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An integrated modelling approach for an optimal location of warehouses in the defence industry organisation

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Abstract

Countries' defence industries are the leading indicator of their global power. The warehouse is the place where the materials are kept until the customer order arrives so that the companies are viable and can respond appropriately to internal/external customer demands. In this regard, warehouse location plays a vital role in the defence industry in terms of storage options with increased flexibility, a simplified supply chain with cost management and optimal positioning according to deployment locations. In this study, the decision on the location of warehouses for logistic support during the warranty period of military vehicles manufactured and supplied to the armed forces by a defence company was made. It is aimed to propose the best solution to a real-life problem with high complexity, containing many data and constraints. In this context, the criteria that are thought to be most relevant to this problem have been determined by taking expert opinions. Having determined the order of importance of the requirements by the analytical hierarchy process (AHP) with the Super Decisions V 2.10, their weights were included as a coefficient of the objective function in the goal programming (GP) model. As a result of solving the GP model using GAMS (general algebraic modelling system), it was decided to select the warehouses that provided the optimal results among the alternative warehouse locations in 9 different locations. Furthermore, to see the impact of changes in criterion weights, sensitivity analysis has also been included. The significance of this research lies within the integrated usage of AHP and GP in the defence industry when determining warehouse locations by the experts' opinions. With this study, not only a solution strategy was developed, but also a basis for the warehouse location decision in the defence industry projects already signed or to be signed was given.

Keywords: *warehouse location, integer programming, defence industry, analytic hierarchy process, goal programming*

1. Introduction

The defence industry is the sector that provides the production and sale of weapons and military technology. Although the first thing that comes to mind is weapons, missiles and military vehicles; logistics and operational support are also the building blocks of the defence industry.

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The current structures of countries, their geopolitical situation, and economic and demographic characteristics lead to differences in military spending. Supporting the limited resources in the defence industry with the right investments and cost-effective solutions brings strategic advantages in the international arena. For this reason, a project in the defence industry studied the problem of selecting warehouse locations, assuming that the sustainability of the systems produced can be maintained at a high level if the necessary support is provided at the time of operation. The location theory was originally proposed by Weber to position a single warehouse in such a way as to minimize the overall distance between customers and the warehouse [8]. Shortening the response time is possible by choosing the right location of the facility or warehouse. The facility or warehouse location selection problem aims at choosing the best location and the best number of facilities. If the right choice is made, companies can achieve great profits and market share in today's conditions [11].

The decision is a series of algorithms that become increasingly difficult as the number of options increases, requiring detailed examination and evaluation. To achieve the best results in cases where the options increase and the problem becomes complex, it is necessary to use analytical and mathematical decision-making models. Figure 1 shows the graphical representation of conflicting goals in space.

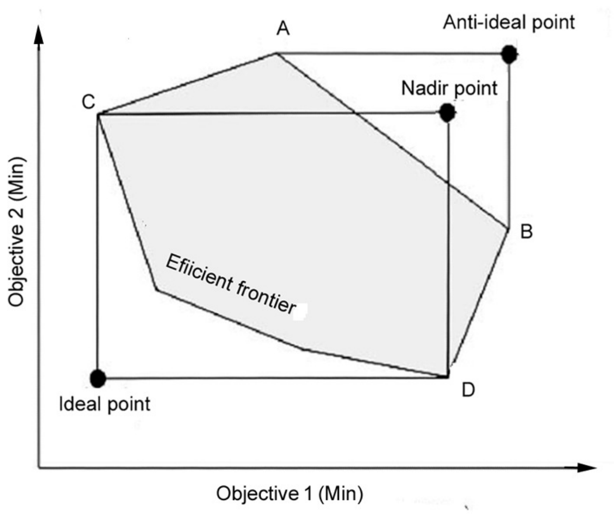

Figure 1. Conflicting goals in space [12]

In the project conducted in the defence industry, decision models are used because there are many decision-makers and alternatives to solve the problem. The objective of this study is to make an effective decision in the defence industry project. The paper is organized as follows; after a short literature review regarding the core problem is given in the next section, we present our mathematical model and solution algorithm in Section 3. Having given the computational analysis and results in Section 4, our paper ends with conclusions and future research suggestions in Section 5.

2. Methodology adopted. Integrated usage of AHP-GP and a brief look to related literature

Goal programming (GP) was first introduced in 1955 by Charnes, Cooper, and Ferguson in a study on the analysis of executive salaries, and GP was clearly defined in Charnes and Cooper's study [24]. GP can be considered a branch of multi-objective optimization, which is a part of multicriteria decision analysis.

GP is used in the optimization of multi-objective goals by minimizing the deviation from the desired goal for each of the goals. Although the GP model dates back to the 1950s, it has been in active use since the mid-1970s. Some of the articles that were examined during this study using GP are given below.

Sharma et al. [23] studied the GP model for the supplier selection problem, which aims to achieve the least deviation from price, quality, and lead time goals Mukherjee and Bera [17] addressed the project selection problem using the GP technique. Lee and Kim [15] used the analytical network process (ANP) and GP, considering the interdependencies among projects in information systems selection. Uludağ [25] developed a GP model that would give the most appropriate frequency values for 26 lines passing through two stops in the Izmir city bus network, and then established a fuzzy linear programming model. Dengiz et al. [7] used the weighted GP method to solve the home health services routing problem in their study.

The AHP method, developed by Saaty in 1976, is a systematic approach used to solve complex multidimensional problems that helps the decision-maker choose among alternatives. The AHP method is used in military strategic areas, ammunition, unit, tactical selection decisions, exercises, and election decisions in competitive environments in social life, in the fields of health and law; environmental issues, economy and marketing, technology and investment projects, transportation problems, etc. AHP compares alternatives, ranks them, and makes a decision among the alternatives; it provides the necessary planning by predicting the results. Thus, the outcome that must be found by trial and error when resources are scarce in real life is simulated by the AHP method and a cost-effective solution is presented to the decision-maker.

GP and AHP in handling quantitative and qualitative criteria, respectively. This is done by:

- employing the quantitative criteria directly in the GP model,
- deriving AHP priorities for the qualitative criteria after eliciting expert judgments,
- employing the AHP priorities as coefficients of the decision variables in the corresponding objective functions of the GP model.

Thus, the integrated model has the potential to extend the applicability of GP to problems involving qualitative criteria, and, at the same time, reduce the burden on decision-makers while eliciting AHP judgments. Additionally, AHP has been used in our integrated model to arrive at the weights to be assigned to the various objectives [20].

In this study, an integrated model of the AHP and GP (GP) was used. Therefore, some literature review for using AHP or GP is given below.

Dağdeviren and Eren [6] used AHP and 0–1 GP techniques to select the supplier and the two methods together are also discussed. Badri [4] used an integrated model of AHP and GP for obtained weighting of a firm's unique service quality measures, considered the real-world resource, and selected the optimal set of service quality control instruments.

Kwak et al. [13] used the AHP-GP approach to determine the best combination of media advertising for a Korean company that manufactures digital devices. Lee et al. [14] developed a multi-objective GP model using fuzzy AHP and GP integrated for supplier selection for a company that produces TFT-LCD screens. Liao and Kao [16] developed a supplier selection model by combining the Taguchi loss function, AHP and GP approaches. Darko et al. [5] used fuzzy AHP and MABAC methods in site selection for facilities related to warships. Sadeghpour et al. [22] conducted a descriptive survey. They compared 15 experts to decide and prioritize the factors on which they wanted to collect information through questionnaires. The results showed that the hierarchical validity and reliability of the research instruments were desired. Hamurcu and Eren [9] used integrated AHP and GP approaches for the selection of the monorail projects planned for Istanbul. Patel et al. [18] used the combined AHP-GP model based on the real-world problem, applied to maximize the agility of the supply chain of a manufacturing company situated in North India. Radovanovic et al. [19] build a decision support model based on the fuzzy AHP and the VIKOR methods when choosing the most efficient rectification procedure of the optical sight of the long-range rifle. Alosta et al. [3] solving an EMS centre's location selection problem using an integrated AHP-RAFSI approach. In addition, Ho [10] presented a literature survey study including 66 articles using AHP and AHP-integrated methods between 1997-2006 and concluded that the most popular technique among AHP-integrated methods was the AHP-GP technique with 16 articles.

In this study, the integrated AHP-GP model was used, which takes into account the opinions of experts in the field of the defence industry to make the decision to select the warehouse to be used in the project carried out in the defence industry. Within the scope of the study, first of all, theoretical research was carried out to determine the method to be used, and as a result of the literature research, it was decided to use AHP and GP integrated. Five criteria selected specifically for the project carried out in the defence industry sector were analyzed with AHP and then the best solution was obtained with GP.

3. Case study

The integrated method of AHP and GP helps the decision-maker to achieve the best result when there are multiple criteria and more than one decision-maker. Since sensitivity analysis can be used in this approach, it is preferred for choice problems between alternatives because one can observe how much the outcome changes when the objective is affected. As is seen in Figure 2, the usage rate has increased over the years. The steps to solve the problem are summarized in Figure 3.

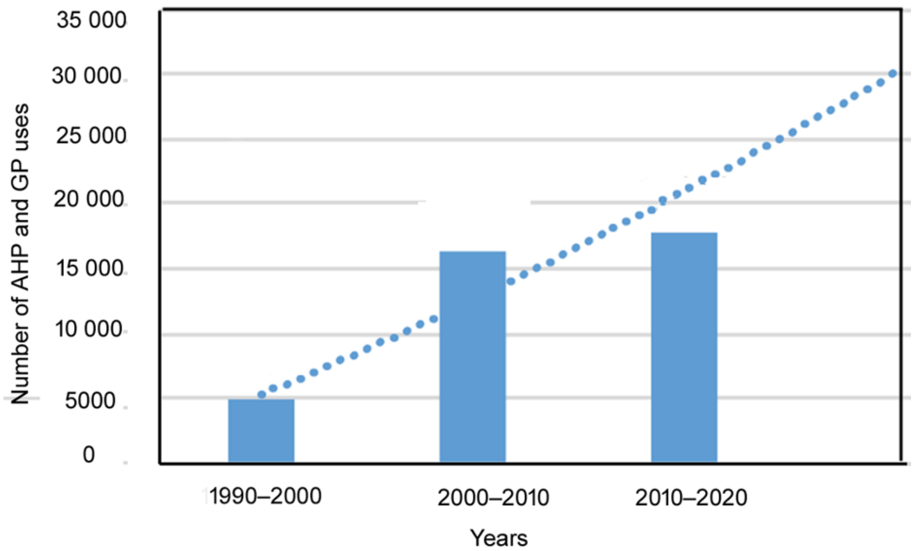

Figure 2. Usage of integrated AHP and GP method by years [1]

Below, the general mathematical model is presented and then, in line with the AHP's output, the GP model is given in the open form.

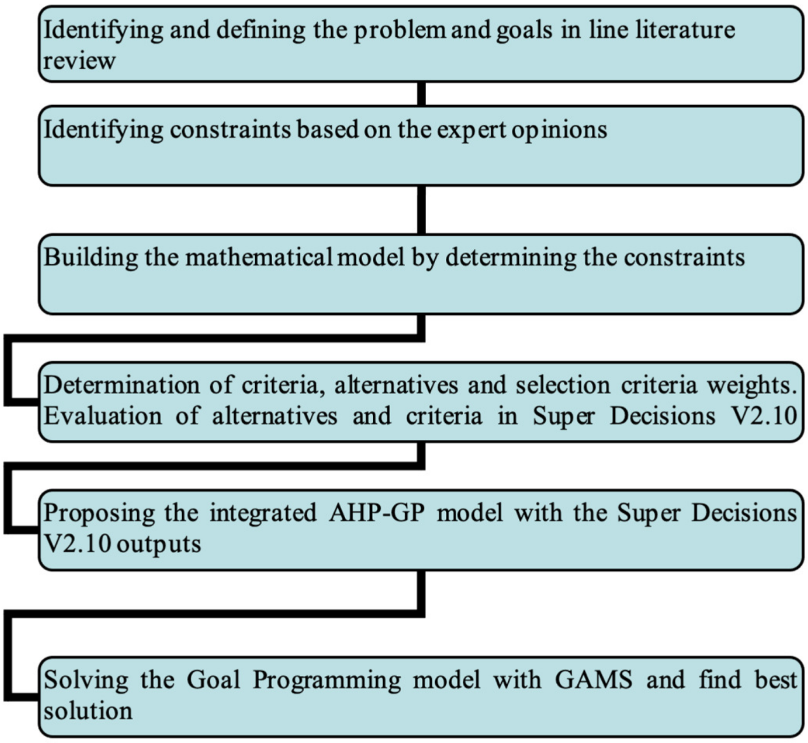

Figure 3. The steps to solve the problem

3.1. Model assumptions

- The company, which provides services in the defence industry, has a production facility in Ankara.
- There are 175 military vehicles to be manufactured and delivered to the user in accordance with a tender that the company has received.
- These military vehicles will be delivered to a total of seven military units.
- The warranty period for each vehicle is three years from the date of delivery of the vehicle. At the end of the three-year period, the company's responsibility for providing spare parts and intervention vehicles expires. After the expiration of the warranty period, the user may receive temporary service from the company with a maintenance and repair contract, if necessary.
- A warranty service centre (hereinafter referred to as warehouse) is installed to provide integrated logistic support service after the delivery of vehicles. Warehouses are intermediate stations that play a strategic role in responding to breakdowns in military installations.
- The warehouses in question: according to company policy, there will be a total of three, one in each region. The locations of the warehouses are specified in this study.
- According to the contract to which the company is subject, there is a condition to support within fifty hours in the event of any malfunction of a vehicle that it delivers to the military installations during the warranty period.
- If the user can use the warehouse space for free, the company will reduce warehouse costs (expenses for the storage space and transportation costs). User associations can open warehouse facilities. In this way, the response time to a malfunction is reduced.

- The coordinate information used in the study is indicated as an approximate location because it is military information and contains confidentiality. In the study, information about companies, organizations, military vehicles, etc. was not included in any way.

3.2. Notation

Decision variables

$$x_{ij} = \begin{cases} 1, & \text{if there is logistic sup port from } i \text{ to } j \\ 0, & \text{otherwise} \end{cases}$$

Parameters

i – alternative warehouse points
j – military installations
d_{ij} – distance from i to j, km
r_{ij} – risk coefficient of i to j
t_{ij} – support time from i to j, min
c_{ij} – transportation cost from i to j, TL
m_i – cost of installing the ith warehouse, TL
k – AHP criteria
P_k – AHP importance value of the kth criterion
D – maximum desired distance to Ankara, km
R – risk coefficient
T – desired max response time, min
S – desired maximum transportation cost, TL
F – desired maximum warehouse installation cost, TL
d_1^+ – positive deviation from the distance to Ankara
d_1^- – negative deviation from the distance to Ankara
d_2^+ – positive deviation from the risk coefficient $(i = 1, \ldots, 9)$
d_2^- – negative deviation from the risk coefficient $(i = 1, \ldots, 9)$
d_3^+ – positive deviation from the response time
d_3^- – negative deviation from the response time
d_4^+ – positive deviation from the transportation cost
d_4^- – negative deviation from the transportation cost
d_5^+ – positive deviation from the warehouse installation costs
d_5^- – negative deviation from the warehouse installation costs
TL – Turkish lira

General goal programming model

$$\min Z = P_1 d_1^+ + P_2(d_{21}^+ + d_{22}^+ + d_{23}^+ + d_{24}^+ + d_{25}^+ + d_{26}^+ + d_{27}^+ + d_{28}^+ + d_{29}^+) + P_3 d_3^+ + P_4 d_4^+ + P_5 d_5^+ \quad (1)$$

$$\sum_{i=1}^{9} d_{i10} x_{i10} - d_1^+ + d_1^- = D \quad (2)$$

$$\sum_{i=1}^{9}\sum_{j=1}^{9} r_{ii}x_{ij} - d_{2i}^{+} + d_{2i}^{-} = R \tag{3}$$

$$\sum_{i=1}^{9}\sum_{j=1}^{9} t_{ii}x_{ij} - d_{3}^{+} + d_{3}^{-} = T \tag{4}$$

$$\sum_{i=1}^{9}\sum_{j=1}^{9} c_{ii}x_{ij} - d_{4}^{+} + d_{4}^{-} = S \tag{5}$$

$$\sum_{i=1}^{9}\sum_{j=1}^{9} m_{ii}x_{ij} - d_{5}^{+} + d_{5}^{-} = F \tag{6}$$

$$\sum_{i=1}^{4}\sum_{j=1}^{9} x_{ij} = 1 \tag{7}$$

$$\sum_{i=5}^{9}\sum_{j=1}^{9} x_{ij} = 1 \tag{8}$$

$$x_{99} = 1 \tag{9}$$

$$x_{ij} = 0 \quad \text{or} \quad 1 \quad i,j = 1, 2, \ldots, 9 \tag{10}$$

Equation (1) minimizes logistics support cost with minimum deviation. Equation (2) provides that distance to Ankara is less than the equal desired distance with minimum deviation. Equation (3) ensures that all alternative warehouse points' risk coefficient is less than the equal desired coefficient with minimum deviation. Equation (4) assumes that support time is less than the equal desired time. Equation (5) aims for minimum deviation from desired transportation cost. Equation (6) provides minimum deviation from desired installation cost. Equation (7) assumes installing only one warehouse in Marmara Region. Equation (8) ensures installing only one warehouse Southeastern in Anatolia Region. Finally, Equation (9) provides only one warehouse in Cyprus. Finally, equation (10) shows the binary values for a decision variable.

4. Performing the integrated AHP-GP and analyzing the results

The weights of the selection criteria are determined based on the expert opinions to specify the AHP outputs, the alternatives and criteria are evaluated in the Super Decisions V2.10 program. Then, the GAMS (General Algebraic Modeling System) output of the GP model is obtained [2].

This study discusses the problem of location selection of warehouses that will support military vehicle breakdowns at military installations in various geographic locations. The problem is to select the best location for the warehouse among the alternatives. The criteria weights to be found with the AHP are integrated into the GP and the warehouse at the best location is found. This warehouse is to serve seven military installations with minimal deviation from the goals. The approximate locations of the military installations to which the vehicles are to be delivered are shown in Figure 4 by marking them with different colors on a regional basis.

Figure 4. Vehicle delivery points map

The number of vehicles delivered to the regions and the regions' cities are summarized in Table 1.

Table 1. Distribution of the number of vehicles by regions

City	Region	The number of vehicles
Edirne, Kırklareli, Tekirdağ, Istanbul	Marmara	69
Mardin, Şırnak	Eastern Anatolia	76
Cyprus	Cyprus	30
Total number of vehicles		175

The number of military vehicles to be delivered for each city can be found in Table 2.

Table 2. The number of military vehicles for each city

City	Edirne	Kırklareli	Tekirdağ	Istanbul	Mardin	Şırnak	Cyprus
No. of vehicles	12	24	30	3	4	72	30

4.1. Application of AHP to the problem

Some basic steps of the AHP method are as follows.

- The problem is defined.
- The criteria and alternatives are established.

- The hierarchical structure is created.
- A pairwise comparison matrix is created.
- The priority vector matrix is created by determining the priority vectors.
- Consistency calculation is performed.
- The ranking is created based on the superiority values between the criteria or alternatives.

The following stage is the application of the AHP to the problem [21].

Determination of criteria. There are many criteria in the selection of warehouse location but in this problem, the criteria, which were determined as the most important (5 criteria) based on past project experiences, were discussed by the project team members. They are experts in the field of the defence industry, with at least 5 years of industry experience, senior managers, and military personnel. As a result of the evaluation made with the decision-makers consisting of the staff and consultants in the project management group, which consists of the project executive government authority, the company and the user personnel, 5 criteria were determined:

- criterion 1 (C1) – distance to Ankara,
- criterion 2 (C2) – risk coefficient,
- criterion 3 (C3) – support time,
- criterion 4 (C4) – transportation cost,
- criterion 5 (C5) – installation cost.

Comparison of criteria. The criteria comparison matrix, A, is given in Table 3. It is formed by taking the geometric mean of the data collected as a result of the brainstorming of the project team members, consisting of senior managers and military personnel, who are experts in the field of the defence industry, with at least 5 years of industry experience.

Table 3. Criteria comparison matrix A

Criterion	C1	C2	C3	C4	C5
C1	1.0000	0.7937	0.1529	0.2321	0.2752
C2	1.2599	1.0000	0.1812	0.2924	0.2554
C3	6.5421	5.5178	1.0000	3.5569	6.4633
C4	4.3089	3.4200	0.2811	1.0000	3.5569
C5	3.6342	3.9149	0.1547	0.2811	1.0000

Normalization of the comparison matrix. In the pairwise comparisons matrix of the criteria created, each cell value is divided by the sum of the column values it is in, and the proportional values of the criteria in Table 4 are found.

Table 4. Normalized matrix

Criterion	C1	C2	C3	C4	C5
C1	0.0597	0.0542	0.0864	0.0433	0.0238
C2	0.0752	0.0683	0.1024	0.0545	0.0221
C3	0.3907	0.3767	0.5650	0.6633	0.5596
C4	0.2573	0.2335	0.1588	0.1865	0.3079
C5	0.2170	0.2673	0.0874	0.0524	0.0866

Criterion weight. The weight values of the criteria calculated from the average of each row are shown in Table 5.

Table 5. Criterion weight

Criterion	C1	C2	C3	C4	C5
Criterion weight (W_i)	0.0535	0.0645	0.5111	0.2288	0.1421

Calculation of consistency. In this step, the pairwise comparison matrix of the criteria given in Table 4 and the values calculated in Table 5 are multiplied as a matrix and the resulting column vector is divided by the weighting values in Table 5 and the value $(A \times W)/W$ is calculated. $(A \times W)/W$ matrix is shown Table 6.

Table 6. $(A \times W)/W$ matrix

Criterion	C1	C2	C3	C4	C5
$(A \times W)/W$	5.1429	5.0801	5.7714	5.8088	5.1526

$$CI = \frac{\lambda - n}{n - 1} \tag{11}$$

Equation (11) formulates the consistency index. n in the formula stands for the number of criteria, and λ is the arithmetic mean of the elements of the $(A \times W)/W$ matrix.

$CI = ((5.3911) - 5)/4 = 0.0977$ was calculated as.

Table 7. Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Since the number of criteria in the problem is 5, the RI value is taken as = 1.12 according to Table 7 which is adapted from Saaty [16]. The consistency ratio (CR) is obtained by dividing the consistency indicator (CI) by the random index (RI), CR = 0.0872. A value less than 0.1 means that the result is consistent. The results of super decisions can be seen in Figures 5 and 6 and gave the same result as the Excel solution. The high weights found indicate that it should be in the top rank in the election [2].

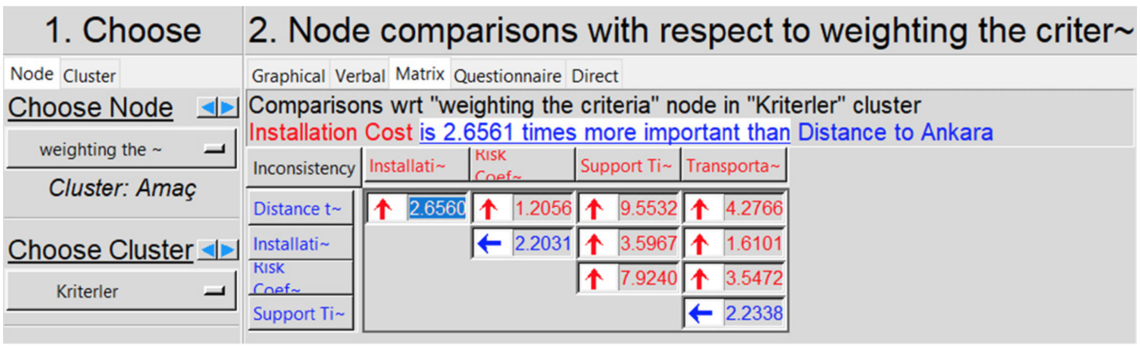

Figure 5. Super decisions weight values

The high level of sustainability of the vehicles during the warranty period, low warranty support costs and minimum support time depend entirely on the fastest and most effective repair of military vehicles.

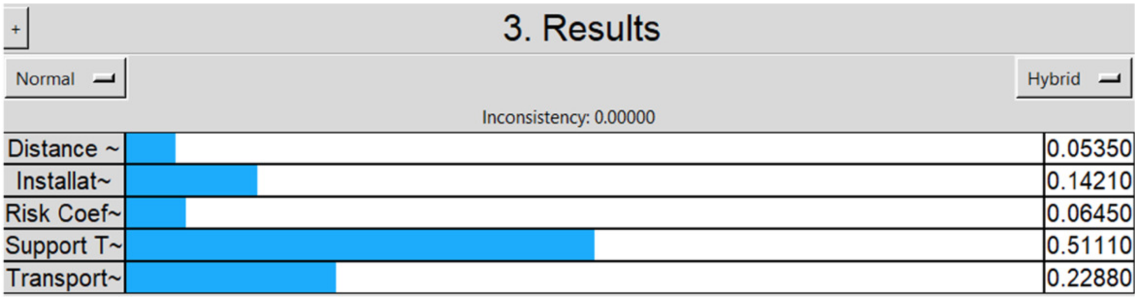

Figure 6. Super decisions criteria weight ranking

For this reason, it is an expected result that Criterion 3 (support time) is determined as the most important criterion.

4.2. Open form of the GP model

Given all this information, the given mathematical model is explained below in open form in line with the AHP outputs. The formulation of the GP model based on minimizing objective function deviations using AHP outputs is presented in (12).

$$\begin{aligned} \min Z = & 0.05d_1^+ + 0.06\,(d_{21}^+ + d_{22}^+ + d_{23}^+ + d_{24}^+ + d_{25}^+ \\ & + d_{26}^+ + d_{27}^+ + d_{28}^+ + d_{29}^+) + 0.51d_3^+ + 0.22d_4^+ + 0.14d_5^+ \end{aligned} \tag{12}$$

To find the deviations (d_i) in the formula, the GP constraints are included in the next step.

Distance constraint to Ankara. The company's production facility is located in Ankara. The total distance to Ankara must be less than 4800 km. This condition is shown as a formulation

$$\sum_{i=1}^{9} d_{i10}x_{i10} \leq 4800 \tag{13}$$

Risk coefficient constraint. The risk coefficients of the warehouse locations were determined by the project team considering the geographic location, distance from the military installation, and the security situation of the city in the study conducted with the project team, as shown in Table 8.

Table 8. Risk coefficient matrix

City	Edirne	Kırklareli	Tekirdağ	Istanbul	Mardin	Şırnak	Cyprus	Siirt	Batman
RI	1.5	1.5	1	1	3	4	1	2	2

Formulation of the constraints for the risk coefficients determined by the project team bare as follows:

$$\sum_{j=1}^{9} r_{1j}x_{1j} \leq 1.5 \tag{14}$$

$$\sum_{j=1}^{9} r_{2j}x_{2j} \leq 1.5 \tag{15}$$

$$\sum_{j=1}^{9} r_{3j}x_{3j} \leq 1 \tag{16}$$

$$\sum_{j=1}^{9} r_{4j}x_{4j} \leq 1 \tag{17}$$

$$\sum_{j=1}^{9} r_{5j}x_{5j} \leq 3 \tag{18}$$

$$\sum_{j=1}^{9} r_{6j}x_{6j} \leq 4 \tag{19}$$

$$\sum_{j=1}^{9} r_{7j}x_{7j} \leq 2 \tag{20}$$

$$\sum_{j=1}^{9} r_{8j}x_{8j} \leq 2 \tag{21}$$

$$\sum_{j=1}^{9} r_{9j}x_{9j} \leq 1 \tag{22}$$

Response time constraint. Constraint that the response time to the military installation responsible for vehicles travelling at 55 km/h from alternate warehouse points is less than 3000 min:

$$\sum_{i=1}^{9}\sum_{j=1}^{9} t_{i_j}x_{ij} \leq 3000 \tag{23}$$

Transportation cost constraint. Limiting transportation costs to less than 250 000 TL is

$$\sum_{i=1}^{9}\sum_{j=1}^{9} c_{i_j}x_{ij} \leq 250\,000 \tag{24}$$

Warehouse installation cost constraint. The cost of installation of the warehouse depends on the number of personnel to be sent, which depends on the number of vehicles to be delivered to each military installation. It has been determined as 500 000 TL for Cyprus, 1 500 000 TL for Edirne and Mardin, other cities 1 000 000 TL. Formulation of the constraint that the cost of installation of a warehouse is less than 3 000 000 TL is included in

$$1\,000\,000(1.5x_{11} + x_{22} + x_{33} + x_{44} + 1.5x_{55} + x_{66} + x_{77} + x_{88} + 0.5x_{99}) \leq 3000000 \tag{25}$$

Constraint of installation of a warehouse in each region. The cities of the Marmara Region and the Southeastern Anatolia Region are listed in Tables (9) and (10), respectively.

The equations to be used for the installation of a warehouse in each region according to the company's policy can be found in the following equations

Table 9. Marmara Region cities

City	Edirne	Kırklareli	Tekirdağ	Istanbul
i_n	i_1	i_2	i_3	i_4

Table 10. Cities of Southeastern Anatolia Region

City	Mardin	Şırnak	Siirt	Batman
i_n	i_1	i_2	i_3	i_4

$$\sum_{i=1}^{4}\sum_{j=1}^{9} x_{ij} = 1 \tag{26}$$

$$\sum_{i=5}^{9}\sum_{j=1}^{9} x_{ij} = 1 \tag{27}$$

Constraints (28)–(35) are used to ensure (26).

$$x_{11} \leq M\,(1 - y_1) \tag{28}$$

$$x_{22} + x_{33} + x_{44} \leq M y_1 \tag{29}$$

$$x_{22} \leq M\,(1 - y_2) \tag{30}$$

$$x_{11} + x_{33} + x_{44} \leq M y_2 \tag{31}$$

$$x_{33} \leq M\,(1 - y_3) \tag{32}$$

$$x_{11} + x_{22} + x_{44} \leq M y_3 \tag{33}$$

$$x_{44} \leq M\,(1 - y_4) \tag{34}$$

$$x_{11} + x_{22} + x_{33} \leq M y_4 \tag{35}$$

M is a very big number and y_i is zero-one variable.
Constraints (36)–(43) are used to ensure (27).

$$x_{55} \leq M\,(1 - y_5) \tag{36}$$

$$x_{66} + x_{77} + x_{88} \leq M y_5 \tag{37}$$

$$x_{66} \leq M\left(1 - y_6\right) \tag{38}$$

$$x_{55} + x_{77} + x_{88} \leq M y_6 \tag{39}$$

$$x_{77} \leq M\left(1 - y_7\right) \tag{40}$$

$$x_{55} + x_{66} + x_{88} \leq M y_7 \tag{41}$$

$$x_{88} \leq M\left(1 - y_8\right) \tag{42}$$

$$x_{55} + x_{66} + x_{77} \leq M y_8 \tag{43}$$

M is a very big number and y_i is zero-one variable.

$$x_{99} = 1 \tag{44}$$

Equation (44) is used for the installation of a separate warehouse in Cyprus.

4.3. Solution of the integrated AHP-GP model

The GP model was solved using GAMS which is a mathematical modelling language designed particularly for formulating and solving a wide variety of optimization problems, including linear programming, nonlinear programming, and integer programming. In solving the integrated AHP-GP model with GAMS, it has been concluded that it is necessary to assign 3 points (these shown in Table 12) that provide the best results among the alternative warehouse points at 9 different geographical locations. Information about this location is shown in Table 11.

Table 11. Information about the assignment of the cities

City	Edirne	Kırklareli	Tekirdağ	Istanbul	Mardin	Şırnak	Siirt	Batman	Cyprus	Ankara
x_i	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}

x_{10} is not an alternative but is defined only for the distance constraint to Ankara. x_7 (Batman) and x_8 (Siirt) are not delivered vehicles and have been defined as alternative warehouse locations that may affect x_5 and x_6 in terms of safety and proximity.

As a result, it was evaluated that the installation of warehouses in Kırklareli, Şırnak and Cyprus (summarized in Table 12) is the best result and the company should make this choice with minimum deviation from its goals.

4.4. Sensitivity analysis

During this phase, two different analyzes were conducted for the sensitivity analysis. Firstly, the effect of the change of criterion weights, obtained in AHP, which are used as an input of the GP model is

Table 12. Summary assignment table

Assigned city	Cities to be supported	Description
	x_{21}	support from Kırklareli to Edirne
x_2	x_{22}	install a warehouse in Kırklareli
Kırklareli	x_{23}	support from Kırklareli to Tekirdağ
	x_{24}	support from Kırklareli to Istanbul
	x_{65}	support from Şırnak to Mardin
x_6	x_{66}	install a warehouse in Şırnak
Şırnak	x_{67}	Siirt (not considered because it is only an alternative)
	x_{68}	Batman (not considered because it is only an alternative)
x_9	x_{99}	supporting only vehicles in Cyprus
Cyprus		by install a warehouse in Cyprus

examined. Secondly, the effect of the change of the right-side value of the criterion with the highest importance (support time) on the GP model was examined.

4.4.1. Changing criterion weights

In this phase, the sensitivity of the applied mathematical model was examined, in order for the decision-maker to receive confirmation of the rationality and quality of the obtained solution, that is to determine how changes in the significance of criteria lead to changes in the ranks of alternatives [19]. The analysis for changing criterion weights is shown in Table 14, which is formed by taking the geometric average of the data collected as a result of the brainstorming of the project team members, consisting of senior managers and military personnel, who are experts in the field of the defence industry, with at least 5 years of industry experience. The proportional value matrix of changing criteria is shown in Table 13.

Table 13. Normalized matrix for sensitivity analysis

Criterion	C1	C2	C3	C4	C5
C1	0.0708	0.0606	0.0885	0.0559	0.0309
C2	0.2037	0.1742	0.2260	0.1188	0.0652
C3	0.3897	0.3754	0.4869	0.6269	0.3899
C4	0.2286	0.2646	0.1401	0.1804	0.4671
C5	0.1072	0.1253	0.0585	0.0181	0.0469

Table 14. Changing criterion weights

Criterion	C1	C2	C3	C4	C5
Criterion weight (W_i)	0.0309	0.0652	0.3899	0.4671	0.0469

When the GAMS model was run as a result of the sensitivity analysis with changed criterion weights, it was evaluated that the installation of warehouses in Istanbul, Batman and Cyprus (Table 15) is the best result and the company should make this choice with minimum deviation from its goals.

4.4.2. Changing right side value of the most important criteria

According to the contract, support time which is the most important criterion, is less than 3000 min, as was shown in equation (23). If this time was less than 4500 min shown in equation (45), the city information would be as follows

Table 15. Summary assignment table after changing significance of criteria

Assigned city	Cities to be supported	Description
x_4 Istanbul	x_{41}	support from Istanbul to Edirne
	x_{42}	support from Istanbul to Kırklareli
	x_{43}	support from Istanbul to Tekirdağ
	x_{44}	install a warehouse in Istanbul
x_8 Batman	x_{85}	support from Batman to Mardin
	x_{86}	support from Batman to Şırnak
	x_{87}	Siirt (it is only an alternative)
	x_{88}	Batman (it is only an alternative)
x_9 Cyprus	x_{99}	supporting only vehicles in Cyprus by install a warehouse in Cyprus

$$\sum_{i=1}^{9}\sum_{j=1}^{9} t_{i_j} x_{ij} = 4500 \tag{45}$$

Table 16. Summary assignment table after changing right side value of most important criteria

Assigned city	Cities to be supported	Description
x_4 Istanbul	x_{41}	support from Istanbul to Edirne
	x_{42}	support from Istanbul to Kırklareli
	x_{43}	support from Istanbul to Tekirdağ
	x_{44}	install a warehouse in Istanbul
x_8 Batman	x_{85}	support from Batman to Mardin
	x_{86}	support from Batman to Şırnak
	x_{87}	Siirt (it is only an alternative)
	x_{88}	Batman (it is only an alternative)
x_9 Cyprus	x_{99}	supporting only vehicles in Cyprus by install a warehouse in Cyprus

When the GAMS model is run as a result of the sensitivity analysis with changing response time constraints shows that; the installation of warehouses in Istanbul, Batman and Cyprus (Table 16) is the best result and the company should make this choice with minimum deviation from its goals. In the case of a 50% increase in response time, the optimal assignment warehouse points change.

5. Conclusion

In today's cost-efficient environment, profitability is improved thanks to warehouses with increased flexibility, a simplified supply chain with cost management, and optimal positioning according to intervention points instead of bulky warehouse concepts. For this reason, this study was conducted to make an effective decision and increase profitability in a real problem of projects signed in the defence industry.

The purpose of this study was to develop a solution for the selection of warehouse locations for the defence industry company and to select the best warehouse/s based on this proposed solution. Five criteria, specifically selected for the defence industry project, were analyzed using AHP and then the best solution was determined using the GP.

Evaluated using AHP: as a result of comparing and ranking the weights of distance to Ankara, risk coefficient, response time, transportation cost, and establishment cost criteria; support time was determined as the most important criterion. The effective use of the systems/subsystems/components included in the inventory in the defence industry projects is ensured only to the extent of their sustainability. The highest level of sustainability during the warranty period also depends on the company intervening in the product in the inventory as soon as possible and eliminating the malfunction as quickly and effectively as possible. In accordance with all this information, it is expected result that the criterion of support time is determined as the most important criterion. On the other hand, the criterion of transportation cost ranks second in importance. Since the defence industry is a sector that has recently gained importance, more efficient use of national resources is important for both the project implementing company and the government agency. In addition, transportation costs are associated with disadvantages, such as traffic, loss of labour, and carbon emissions. The installation cost criterion ranks third and is followed by the risk factor. Finally, distance to Ankara is ranked as the lowest criterion.

Apart from the cities where the vehicle is to be delivered, Siirt and Batman in the Southeastern Anatolia Region were selected as alternatives because they are close to the provinces to be delivered in this region and are more advantageous in terms of security. In accordance with the company's business rules, the conditions for delivery in each region, the distance information, the risk analysis study, and the distance to Ankara, the central facility, were used as inputs for GP. GP constraints have been solved using GAMS and it was determined that opening warehouses in Kırklareli, Şırnak, and the Turkish Republic of Northern Cyprus (Cyprus) is the best result and that the company should make this choice with the least deviation from its goals. In addition, with the help of sensitivity analysis, the effects of change in criterion weights and increase in a certain amount in response time, as a most important criterion, were also observed in the overall decision.

As a result, while we found an optimal solution to a real-life problem, we also proposed a solution strategy that will be a basis for further projects in the defence industry.

Standard warehouse size and standard warehouse opening costs were used in this study. As further directions, a solution with variable warehouse size and thus variable costs, etc., with a different number of vehicles and the province's conditions to be opened can be considered. Besides, other MCDM techniques can be used alternatively for future studies.

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