and CORELAP Methods in the Furniture Industry

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Facility location selection and internal layout planning are critical strategic decisions for long-term sustainability. This study identified the most feasible location and optimal layout for a commercial bedroom furniture manufacturing facility through a seven-phase evaluation of Istanbul, Ankara, Izmir, and Bursa. The Analytical Hierarchy Process (AHP) and PROMETHEE were used for city and district selection, with AHP calculating criteria weights and PROMETHEE ranking alternatives. The Borda Count Method aggregated MCDM results, selecting Istanbul as the optimal city and Dudullu Organized Industrial Zone (O.I.Z.) as the most favorable district. The CORELAP method developed an optimal single-story layout for a 2688 m² production and assembly facility, enhancing production flow, reducing material handling costs, and improving efficiency. These findings underscore the importance of strategic facility location and layout planning in improving the furniture industry's competitiveness and sustainability. The practical implications of this research are significant, as the findings can be directly applied to improve the competitiveness of the furniture industry. The study offers a comprehensive framework for strategic decision-making, providing valuable insights and a systematic approach applicable to similar problems in various sectors.

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INTRODUCTION

Organizations carry out continuous improvement activities at many stages of their life cycle. During the establishment phase, executives face two major decision-making problems. These can be summarized with the questions of (1) where the facility will be established and (2) how the interior layout will look. Answers to such questions require multi-criteria decisions, which bear complex relationships.

With such selection decisions, these enterprises aim to increase productivity and efficiency. "Choosing the Place of Establishment" is of great importance but is also associated with a potential competitive advantage in the market, where firms face fierce challenges for the same market share (Alp and Gündoğdu 2012). For this reason, business managers want to start their attempts to reduce costs from the establishment stage of the organization.

Decision-making is a process that exists not only in the business world but also in all areas of life. Decision-making occurs in the lives of people and organizations in three different ways. The first of these is called uncomplicated decisions that are routinely made daily. These decisions do not require much thought because they require a low level of consideration regarding the risk they involve. As another form of decision, there are sudden decisions. While making these decisions, decision-makers act based on previous experiences and current judgments. Finally, it is possible to talk about decisions that can neither be made routinely nor instantaneously. To be able to make such decisions, the factors affecting the decision should be thoroughly examined and scrutinized. These decisions are made through a process called Multi-Criteria Decision Making (MCDM) (Emhan 2007). In such a decision, a goal is defined, and alternatives are determined according to this purpose. Then, a set of criteria is established to evaluate the identified alternatives, and a comparison is made.

The MCDM techniques have been used to solve complex problems in many sectors, such as finance (Steuer and Na 2003), renewable energy (Shang *et al.* 2021), marketing (Hung *et al.* 2012), transportation (Görçün 2021), food (Wang *et al.* 2023), health-care (Hsu *et al.* 2023), aviation (Chung and Tan 2022), agriculture (Wang 2022), and ecology (Sarkar *et al.* 2022). MCDM has helped address a wide range of industrial problems, including but not limited to logistics cost minimization (Yan *et al.* 2021), identifying tourism competitiveness of countries (Liu *et al.* 2021), measurement of entrepreneurship characteristics of business entities (Drejeris *et al.* 2021), green supplier selection (Li *et al.* 2021), leasing company selection (Chien *et al.* 2021), and storage management (Lin and Ma 2021). Another area in which MCDM is used is facility location selection. Site selection includes studies related to the determination of the region where the business will be established and the settlement within the region in a way that will minimize unit costs and allow for expansion and development (Özden 2016). Facility location selection is critical to preventing future problems because its location has a decisive role in the firm's access to raw materials, proximity to the market, and access to a qualified workforce.

In contrast, the workplace arrangement constitutes a critical stage in the design of the production system. The workplace arrangement starts with determining the establishment location. It continues with the following stages: arranging the layout of existing departments, arranging the machinery/equipment, defining the movement areas of the workers and machinery in these sections, and arranging the individual workstations. While the individual workstations are arranged within the departments, ergonomics, work, time, and movement studies are carried out, and then an arrangement plan is prepared according to the results of these studies (Heragu 2008; Tompkins *et al.* 2010). In summary, when the in-plant arrangement is appropriately made, many invisible costs within the company could be minimized proactively, and an uninterrupted production flow that ensures the supply/demand balance could be achieved. For this reason, companies get help from scientific methods and experts in the field when deciding on in-plant arrangements after establishing the facility.

In recent years, several academic studies have focused on using MCDM methods in facility location selection and layout planning. A detailed examination of these studies revealed that MCDM has been used in many sectors for facility location selection and in-plant planning purposes. The following study sections reviewed and summarized previous literature on MCDM, facility location selection, and facility layout planning in this context.

Yang and Lee (1997) used the Analytical Hierarchy Process (AHP) method to determine the best location for a consulting firm (Yang and Lee 1997). Ertugrul and

Karakasoglu (2008) employed Fuzzy TOPSIS and Fuzzy AHP methods to select a textile company's facility location.

Similarly, Eleren (2010) used the AHP method to select the optimal location for a leather sector business, determining Istanbul as the preferred choice. Alp and Gundogdu (2012) utilized AHP and Fuzzy AHP methods to select a clothing production facility location in the textile sector, identifying Istanbul as the most suitable alternative. Akyuz and Soba (2013) employed the ELECTRE method to choose a location for a textile business in Usak, determining the Usak Organized Industrial Zone as the preferred alternative.

Ucuncu *et al.* (2017) used the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method to evaluate alternative locations for a modular furniture factory, finding Kastamonu, Düzce, and Bolu to be the most favorable options. Gulsun and Sahin (2017) employed MCDM methods to select the best facility location for a whey powder production enterprise, determining Tekirdag as the most favorable alternative. Shanshan *et al.* (2018) compared AHP-based TOPSIS and ANP-based TOPSIS methods for facility layout planning.

Yesilkaya (2018) utilized AHP, TOPSIS, and Preference ranking organization method for enrichment evaluation (PROMETHEE) methods to determine a suitable location for a paper mill, selecting Mersin as the optimum facility. Yulu and Doldur (2019) investigated facility location selection factors in the automotive industry in Tu, considering criteria such as market, transportation, capital, labor, and raw materials. Yıldız and Demir (2019) used the Fuzzy TOPSIS method to select the optimum facility location for a domestic automobile factory, identifying Gemlik, Bursa as the most suitable option.

Aydemir Karadağ (2019) studied the optimal location for a solid waste landfill facility, selecting Gölbaşı district as the preferred choice using AHP and GP methods. Inag and Arikan (2020) conducted a site selection study for a solid waste collection center, determining Çukurambar District as the most suitable location. Seker and Aydin (2020) conducted a site selection study for a hydrogen production facility, favoring Sinop as the best location.

Kayadelen (2021) conducted a facility location selection study for a furniture factory, suggesting the Marmara Region as the most suitable option based on the main criteria and the Central Anatolia Region as the best alternative considering sub-criteria. Ekin and Okutkan (2021) used the PROMETHEE method to select an office supplies facility location, determining Ankara province as the best alternative.

Kara *et al.* (2022) conducted a branch selection study for a maritime sector company, using AHP, ARAS, and fuzzy TOPSIS methods to favor the city of Izmit as the most suitable location. Durak *et al.* (2022) employed AHP and TOPSIS methods to select a technology development zone, identifying the ITU Technopark as the best alternative.

A concise review of several case studies focusing on facility layout planning was presented, highlighting the methodologies employed and their corresponding outcomes: Rawabdeh and Tahboub (2006) developed a new package program called FLASP to optimize the facility layout of a mineral oil manufacturing and filling plant. They compared the three new layouts with the existing layout based on flow distance, travel cost, and free space. New Layout 3 achieved the best results, showing significant improvements in flow distance (68.6%), travel costs (62.6%), and free space (6.4%) (Rawabdeh and Tahboub 2006).

Ertay *et al.* (2006) developed an organization planning framework using DEA/AHP methodology to evaluate 18 plant layout alternatives in the plastic profile manufacturing sector. Nine relatively effective alternatives were identified, with the 16th option being the most efficient (Ertay *et al.* 2006). Deshpande *et al.* (2016) utilized the CRAFT and ALDEP methodologies in the alloy steel industry, resulting in a 0.10% improvement with CRAFT and a 23% improvement potential with ALDEP compared to the current layout (Deshpande *et al.* 2016).

Binoy and George (2018) addressed productivity issues in the steel forging industry by optimizing a layout using the CORELAP algorithm. The modified layout showed a 7.98% improvement in productivity (Binoy and George 2018). Mebrat *et al.* (2020) compared two alternative layouts for a mechanics workshop using the CORELAP algorithm, concluding that the layout plan designed based on weight placement value achieved higher efficiency (71.4%) (Mebrat *et al.* 2020).

Bagaskara *et al.* (2020) examined various algorithms for facility layout planning, such as SLP, GBT, Integer Linear Programming Model, CORELAP, and BLOCPLAN. The authors emphasized the need to select algorithms based on specific problem dynamics and requirements (Bagaskara *et al.* 2020). Kiran (2021) explored facility layout techniques, suggesting the integration of 3D modeling options alongside existing 2D modeling approaches. Evaluation techniques, such as Multi-Purpose Optimization, DEA, Simulation Non-Linear Programming, and Fuzzy Constraint, were highlighted as valuable tools for productivity analysis (Kiran 2021).

Tjusila *et al.* (2021) applied SLP, CRAFT, and CORELAP methods to develop facility layout alternatives for an industrial packaging company. The SLP method significantly reduced distance and material handling costs (Tjusila *et al.* 2021). Belachew (2021) optimized plant layout in the manufacturing industry using CORELAP and CRAFT Excel methods and achieved a 22.1% reduction in distance traveled compared to the current layout (Belachew 2021). Wahyudi *et al.* (2021) used the CORELAP algorithm and the CRAFT method to enhance facility layout organization in a mattress production company. The layout created with the CRAFT technique demonstrated a 26% efficiency improvement (Wahyudi *et al.* 2021).

Hanum (2021) employed CORELAP 1.0 software to design a facility layout for a heavy equipment manufacturing facility, achieving a 39.5% reduction in the total distance (Hanum 2021). Lufika *et al.* (2021) proposed alternative facility layouts for a bread-producing firm using the CORELAP and BLOCPLAN algorithms. The layout developed through the BLOCPLAN algorithm was selected due to its superior efficiency (Lufika *et al.* 2021).

The reviewed facility layout planning studies utilized methodologies such as DEA/AHP, CRAFT, ALDEP, CORELAP, SLP, GBT, Integer Linear Programming Model, and BLOCPLAN. Evaluation techniques were used to compare and assess alternative facility layouts, including Multi-Purpose Optimization, DEA, Simulation Non-Linear Programming, and Fuzzy Constraint. The reviewed case studies and methodologies in facility layout planning emphasize the significance of selecting appropriate techniques and evaluating productivity gains. These findings contribute to informed decision-making and improving efficiency in various industries. Based on these studies, it was evident that different methodologies and algorithms could effectively address facility layout planning problems across many industries. The selection of the most suitable approach depends on the specific sector, problem requirements, and available data.

The literature review also revealed that a wide range of MCDM methods, such as AHP, VIKOR, ELECTRE, PROMETHEE, and TOPSIS, have been extensively and effectively employed in numerous studies addressing facility selection challenges in diverse sectors, including furniture, automotive, aviation, and solid waste storage. These methods have proven effective in facilitating informed decision-making for optimal facility placement. Based on the literature review, within the furniture industry and related sectors, the TOPSIS (Üçüncü *et al.* 2017) and Fuzzy TOPSIS (Kayadelen 2021) methods were preferred for facility location selection while CORELAP and CRAFT methods were applied by Wahyudi *et al.* (2021) for the facility layout planning.

Furthermore, the literature on MCDM, facility location selection, and facility layout planning demonstrates the development and utilization of various criteria to address industrial facility location selection and planning problems. In past studies, site selection criteria are typically identified through literature review, expert consultation, and empirical analysis. Studies often start by reviewing existing research to identify criteria and best practices commonly used in similar contexts. For example, Yıldız and Demir (2019) employed a literature review and expert opinion to determine the criteria for site selection in the automotive sector. Similarly, İnağ and Arıkan (2020) employed a literature review and expert opinion to ascertain the criteria for site selection in the context of the paper industry. Similarly, Kayadelen (2021) used a combination of a literature review and expert input to enhance and validate the site selection criteria as they pertain to the furniture industry. This approach ensures the criteria are comprehensive and relevant to the specific industry context.

While previous studies have explored facility location and layout planning using various MCDM methods, there is a lack of comprehensive models that simultaneously address both problems within the context of the furniture industry. Most existing research tends to focus on either facility location selection or internal layout optimization, but not both in a unified framework. Furthermore, the specific needs and operational characteristics of the commercial bedroom furniture sector, such as the importance of proximity to raw material suppliers and market access, have not been adequately addressed in the literature. Therefore, the objectives of this study were as follows: (1) to identify the optimal city alternative for the commercial bedroom furniture manufacturing facility, (2) to decide on the optimal district alternative within the selected city, and (3) to determine the most suitable in-plant layout planning through a systematic approach using MCDM methods.

This study was designed to contribute to the intersection of multi-criteria decision-making (MCDM), facility location selection, and in-plant optimization by integrating these processes into a cohesive framework specifically for the commercial bedroom furniture manufacturing sector. It employed AHP and PROMETHEE for city and district selection and used the CORELAP method for internal facility layout planning. This comprehensive approach ensured strategic decision-making that enhanced long-term sustainability and operational efficiency.

The expected outcomes of the study included (1) the identification of the most feasible city for establishing the commercial bedroom furniture manufacturing facility, (2) the selection of the optimal district within the chosen city, and (3) the development of an optimal facility layout plan that would potentially help to minimize material handling costs and maximizing production efficiency.

MATERIALS AND METHODS

Regardless of the industry, one of the most critical decisions in the facility establishment is the facility location selection and facility layout planning. These decisions are of great importance for the success and future sustainability of the company, as they are part of strategic planning, are not made frequently, are not easy to change, and have high costs. This study focuses on determining the most feasible location and facility layout planning for a commercial bedroom furniture production facility. The study was initiated upon request of a conglomerate company whose headquarters was in Türkiye and who wanted to make a new venture with the aim of market expansion. The company's name was not shared throughout the study due to the confidentiality agreement signed with the company. To select the establishment location and decide on the facility's departmental arrangement most accurately, the systematic steps, consisting of seven phases shown in Table 1, were followed.

The researchers and the investor company decided on the methods preferred and criteria used based on a deliberate literature review and discussions to ensure practical outcomes were in the firm's favor while providing the scientific merit and validity of the systematic research approach.

For establishing a facility, the city alternatives where the facility could be established must be determined first. After determining the city, an answer is sought as to which region it would be based in the selected city. For this reason, four alternative cities were chosen as the potential hosts of the facility (Phase 1). The city alternatives were identified as Istanbul, Izmir, Ankara, and Bursa based on the strategic plan and preferences of the investor company, as shown in Fig. 1. The investor company was willing to establish the new facility in one of the most industrialized cities in the nation. The ISO 500 ranking reports the first 500 firms contributing the most to the nation's economy. The alternatives mentioned above were the largest four cities in the nation with the highest contribution to the country's economy, with approximate sales revenues from manufacturing activities of \$2,146 billion, \$1,697 billion, \$1,626 billion, and \$1,298 billion, respectively (ISO 500 2022). The company executives were persistent in establishing the new facility in a highly industrialized city. Therefore, the industrialization levels of cities played a decisive role in specifying the geographical scope of this study. The specific constraints also included the total land cost and the size of the available land. The firm needed a construction-ready land area of at least 6500 m^2. The budget limit of the company for the total land cost was around ₺35.2 million (\$1.1 million). These constraints were influential in the district selection phase. Following an extensive literature review, a pool of criteria was created for use in the site selection phase. The criteria were selected through three rounds of the Delphi survey involving three furniture industry professionals and two academic subject matter experts. The furniture industry professionals and academics were selected based on their past experiences and proven merits. The consensus was reached when there was more than 70% agreement on the suitability of the selected criteria.

Table 1. Phases-Based Systematic Approach of the Study

Phase No.	Phase Description	Objective	Method
1	Identification of the most favorable location alternatives	Choosing the location alternatives with high strategic value.	Venturing company's preference
2	Identification of criteria for city selection	Choosing the suitable alternative with the lowest risk.	Literature review and Delphi method
3	Selection of the most feasible city where the plant is to be built		AHP and PROMETHEE
4	Identification of criteria for district selection		Literature review and Delphi method
5	Selection of the district in the most feasible city alternative		AHP, PROMETHEE, and Borda counting method
6	Determination of departments to be located in the facility	Planning a modern assembly/production facility in line with today's requirements.	Opinion of the architectural planning team and the technical ad visors of the entrepreneur
7	Planning of production and assembly facility layout		CORELAP

Table 2. Decision Matrix Used in the City Selection Phase

City Alternatives	Proximity to Potential Customers			Raw Material Suppliers (Count)	Total Value Generated by ISO 500 Companies (₺) ($/₺ Conversion Ratio =1/32)	By-Product / Accessories Suppliers (Count)	Total Employment in Sector (Count)
	Dorms (Count)	Hotels (Count)	Hospitals (Count)				
Istanbul	24.00	1,950.00	236.00	23.00	₺2,145,784,073,307.00 ($67,055,752,290.84)	41.00	677,474.00
Bursa	11.00	260.00	41.00	17.00	₺1,297,996,010,864.00 ($40,562,375,339.50)	23.00	273,871.00
Izmir	20.00	396.00	58.00	7.00	₺1,667,461,585,121.00 ($52,108,174,535.03)	11.00	216,397.00
Ankara	31.00	1,801.00	88.00	11.00	₺1,625,697,217,983.00 ($50,803,038,061.97)	17.00	172,585.00

Table 3. Decision Matrix Used in the District Selection Phase

Alternatives	District Selection Criteria				
	Competitors (Count)	**Total Land Cost (₺)/($/₺Exchange Rate =1/32)**	**Major Suppliers Nearby (Count)**	**Available Land Size (m^2)**	**Proximity to the Highways (m)**
Dudullu	6.00	₺27,500,000.00 ($859,375.00)	18.00	7,400.00	800.00
Kimyacilar	3.00	₺28,500,000.00 ($890,625.00)	9.00	19,000.00	1,700.00
Ikitelli	6.00	₺35,000,000.00 ($1,093,750.00)	12.00	6,500.00	2,000.00
Beylikduzu	3.00	₺33,000,000.00 ($1,032,250.00)	3.00	6,637.00	3,000.00

From a pool of criteria, a total of 8 criteria, including five main criteria and three sub-criteria, were agreed upon by the experts with consensus. After a series of deliberate back-and-forth communications, the availability of raw material suppliers, the total value generated by ISO 500 companies in the city (as an indicator of industrialization strength), availability of by-product/accessories suppliers, total employment in the sector, and proximity to potential customers were included in the study as the main criteria. The proximity to potential customers criterion had three sub-criteria: the number of dormitories, hotels, and hospitals (Phase 2). The decision matrix containing the corresponding values of each criterion per each alternative is presented in Table 2. Regarding the district selection phase, as the results of the Delphi method indicated and were supported by the literature findings, the following five criteria were included in the study: total land cost, competitors, major suppliers nearby, available land size, and proximity to highways (Phase 4). The decision matrix with corresponding values for each criterion used for the district selection analysis within the scope of AHP be PROMETHEE methods is given in Table 5.

All the data presented in Tables 2 and 3, excluding the Total Value Generated by ISO 500 Companies, were obtained from an independent service provider's market research report prepared for the organization.

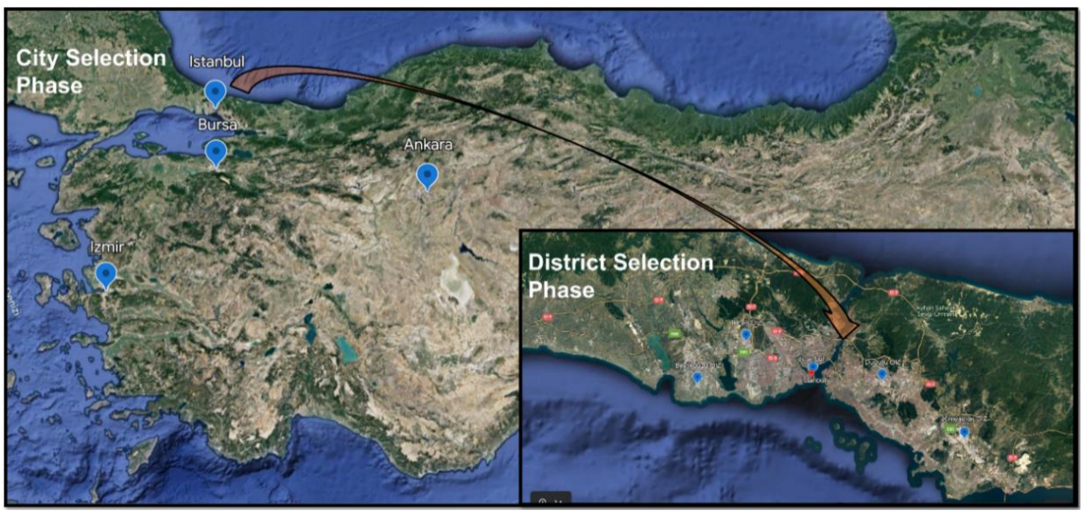

Fig. 1. Geographical illustration of city and district alternatives

AHP and PROMETHEE methods were applied to select the most feasible city (Phase 3) and district (Phase 5), and a final decision was reached by comparing the analysis results through the Borda Count method. The selection of these two methods for facility location decision-making was based on a review of existing literature, which revealed their frequent utilization in site selection issues. The Analytic Hierarchy Process (AHP) was chosen for its simplicity and effectiveness in deriving criteria weights through pairwise comparisons. PROMETHEE was selected for its ability to handle higher-level rankings and provide clear preference structures. The Borda Count method was used to aggregate individual rankings from AHP and PROMETHEE to obtain a final decision, ensuring a balanced and comprehensive evaluation. CORELAP was chosen for its effectiveness in optimizing facility layout by minimizing material handling costs and improving workflow efficiency. The AHP method was used to determine the criteria weights and to evaluate district alternatives comparatively. The criterion weights determined by AHP were also used as input in the PROMETHEE method.

As for the validation of the results, the AHP method includes a consistency analysis within its methodology (see page 11, step 6). The Consistency Ratio (CR) is calculated using the eigenvector obtained from pairwise comparisons. If the computed Consistency Ratio is below 0.1, the accuracy of the results is confirmed. This methodology is also applied in the Super Decisions software. Since no significant differences were observed in the results between the AHP method and the PROMETHEE method, a sensitivity analysis was not conducted for the PROMETHEE results. However, the Borda Count Method ensured increased robustness of the analysis results.

The Super Decision software package was used to determine criteria weights and evaluate alternatives using the AHP method. All sensitivity analyses and consistency ratios were calculated using the same software program. The Visual PROMETHEE software package was utilized to apply the PROMETHEE method.

AHP Method

The AHP method enables us to identify the importance of the criteria in complex multi-criteria and multi-alternative problems and helps reduce multi-dimensional problems to one-dimensional ones. In the AHP method, pairwise comparison matrices were constructed based on expert inputs from the Delphi survey. Experts rated the importance of each criterion relative to others on a scale of 1 to 9, where 1 indicates equal importance, and 9 indicates extreme importance of one criterion over another, as given in Table 4. The individual pairwise comparison matrices from the experts were aggregated using the geometric mean method to form a consensus matrix, as shown in Eq. 1 (Saaty 2008),

$$A_{consensus} = \left(\prod_{k=1}^{m} A_k\right)^{\frac{1}{m}} \quad (1)$$

where A_k is the pairwise comparison matrix from expert *k*, and *m* is the number of experts. This approach ensures that the final criteria weights reflect the collective judgment of the expert panel. The consistency ratio (CR) was calculated to ensure the reliability of the comparisons. The CR was obtained by calculating the eigenvector and eigenvalue of the pairwise comparison matrix, computing the consistency index (CI), and dividing the CI by the random index (RI) corresponding to the matrix size. A CR value of less than 0.1 was considered acceptable, indicating a consistent comparison matrix. The detailed steps and formulas used are outlined in the following parts of the methodology section.

Table 4. Table of Importance Levels Used in Pairwise Comparisons

Severities	Value Definitions
1	Both factors are of equal importance.
3	Factor 1 is slightly more important than Factor 2.
5	Factor 1 is more important than Factor 2.
7	Factor 1 has extreme importance compared to Factor 2.
9	Factor 1 has superior importance compared to Factor 2.
2,4,6,8	Intermediate values.
Reciprocity	$a_{ji} = \frac{1}{a_{ij}}$. Therefore, $a_{12} = \frac{1}{a_{21}}$ I.E., if a_{12} =5, then $a_{21} = \frac{1}{5}$

Step 1: Setting the Goal

Within the scope of the AHP method, an objective was first determined. In this case, the objective was to select the facility location city and district-wise. A hierarchical structure was established to achieve such an objective (Saaty 1980). The general representation of the hierarchical structure created for this study is given in Fig. 2.

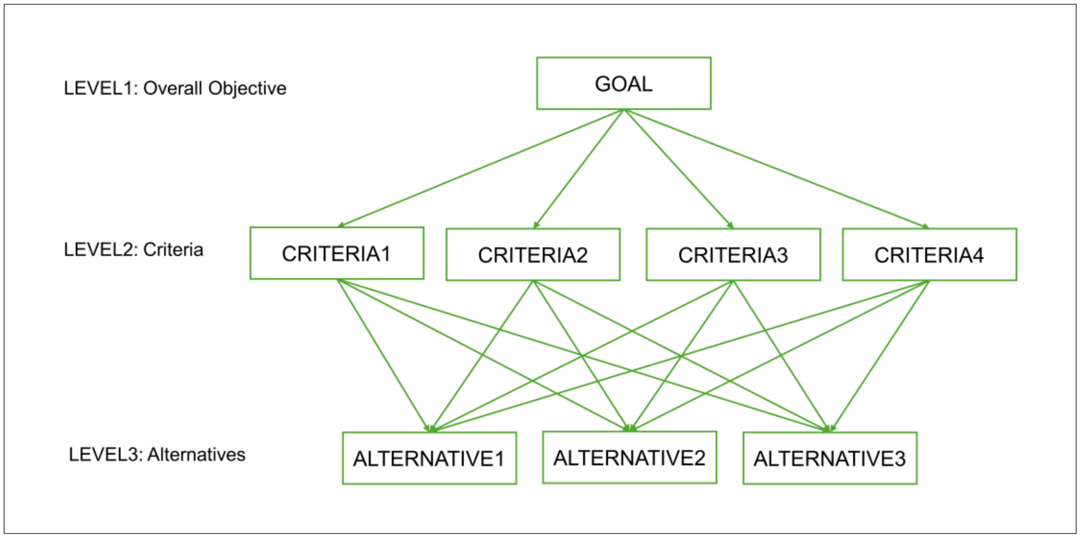

Fig. 2. The hierarchical structure of the AHP method

Step 2: Establishing the Pairwise Comparison Matrix (Matrix A) and Determining the Priorities

After establishing the hierarchical structure, a comparative evaluation of the criteria and alternatives was carried out. These evaluations were done with pairwise comparison matrices of $n \times n$ size (Saaty 1980). The structure of comparison matrices is shown in Eq. 2.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \dots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \dots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \dots & 1 \end{bmatrix} \tag{2}$$

The factors were compared for all matches above the diagonal line of the comparison matrix, using the value scores in Table 2 according to their relative importance. The calculations were completed using Eq. 3 for the matches under the diagonal.

$$a_{ji} = \frac{1}{a_{ij}} \tag{3}$$

Step 3: Normalizing the Pairwise Comparison Matrix

Each element a_{ij} of the pairwise comparison matrix A is divided by the sum of its respective column to produce a normalized matrix $\tilde{A}$ (Saaty 1980). The resulting matrix is given in Eq. 4.

$$\tilde{A} = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \\ \frac{a_{21}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{22}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{2n}}{\sum_{i=1}^{n} a_{in}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \end{bmatrix} \tag{4}$$

Step 4: Calculating the Eigenvector

The mean of the elements in each row of the normalized matrix $\tilde{A}$ is calculated from the eigenvector as shown in Eq. 5 (Forman and Selly 2001).

$$w_i = \frac{1}{n}\sum_{j=1}^{n} \tilde{a}_{ij}\,, \quad for\ i = 1, 2, \dots, n \tag{5}$$

The resulting eigenvector W is:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{6}$$

Step 5: Computing the Principal Eigenvalue λ_{max}

After the criterion weights were determined, the consistency test stage was started. This calculation compares the number of factors with the Principal Eigenvalue (λ) coefficient. To calculate λ, first, the comparison matrix A and the eigenvector W are multiplied. Then, the values obtained by dividing each element of the resulting vector by the corresponding component of W are averaged and calculated as in Eq. 7 (Saaty 1994).

$$\lambda_{max} = \frac{1}{n}\sum_{i=}^{n} \frac{(A.W)_i}{W_i} \tag{7}$$

Step 6: Consistency Check

The consistency Indicator (CI) was calculated utilizing Eq. 8 using the coefficient λ. In the last step of this stage, CI and the Random Value Index (RI) corresponding to the number of relevant factors given in Table 5 were processed, as seen in Eq. 9, to obtain the CR value (Saaty 2008). At this stage, the desired CR value is less than 0.1 (Aczel and Saaty 1983).

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

Table 5. Random Value Indices

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

PROMETHEE Method

The PROMETHEE method was first introduced by L. P. Brans at a conference in Canada in 1982 (Brans 1982). This method initially provided a partial ranking of decision alternatives with PROMETHEE I and a complete ranking with PROMETHEE II. Subsequently, Brans and Mareschal expanded the methodology by introducing different versions into the literature (Brans *et al.* 1986; Mareschal and Brans 1988; Brans and Mareschal 1992; Brans and Mareschal 2005). A fundamental distinction of PROMETHEE from other Multi-Criteria Decision Making (MCDM) methods is its ability to allow the decision-maker to specify different preference functions for each criterion. This feature eliminates the necessity of evaluating all criteria similarly, thus providing flexibility and customization options.

The PROMETHEE method was performed in 6 stages.

Step 1: First, the data matrix reflecting the importance of the criteria was created. In the data matrix, w = (w_1,w_2,…, w_k) represents the criteria weights, c = (f_1, f_2,…, f_k), and A = (a, b, c,…) represent the criteria and the evaluated alternatives, respectively.

Step 2: Six different preference functions, namely Ordinary, U-Type, V-Type, Level, Linear, and Gaussian, were identified as defined by Brans and Vincke for the criteria determined in the previous stage.

First Type Preference Function (Usual or Ordinary): If the decision maker had no preference regarding the relevant evaluation criterion, that criterion's preference function was determined as the First Type (Usual or Ordinary) Preference Function.

Second Type Preference Function (U Type): If the decision maker used a preference judgment for decision alternatives with a value higher than the value determined by the relevant evaluation criterion, the preference function to be selected was identified as the Second Type (U Type) preference function.

Third Type Preference Function (V Type): This function was used for decision alternatives with an above-average evaluation criterion; however, when the decision-makers did not want to neglect the values below this value, the Third Type (V Type) Preference Function was selected.

Fourth Type Preference Function (Level): In cases where a specific range of values was determined for an evaluation criterion, and the preference was made according to these values, the Fourth Type (Level) Preference Function was selected.

Fifth Type Preference Function (Linear): In the cases where one of the above-average value alternatives was used for an evaluation criterion, the Fifth Type (Linear) Preference Function was the appropriate option.

Sixth-Type Preference Function (Gaussian): When the choice was made considering the deviation values from the mean, the Sixth-Type (Gaussian) Preference Function was selected.

Step 3: Based on the preference functions defined in the previous step, the shared preference functions for the pairs of alternatives were determined per the relations given in Eqs. 10 and 11,

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \tag{10}$$

$$d_j(a,b) = g_j(a) - g_j(b) \tag{11}$$

where $g_j(a)$ represents the value obtained by alternative *a* for any criterion *j*, while $d_j(a,b)$ denotes the value difference between alternatives *a* and *b* for criterion *j*. In this study, a linear function type has been employed for all criteria used in city and district selection, and the values for $d_j(a,b)$ have been calculated as shown in Eq. 12. The p and q values included in the model for each criterion are provided in Figs. 7 and 13. The Visual PROMETHEE software recommended these p and q values based on the data characteristics. Fig. 3 gives a schematic representation of the shared preference functions.

$$p(d) = \begin{cases} 0, & d \leq q \\ \frac{(d-q)}{(p-q)}, & q < d < p \\ 1, & d > p \end{cases} \tag{12}$$

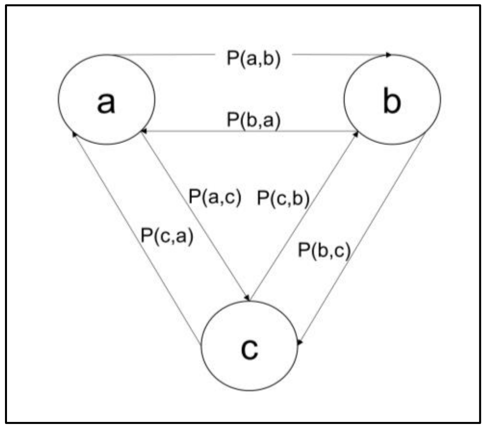

Fig. 3. Schematic representation of preference functions

Step 4: Based on the determined ordinary preference functions, preference indices for each pair of alternatives were calculated using Eq. 13 for pairs of alternatives evaluated with *k* criteria with weight w_i *(i = 1, 2,…,k)* in the alternative set.

$$\pi(a,b) = \frac{\sum_{i=1}^{k} w_i \times p_i(a,b)}{\sum_{i=1}^{k} w_i} \tag{13}$$

Step 5: The alternatives' positive (ϕ+) and negative (ϕ-) superiorities were determined using Eqs. 14 and 15. The schematic structure of positive and negative superiority for a generic alternative is shown in Fig. 4. Positive and negative supremacy structures were constructed for all alternatives.

$$\Phi^{+}(a) = \sum \pi(a,x) \;\; x = (b,c,d,\ldots) \tag{14}$$

$$\Phi^{-}(a) = \sum \pi(a,x) \;\; x = (b,c,d,\ldots) \tag{15}$$

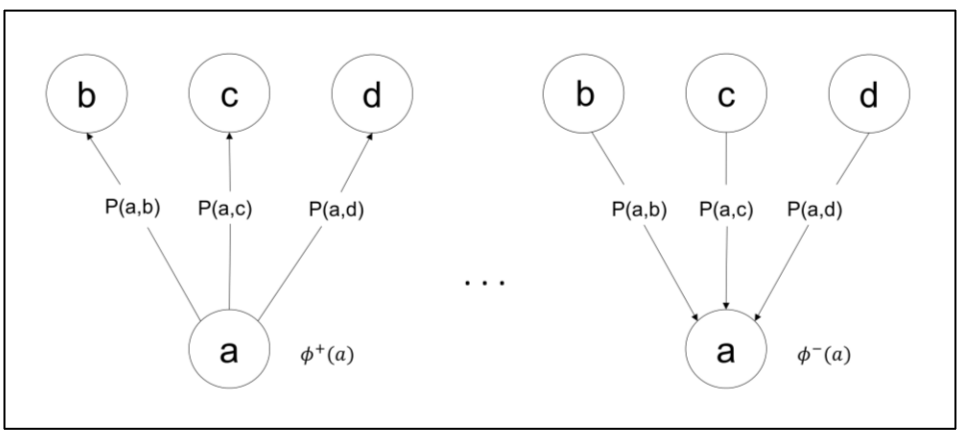

Fig. 4. Schematic representation of positive and negative supremacies

Step 6: In this step, partial priorities were determined with PROMETHEE I. Partial priorities were used to assess the preferability of alternatives over each other, alternatives that are indistinguishable from each other, and alternatives that cannot be compared. Equations 16 to 21 were used to determine the partial priorities of the alternative pairs.

If any of the following conditions were met, alternative *a* was preferred to alternative *b*.

$$\Phi^{+}(a) > \Phi^{+}(b)\ ve\ \Phi^{-}(a) < \Phi^{-}(b) \tag{16}$$

$$\Phi^{+}(a) > \Phi^{+}(b)\ ve\ \Phi^{-}(a) = \Phi^{-}(b) \tag{17}$$

$$\Phi^{+}(a) = \Phi^{+}(b)\ ve\ \Phi^{-}(a) < \Phi^{-}(b) \tag{18}$$

If the following condition was met, alternative *a* was indistinguishable from *b*.

$$\Phi^{+}(a) = \Phi^{+}(b)\ ve\ \Phi^{-}(a) = \Phi^{-}(b) \tag{19}$$

If any of the following conditions were met, alternative *a* could not be compared with alternative *b*.

$$\Phi^{+}(a) > \Phi^{+}(b)\ ve\ \Phi^{-}(a) > \Phi^{-}(b) \tag{20}$$

$$\Phi^{+}(a) < \Phi^{+}(b)\ ve\ \Phi^{-}(a) < \Phi^{-}(b) \tag{21}$$

Step 7: In this step, the absolute priorities of the alternatives were calculated according to the PROMETHEE II procedure using Eq. 24. The exact ranking was determined by evaluating all alternatives on the same plane with the calculated complete priority values. The superiority or indifference decision of the alternatives was determined with the help of Eqs. 22 to 24:

$$\phi(a) = \Phi^{+}(a) - \Phi^{-}(a) \tag{22}$$

If $\phi(a) > \phi(b)$, alternative *a* is superior to alternative *b*. (23)

If $\phi(a) = \phi(b)$, alternative *a* is indifferent from alternative *b*. (24)

AHP and PROMETHEE MCDM methods were also simultaneously deployed for the study's district selection phase. A final decision was made by choosing the most feasible location for establishing the facility among potential districts based on the same evaluation steps outlined above. Following Phase 4 of the study, the venturing company identified four alternative industrial zones (Dudullu O.I.Z., Kimyacilar O.I.Z., Beylikduzu O.I.Z., and Ikitelli O.I.Z.) within the determined city according to the attractiveness of the existing investment incentives, as shown in Fig. 1 (Phase 5). A final decision regarding the most feasible district in the best city alternative was reached through the Borda Count method by aggregating the results of the MCDM analysis.

Borda Count Method

The "Borda Count Method," which has been essential in developing modern electoral systems, was first introduced as a voting technique by Jean-Charles De Borda (1784) (Lumini and Nanni 2006).

The method's underlying principle ranks the alternatives based on an aggregate performance score called the Borda Score. This study used the Borda Count method as a data aggregation technique, enabling scientists to combine the independent rankings generated by the AHP and PROMETHEE methods into a more valid single ranking. In the Borda scores calculation procedure, each alternative received *n–1* point for a first preference, *n–2* for a second preference, and so on. Zero points were assigned to the least preferred alternative, where *n* is the number of alternatives. The best alternative was determined by arranging the obtained Borda Scores from the largest to the smallest.

To represent the order given to the i^{th} alternative by the B_i^kth decision maker (classifier), the Borda Score for the ith alternative was calculated as shown in Eq. 25.

$$B(i) = \sum_{k=1}^{n} B_i^k \tag{25}$$

After deciding where the facility would be established, the sixth and seventh phases of the study, which were identifying the departments for the production and assembly facility and planning the final facility layout, were initiated. The CORELAP (Closeness Rating and Layout Planning) method has been selected for the facility's internal layout planning. CORELAP is a constructive algorithm that optimizes inter-departmental relationships. The rationale for choosing this method is its ability to minimize material handling costs and workflow durations in the internal layout planning of production and assembly facilities, thereby enhancing production efficiency. The sections subject to the interior arrangement optimization study were determined in cooperation with the architectural project team and the company's technical consultants. The plant was determined to be established upon a land area of approximately 7400 m^2. It involved seven interconnected but independent sections with various area requirements: a production and assembly facility (2688 m^2), a finished goods warehouse (832 m^2), a raw material warehouse (468 m^2), a cafeteria (168 m^2), a recyclable collection zone (128 m^2), and a social interaction zone called MSD (72 m^2). Within the scope of this study, the production and assembly facility were subject to in-plant layout planning efforts. At the end of deliberate discussions, a consensus was reached, and the team experts agreed upon 13 distinct departments for the production and assembly facility. The optimization work focused on placing these departments within the allocated land parcel of 2688 m^2. Agreed upon facility design involved Quality Control (96 m^2), Shop-Floor (1736 m^2), Production Planning (80 m^2), Administrative Offices (48 m^2), Maintenance and repair (120 m^2), Accounting (60 m^2), Human Resources (80 m^2), Sales (108 m^2), R&D (84 m^2), Logistics (40 m^2), Occupational Health and Safety (36 m^2), Restrooms (32 m^2), and Meeting Room (168 m^2). An inter-departmental relationship diagram has been created, and the Corelap 01 software package has been utilized for the internal arrangement of the facility. This approach facilitated optimizing spatial relationships and the effective placement of departments based on their interaction levels.

CORELAP Method

CORELAP is one of the first computerized organization algorithms (Heragu 1997). This method helps plan the first part to be placed in the layout by converting the attribute type input data to the quantity type input data. According to the created relationship diagram, successive sections were included in the layout in consecutive order. In-plant layout optimization was carried out in two stages through the CORELAP algorithm. The department selection order was determined in the first and second stages, and the final layout was reached by following the department placement procedure. The relationship values shown in Table 6 and the Total Closeness Rating (TCR) calculated based on these relationship values were used in the department selection order process and placement procedure of the departments.

Table 6. The Verbal and Numeric Scales Used in the Identification of the Relationship of Departments with Each Other

Relation	Relationship Notation	Value
Proximity is absolutely necessary	A	125
Proximity is reasonably necessary	E	25
Proximity matters	I	5
Habitual proximity is enough	O	1
Proximity does not matter	U	0
Proximity is not desirable	X	-125

RESULTS

As a product of the first two phases of the study, the most favorable and feasible city alternative was identified for the commercial bedroom furniture manufacturing facility. The criteria to be used in city selection and the hierarchical structure of alternatives are shown in Fig. 5.

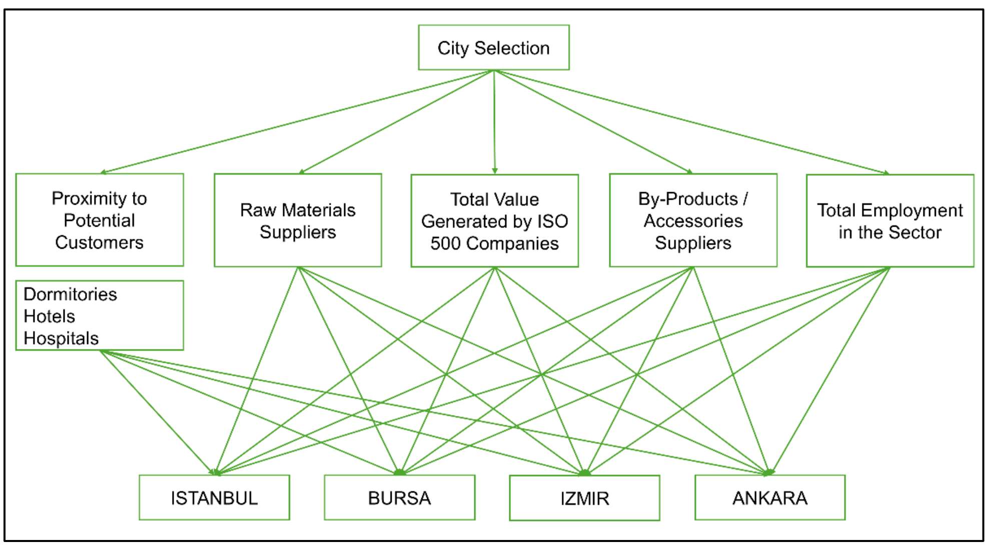

Fig. 5. The hierarchical structure of the city selection problem

The criteria weights used in the city selection procedure were determined according to the hierarchical structure shown in Fig. 5, and these weights are given in Fig. 6.

Name	Normalized by Cluster	Limiting
City Selection	**0.00000**	**0.000000**
By-Product /Accessories Suppliers	0.06698	0.022863
Proximity to Potential Customer	0.33910	0.144971
Raw Material Suppliers	0.45101	0.192811
Total Employment in Sector	0.10692	0.045710
Total Value Generated By ISO 500 Companies	0.03600	0.015389
Dorms	0.06764	0.009792
Hospitals	0.19907	0.028860
Hotels	0.73338	0.106319

Fig. 6. Weights of criteria determined for city selection

Following the determination of the criteria weights for the city selection phase, the next step of the city selection process was started, and the analysis was carried out per the PROMETHEE algorithm. First, criteria, criteria weights, and preference functions were defined in the solver program. A screenshot of the Visual PROMETHEE model showing the assigned preference functions, criteria set, and criteria weights is given in Fig. 7.

Scenario1	Dorms	Hotel	Hospital	Raw Material...	Total Value ...	By-Products/...	Total Employ...
Unit	custom	custom	custom	custom	TL	custom	number of
Cluster/Group							
Preferences							
Min/Max	max	max	max	max	max	max	max
Weight	0,02	0,25	0,07	0,45	0,04	0,07	0,11
Preference Fn.	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	5,055	667,435	72,999	4,123	231848256266	8,944	197460,546
- P: Preference	15,722	1746,601	175,499	13,123	667703515343	24,944	459484,046
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics							
Minimum	11,000	260,000	41,000	7,000	129799601086	11,000	172585,000
Maximum	31,000	1950,000	236,000	23,000	214578407330	41,000	677474,000
Average	21,500	1101,750	105,750	14,500	169173397181	23,000	335081,750
Standard Dev.	7,228	777,030	77,060	6,062	302318181391	11,225	200916,943
Evaluations							
ISTANBUL	24,000	1950,000	236,000	23,000	214578407330	41,000	677474,000
BURSA	11,000	260,000	41,000	17,000	129799601086	23,000	273871,000
IZMIR	20,000	396,000	58,000	7,000	169746158512	11,000	216397,000
ANKARA	31,000	1801,000	88,000	11,000	162569421798	17,000	172585,000

Fig. 7. Criteria for city selection and definition of preference functions

After defining the criteria, criteria weights, and preference functions, using PROMETHEE I and PROMETHEE II, the superiority of the alternatives to each other was determined, and the partial and final ranking of the alternatives was found. The partial ranking results obtained from the PROMETHEE I analysis are given in Fig. 8A.

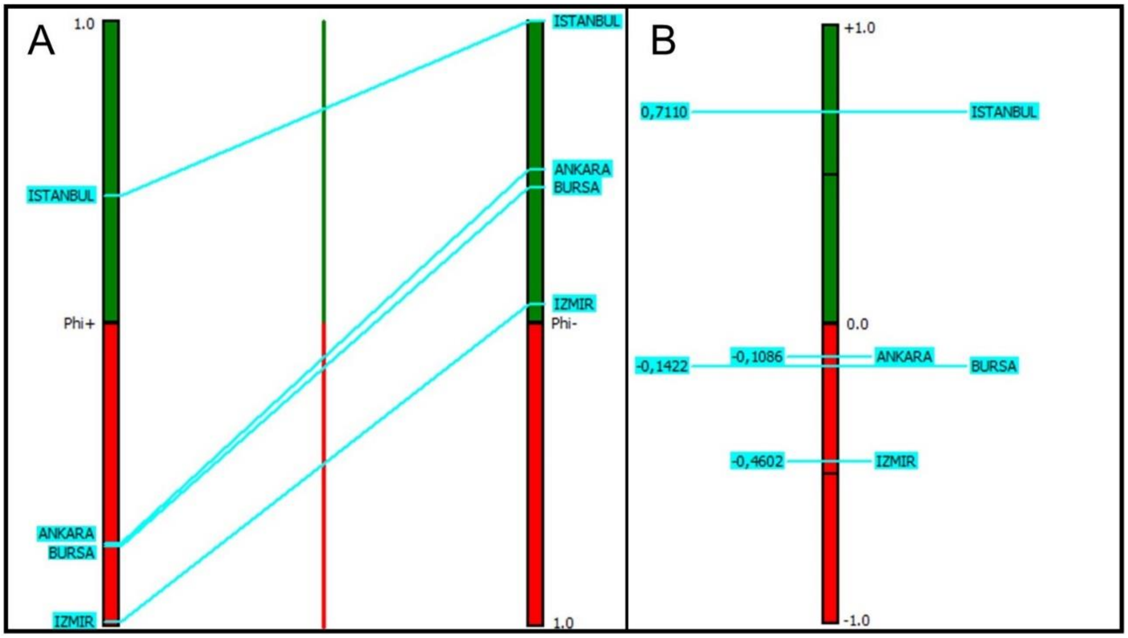

Fig. 8. (A) PROMETHEE I partial sequencing for city selection; and (B) PROMETHEE II final ranking for city selection

According to the PROMETHEE I partial ranking results, the same ranking of alternative cities was obtained in positive and negative superior values. In both cases, the best alternative was the city of Istanbul. Ankara, İzmir, and Bursa, respectively, followed Istanbul. The final interpretation of the comparisons was based on the PROMETHEE II final ranking results for a more accurate evaluation of the alternatives because the partial ranking results were inconclusive. PROMETHEE II solutions are given in Fig. 8B. According to the analysis results, Istanbul was the most suitable city alternative for establishing a production facility for commercial bedroom furniture, followed by Ankara, Bursa, and Izmir. While Istanbul had a phi value of 0.7110, Ankara, Bursa, and Izmir had phi values of -0.1086, -0.1422, and -0.4602, respectively. The rankings for the alternative locations of the facility are also shown in Fig. 9.

Rank	action	Phi	Phi+	Phi-
1	ISTANBUL	0,7110	0,7121	0,0011
2	ANKARA	-0,1086	0,1366	0,2452
3	BURSA	-0,1422	0,1327	0,2748
4	IZMIR	-0,4602	0,0073	0,4675

Fig. 9. Ranking of alternatives by PROMETHEE method

Once the city selection decision was made, choosing the appropriate district in Istanbul started. Four organized industrial zones (O.I.Z.s) within the most feasible city alternative (Istanbul), which could receive the highest investment incentive, have been added to the alternatives pool (Phase 5). The hierarchical structure showing criteria and alternatives for the district selection problem is given in Fig. 10.

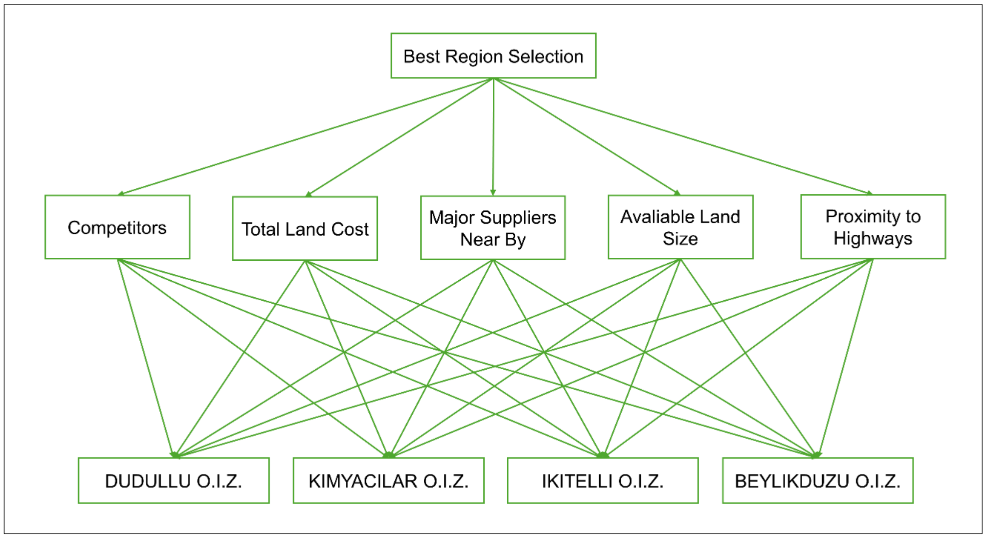

Fig. 10. Hierarchical structure for district selection problem

As a crucial step of the district selection phase, the criteria weights were calculated using the Super Decision package program per the AHP method in the same fashion employed for the city selection problem. The criteria weights were determined based on pairwise comparisons and are shown in Fig. 11.

Name	Normalized by Cluster	Limiting
District Selection	**0.00000**	**0.000000**
Available Land Size	0.10849	0.054246
Competitors	0.03453	0.017267
Major Suppliers Near By	0.21698	0.108492
Proximity to the Highways	0.06094	0.030469
Total Land Cost	0.57905	0.289526

Fig. 11. Criteria weights for district selection

Determined criteria weights provided input to AHP and PROMETHEE methods to select the best district alternative. Employment of these MCDM methods yielded two separate rankings of the alternatives. As explained in the methodology section, the individual pairwise comparison matrices from the experts were aggregated using the geometric mean method to form a consensus matrix. Using the derived weights and consensus matrix, AHP results given in Fig. 12 were obtained. This systematic approach ensured that the decision-making process was quantifiable and traceable, facilitating a systematic evaluation of each district option.

Name	Ideals	Normals	Raw
Beylikduzu O.I.Z.	0.227150	0.102498	0.051249
Dudullu O.I.Z.	1.000000	0.451233	0.225617
Ikitelli O.I.Z.	0.206910	0.093365	0.046682
Kimyacilar O.I.Z.	0.782090	0.352905	0.176452

Fig. 12. AHP results for district selection

According to the results of the AHP method, Dudullu O.I.Z. was the most suitable district alternative with an ideality value of 1.0. The Kimyacılar O.I.Z. followed Dudullu O.I.Z. with an ideality score of 0.7820, whereas Beylikduzu O.I.Z. and Ikitelli O.I.Z. districts ranked third and fourth with ideality scores of 0.2271 and 0.2069, respectively. District selection analyses based on the PROMETHEE method were run in the Visual Promethe package program. The results yielded a slightly different ranking of alternatives. The data input into the program is shown in Fig. 13. Linear preference functions were used for all the criteria. The algorithm aimed to minimize the number of competitors, land cost, and proximity to the highways, while maximization was the target for the criteria of access to the raw materials and land size.

Scenario1	Competitors	Total Land C...	Major Suppli...	Available La...	Proximity to ...
Unit	custom	?	custom	m2	m
Cluster/Group	◆	◆	◆	◆	◆
Preferences					
Min/Max	min	min	max	max	min
Weight	0,03	0,58	0,22	0,11	0,06
Preference Fn.	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	1,41	2327373,34	4,72	5788,71	567,89
- P: Preference	3,41	6827373,34	14,22	12165,88	1717,89
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	3,00	27500000,00	0,00	6500,00	800,00
Maximum	6,00	35000000,00	18,00	19000,00	3000,00
Average	4,50	31000000,00	9,75	9884,25	1875,00
Standard Dev.	1,50	3102418,41	6,50	5274,14	785,41
Evaluations					
DUDULLU O.I.Z.	6,00	27500000,00	18,00	7400,00	800,00
KIMYACILAR O.I.Z.	3,00	28500000,00	9,00	19000,00	1700,00
IKITELLI O.I.Z.	6,00	35000000,00	12,00	6500,00	2000,00
BEYLIKDUZU O.I.Z.	3,00	33000000,00	0,00	6637,00	3000,00

Fig. 13. Criteria and preference function definitions for district selection

After defining the criteria and preference functions, using PROMETHEE I and PROMETHEE II, the relative superiority of the alternatives was set out, and then partial and final rankings were calculated. Partial rankings generated as the function of PROMETHEE I results are shown in Fig. 14A.

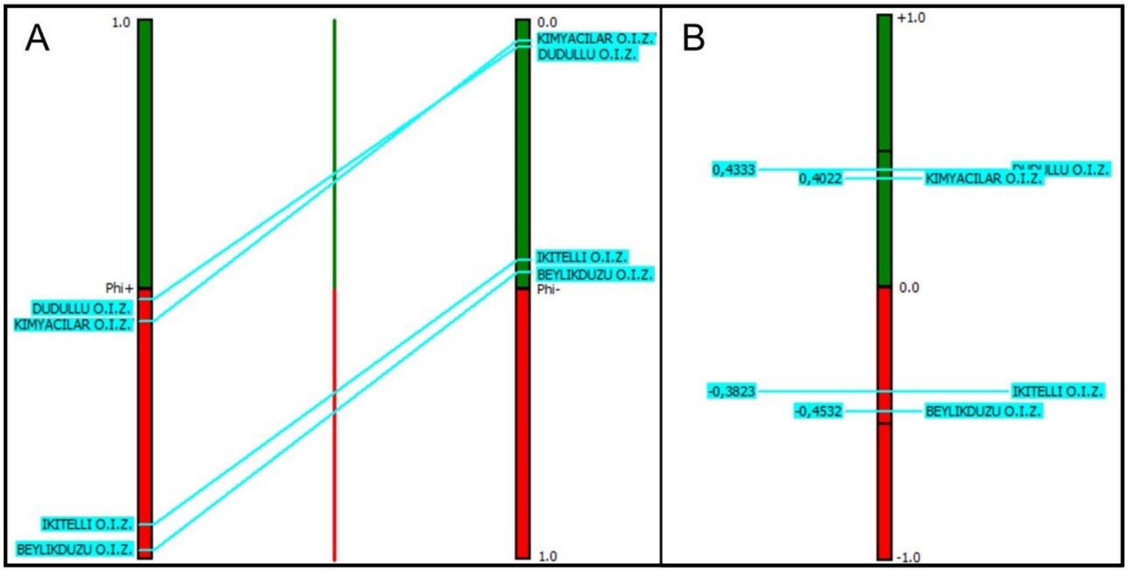

Fig. 14. (A) PROMETHEE I partial rankings for district selection; and (B) PROMEETHEE II final ranking results for district selection

Based on the PROMETHEE I results, the ranking of the alternatives was the same as that of the AHP Method. The alternatives had quite close phi values to each other. Dudullu O.I.Z. was identified as the best alternative and consecutively followed by Kimyacılar O.I.Z., Ikitelli O.I.Z., and Beylikdüzü O.I.Z. However, because the phi values were close to each other, PROMETHEE II was run to obtain more conclusive and consistent results. The final ranking results generated by PROMETHEE II are given in Fig. 14B. Net flow values and district preference rankings generated according to PROMETHEE II complete ranking procedure are shown in Fig. 15. Dudullu O.I.Z. took the first ranking with a phi value of 0.4333. Kimyacilar O.I.Z., Ikitelli O.I.Z., and Beylikduzu O.I.Z. followed Dudullu O.I.Z. district with phi values of 0.4022, -0.3823, and -0.4532, respectively. With these results, according to the PROMETHEE method, the most feasible district alternative for establishing a commercial bedroom furniture manufacturing facility was concluded as the district of Dudullu O.I.Z.

Rank	action	Phi	Phi+	Phi-
1	DUDULLU O.I.Z.	0,4333	0,4827	0,0493
2	KIMYACILAR O.I.Z.	0,4022	0,4410	0,0388
3	IKITELLI O.I.Z.	-0,3823	0,0637	0,4460
4	BEYLIKDUZU O.I.Z.	-0,4532	0,0159	0,4691

Fig. 15. Preference order for district selection

After the district alternatives were ranked independently with the two MCDM methods, these two distinct evaluations were comparatively analyzed with the Borda Count Method. As a result of this analysis, it was determined that Dudullu O.I.Z. could be conclusively preferred as the most feasible facility location option. The results of the Board Count method are given in Table 7. Dudullu O.I.Z. had the highest Borda Score with 8 points while Kimyacilar O.I.Z., Ikitelli O.I.Z., and Beylikdüzü O.I.Z. had 6, 3, and 3 Borda Scores, respectively. The results indicated that Kimyacilar O.I.Z. district was the second-best option, whereas Ikitelli O.I.Z. and Beylikdüzü O.I.Z. were less favorable. These calculations finalized the Phases 1 through 5 of the study.

Table 7. Borda Count Ranking for District Selection

Alternative	PROMETHEE Ranking	PROMETHEE Score	AHP Ranking	AHP Score	BORDA Score	BORDA Ranking
Kimyacilar	2	3	2	3	6	2
Dudullu	1	4	1	4	8	1
Ikitelli	3	2	4	1	3	3
Beylikduzu	4	1	3	2	3	4

After determining the facility's location, the CORELAP method was employed for the interior departmental layout of the facility. In the in-plant arrangement, thirteen departments were identified, as mentioned in the methodology section of the study. A relationship diagram was created for these departments based on the facility's expected material flow and the pairwise association of the departments. The created relationship diagram and the departments' physical space requirements (m2) are given in Fig. 16.

A= 125 E=25 I=5 O=1 U=0 X=-125

	Department Name	Department Area (m^2)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	HUMAN RESOURCES	80		I	A	U	U	E	O	O	U	U	U	O	I
2	SALES	108			I	U	U	O	I	O	I	O	I	A	U
3	ACCOUNTING	60				U	U	E	I	O	O	O	O	I	U
4	MAINTENANCE & REPAIR	120					A	O	X	O	E	E	O	O	A
5	QUALITY CONTROL	96						O	U	O	E	E	E	O	A
6	ADMINISTRATIVE OFFICES	48							A	O	U	U	U	O	O
7	MEETING ROOM	168								X	I	O	I	U	X
8	RESTROOMS	32									O	O	O	O	U
9	PRODUCTION PLANNING	80										E	E	E	A
10	OCCUPATIONAL HEALTH AND SAFETY	36											U	X	E
11	RESEARCH & DEVELOPMENT	84												U	I
12	LOGISTICS	40													I
13	SHOP-FLOOR	1736													

Fig. 16. Relationship diagram and area requirements of departments

After creating the relationship diagram, the Total Closeness Rating (TCR) for each department was calculated. According to the TCR scores, the departmental layout order shown in Fig. 17 was determined.

Order	Department	TCR	m²
1	QUALITY CONTROL	328	96
2	SHOP-FLOOR	291	1736
3	PRODUCTION PLANNING	262	80
4	ADMINISTRATIVE OFFICES	181	48
5	MAINTENANCE & REPAIR	179	120
6	ACCOUNTING	169	60
7	HUMAN RESOURCE	163	80
8	SALES	153	108
9	RESEARCH & DEVELOPMENT	68	84
10	LOGISTICS	40	40
11	OCCUPATIONAL HEALTH AND SAFETY	-21	36
12	RESTROOMS	-115	32
13	MEETING ROOM	-228	168
		Total Deployable Facility Area	**2688**

Fig. 17. Department placement order and TCR scores

According to the positive/negative scores generated based on the relationship diagram given in Fig. 17, the physical allocation and placement of the departments over a 2688 m^2 area for a single-story building shown in Fig. 18 were created for the commercial bedroom furniture manufacturing facility. This unique facility layout enabled managers to stay close to the workstations and minimize the movement waste across the facility.

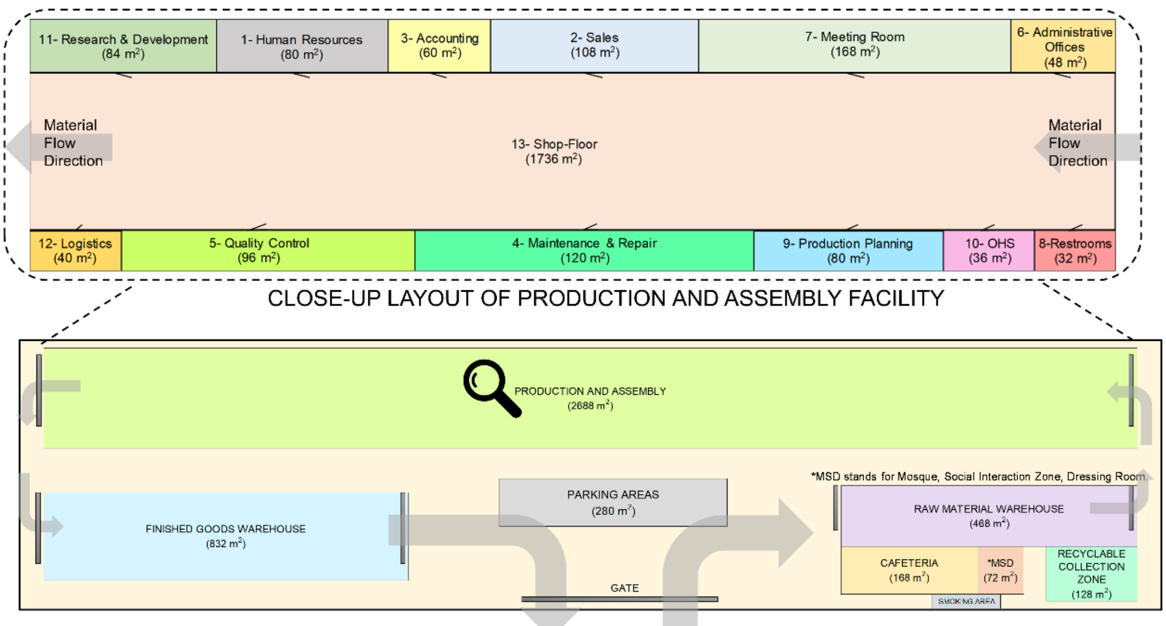

Fig. 18. Department-level facility layout created by the CORELAP method

DISCUSSION

This study addressed the facility location selection and internal layout planning for a company that manufactures commercial bedroom furniture. Four city alternatives were initially evaluated using five main criteria and three sub-criteria. Subsequently, within the chosen city, four regions were assessed using five criteria to select the site for the facility. When the results of the studies of Üçüncü *et al.* (2017) and Kayadelen (2021) were compared with the findings of this study, it was seen that similar selection criteria had been employed in the furniture sector for facility location decisions (Üçüncü *et al.* 2017; Kayadelen 2021). Past studies in the furniture sector identified incentives as the most significant criterion, with a weight of 0.42 for facility location selection using Fuzzy AHP. In contrast, in this study, Raw Material Suppliers and Total Land Cost emerged as the most critical criteria for city and district selection, respectively, with weights of 0.45 and 0.29 (Kayadelen 2021). Another study in the furniture sector provided a different perspective by equally weighing the facility location selection criteria (Üçüncü *et al.* 2017). Historical studies frequently selected Istanbul as the location alternative (Eleren 2006; Alp and Gündoğdu 2012; Durak *et al.* 2022). The findings of this study align with those of previous research, demonstrating consistency in the outcomes across different periods.

Results from this study revealed that proximity to raw material suppliers and potential customers were the most significant criteria among all. Therefore, they had a decisive impact on the outcome of the city selection phase of the study. Such a result forced decision-makers to place the new facility within the country's biggest city, which had much competition and higher overhead costs than other alternatives. In contrast, the selected city alternative has vast opportunities in terms of attractiveness for the qualified workforce and easy access to distribution channels. It is at the heart of many industrial clusters from various sectors. These results are consistent with the findings of previous studies (Eleren 2006; Alp and Gündoğdu 2012; Durak *et al.* 2022).

The district selection phase of the study involved a closer investigation of potential locations by considering land cost, major suppliers nearby, available land size, number of competitors, and proximity to highways. In this phase, the largest weights were on land cost, availability of nearby major suppliers, and land size for sale. Therefore, the selection was made by prioritizing the availability and cost-effectiveness of the land as well as the efficiency and agility of procurement activities. Even though available land size had less weight than the total land cost and major nearby suppliers' criteria, it acted as a constraint throughout the selection process because the company needed at least 6500 m^2 of land area (2688 m^2 was spared for production building). Proximity to the highways rather than other logistics channels was also considered significant because the decision-makers were initially willing to aim for the domestic market. Furthermore, the total land requirement of the facility was the product of six components: the production and assembly facility, raw materials warehouse, finished goods warehouse, parking area, social areas, and recyclable collection area. This phase focused on achieving a lean facility design by ensuring smooth material flow (in an anticlockwise direction) and less movement through the facility components. Moreover, because the production and assembly component involved a shop floor that was longitudinally laid, the land alternatives were required to be rectangular with a ratio of a/b of approximately 1/3.5. This situation forced decision-makers to dig deeper into all district alternatives to identify available lands that meet the requirements before the district selection phase. Such a dwindling structure of the problem also shows that MCDM problems of similar nature are more complex than they seem.

The layout of the production and assembly section of the facility was the product of a relationship matrix constructed by team experts (architects, engineers, and scientists) through detailed consideration of inter-departmental material and people movement. This design matrix also ensured that departments were placed on the two sides of the shop floor, enabling a unique, automated one-way flow of product components.

This study contributed to the existing literature by providing a comprehensive approach that integrated MCDM methods for facility location selection and internal layout planning. It filled a gap in the literature by applying these methods specifically to the commercial bedroom furniture industry. The specific managerial, practical, and social benefits and implications of the study could be itemized as follows:

- Enhanced Decision-Making Accuracy: This study employed AHP and PROMETHEE methods to provide a robust framework for evaluating multiple location and layout alternatives. This ensured that decisions were based on a comprehensive analysis of various critical factors, reducing the risk of suboptimal site selection and layout design.
- Cost Reduction: The study's findings demonstrated that strategic location and layout planning is the foundation of improved material handling costs and workflow inefficiencies. This is particularly beneficial for the commercial bedroom furniture industry, where production costs are a significant concern. Efficient facility layouts minimize unnecessary movement and handling of materials, leading to lower operational costs.
- Improved Production Efficiency: Using the CORELAP method for internal layout planning helped design an optimal facility layout that potentially enhances production flow and reduces bottlenecks. For the commercial bedroom furniture industry, this means a smoother production process, higher output rates, and better utilization of space and resources.
- Competitive Advantage: By strategically selecting locations closer to raw material suppliers and potential markets, companies in the commercial bedroom furniture industry could achieve faster turnaround times and better customer service. This proximity also facilitates attracting skilled labor and ensures easier access to other necessary resources, enhancing the company's competitiveness in the market.
- Sustainability and Long-Term Success: The study's integrated approach to facility location and layout planning ensures that decisions are aligned with the company's long-term strategic goals. This alignment is crucial for maintaining sustainability and achieving continuous growth in the highly competitive furniture market.
- Customized Solutions for Industry Needs: Unlike generic studies, this research specifically addressed the unique needs and challenges of the commercial bedroom furniture industry. The tailored criteria and methods ensure the solutions are relevant and applicable, providing practical insights that industry practitioners can directly implement.
- Social Implications: The commercial bedroom furniture industry could benefit from using MCDM techniques to make informed decisions about facility location selection and internal layout planning. This would also indirectly benefit the local community by creating new jobs.

In summary, this study not only filled a gap in the existing literature by focusing on the commercial bedroom furniture industry but also offered practical, actionable insights that could lead to improved decision-making, cost savings, enhanced production efficiency, and a stronger competitive position in the market.

However, as expected in any scientific work, this study had some limitations. The study focused on departmental-level facility planning; however, it did not involve micro-level (shop-floor-level) layout-planning components because the decision-makers were highly discrete about their new and innovative manufacturing lines. It could have been more effective and holistic if it had included micro-level facility layout considerations. Moreover, the criteria used in both the city and district selection phases were determined by a group of experts approaching the problem from the perspective of company owners. Therefore, the selected criteria's adequacy, scope, and sufficiency may be unsatisfactory for other firms and industries. Such a situation could lead to a bias towards criteria that favor business interests over other potentially relevant factors. For instance, experts from the furniture industry might prioritize operational efficiency and cost reduction, possibly overlooking environmental or social criteria.

Future research could mitigate these biases by including a more diverse panel of experts representing stakeholders such as environmentalists, community representatives, supply chain experts, and industry professionals and academics. This would ensure a more balanced set of criteria that considers various perspectives. Anonymous surveys could be used during the Delphi process to minimize the influence of dominant opinions and encourage unbiased responses from experts. Moreover, expanding the range of criteria to include environmental sustainability, social impact, and community development could ensure a more holistic evaluation of potential locations. Employing fuzzy logic methods to handle linguistic and subjective data could provide a more nuanced understanding of expert opinions and reduce bias.

Furthermore, conducting comparative studies across different industries could provide valuable insights into the generalizability and adaptability of the proposed methods. Understanding how the criteria and methodologies apply in diverse contexts could help refine the approach and expand its applicability. Additionally, longitudinal research could assess the long-term impact and sustainability of the selected locations and layouts. By tracking the performance and outcomes over time, future studies could validate the effectiveness of the decisions and identify areas for continuous improvement. Lastly, conducting thorough validation and sensitivity analysis to test the robustness of the findings under different scenarios and criteria weight variations could help identify any biases in the initial criteria selection and their impact on the final results.

By implementing these strategies, future studies could reduce potential biases and improve the reliability and comprehensiveness of the decision-making process in facility location and layout planning. This approach ensures that the selected criteria and resulting decisions reflect a wide range of stakeholder interests and are better aligned with sustainable and ethical business practices. The study also could serve as a valuable reference point for future research since it demonstrated the application of MCDM methods in a real-world context, providing a template that could be adapted and extended to other facility location and layout planning problems in various sectors.

CONCLUSIONS

Enterprises' sustainability and long-term success highly depend on one of the first macro-level strategic decisions: where the production facilities will be established and how the facility will be laid out. Such fundamental issues could either be the key to desired levels of operational efficiency or cause unrepairable damage to the company. Strategic decisions are neither cheap nor easy to reverse or modify once implemented. Facility location selection and layout planning are critical issues regarding ease of access to the markets, proximity to raw materials and suppliers, access to the qualified workforce, occupational safety, robust material and production flow, expansion potential, *etc*.

1. The systematic approach consisting of AHP, PROMETHEE, and Borda Count effectively identified the optimal city and district alternative for facility location in the commercial bedroom manufacturing sector.

2. Based on five main criteria and three sub-criteria, Istanbul was chosen as the most feasible city alternative.
3. The district alternatives within the city of Istanbul were evaluated through an MCDM model, co-utilizing AHP and PROMETHEE methods. The rankings obtained through these methods were aggregated using the Board Count method. Dudullu O.I.Z. emerged as the most suitable district alternative.
4. Proximity to raw material suppliers and potential customers were identified as the most crucial criteria for determining the city for a commercial bedroom manufacturing facility, while land cost, availability of nearby major suppliers, and available land size for sale were the most decisive factors for district selection.
5. The CORELAP algorithm generated a unique facility layout that enabled managers to stay close to the workstations and minimize movement waste across the facility.
6. For the facility layout phase of the study, an optimum layout plan was created for the 13 departments of the commercial bedroom furniture manufacturing facility using the CORELAP method. The proposed facility layout plan was expected to ensure uninterrupted and efficient batch production flow for the company while minimizing movement waste by placing the administrative office areas and other spaces close to the workstations.

As a result of this study, the optimum facility location and the most appropriate facility layout within a single-story building were identified for a conglomerate company that wants to make a new venture. In conclusion, although this study focused on a commercial bedroom furniture manufacturing facility, it was expected to be a valuable reference point for cases with multi-criteria decision requirements for production facilities in any industry. This study and its findings could also be an essential resource and guide for academics and professionals interested in MCDM techniques, facility location problems, and in-plant optimization studies.

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