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# Facility Location Selection for Ammunition Depots based on GIS and Pythagorean Fuzzy WASPAS

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**ABSTRACT**

The purpose of this study is to determine depot locations where expired ammunition will be controlled before being sent to recycling facilities. Expiration of ammunition means that using, transporting, and even storing that ammunition where it is located poses a greater risk. For this reason, it is important to determine facility locations so that ammunition is stored in places that will cause the least harm to the environment and human health. The criteria to be used for ammunition depot location selection were determined through literature review, various research, and expert opinions. The proposed model is based on the combined use of Geographic Information System (GIS) and multi-criteria decision making. For an example application of the model, a generic study on a district basis in Turkey is presented. Candidate depot locations were determined using GIS with the help of six main criteria and 18 sub-criteria. Then, candidate depot locations were ranked by the Pythagorean fuzzy set-based WASPAS (Weighted Aggregated Sum Product Assessment) method, taking into account the opinions of military experts for the main criteria. The WASPAS method selected location A1 as the most suitable ammunition depot location. The results show that the proposed methodology can be practically applied.

## 1. Introduction

Facility location selection is defined as determining the facility locations and assigning demand locations to the determined points. It has become one of the most important decisions affecting the profitability of businesses and public institutions, especially with the increase in transportation and transportation costs. In the distribution network design, answers are sought to many issues such as the location of the facilities (such as factories, supply centers and depotss), serving of products or services to demand points, production location, production or stock amount. Facility Location Selection (FLS) aims to increase profits, reduce costs, save personnel and time, meet customer demands as soon as possible by shortening delivery times, increase the number of

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customers, and increase buyer satisfaction and it is one of the strategic decisions that are difficult to reverse. In order to make the best decision in FLS, the knowledge and experience must be supported by analytical methods.

Studies are being carried out on issues such as placing some desired facilities in FLS problems such as hospitals, depotss and markets on a network, and distributing services and products to minimize distances in line with the desired criteria. However, FLS decisions are not limited to these only. Unlike other problem models, it has created a new field of study called harmful/undesirable facility layout in applications such as establishing waste cleaning facilities and hazardous materials depotss [1]. By spreading these types of facilities as far and wide as possible from residential areas, possible damages and impacts are tried to be minimized in case of an accident. In addition, it is desired to maximize the service provided [2-3].

Since the contents of hazardous materials pose a great risk to human health, unlike other materials, they must be transported, stored and packaged according to certain rules. These types of hazardous materials are sent to factories, depotss and customers that are kilometers away from suppliers in different locations around the world. Because of that it is important to establish depots in geographical locations where it is safe, the human population is low, the transportation networks are developed and the negative impact on the environment will be minimal.

It is critical that ammunition, which has strategic importance during wartime, is destroyed during peacetime when its useful life expires, without harming the environment and people. If a conflict does not occur or does not occur with the expected intensity, the stored ammunition expires. The end of the life of ammunition means that using, transporting and even storing that ammunition where it is located poses a greater risk. Ammunition accidents are rare, but the destruction, personnel casualties, and damage to the environment and civilian environment caused by these accidents are great. When the causes of accidents are considered, approximately 50% of them occur in shooting and operation activities, while the remaining 50% are caused by activities such as depots and transportation [4,5]. Aged and worn out ammunition plays an important role in accidents that occur specifically in these activities.

In this study, the FLS problem in which expired ammunition is stored is addressed in three stages. In the first stage, the aim is to determine candidate depots locations according to various criteria, which will keep the risk of accidents to a minimum, the number of people who will be negatively affected in the event of an accident, and the negative environmental impact of the explosion. Candidate depot location selection criteria for ammunition depots were determined by military experts, taking into account the depots location selection criteria determined in the literature and especially the hazardous material depots selection criteria. These criteria, which were considered suitable for ammunition depot location selection, were analyzed with the Geographic Information System (GIS) and candidate depot locations were found in the second stage. In the third stage, candidate depots locations were ranked with the Pythagorean Fuzzy Set based WASPAS (Weighted Aggregated Sum Product Assessment) method in line with the opinions of military experts.

The rest of the paper is organized as follows. In the Section 2 of the study, extensive literature research was shared. In the Section 3, Pythagorean Fuzzy Sets and WASPAS are presented. Section 4 includes the analysis results of the applied methods. Finally, results and comments are given in the Section 5.

## 2. Related Literature

The FLS problem, which involves many factors at the same time, has been discussed from different perspectives in the literature. These aspects were examined under two different groups:

studies on determining the criteria for determining candidate places and studies on choosing among candidate points in the literature review.

The first group is the studies on the criteria considered when determining candidate facility locations in FLS problems [6-10]. FLS problems are considered in two categories, single or multi-criteria. In single-criteria residental problems, the criterion based on the solution is usually "scope" or "cost" [11]. The goal is to reduce cost or increase the amount of space covered, demand point or customer. The most common criteria for dual or multi-objective problems are expressed as “profit”, “scope”, “cost” or “service level and effectiveness”, “environmental risks” and “equity” [12]. The criteria used in settlement problems in the study conducted by Farahani and Hekmatfar [13] are grouped under the headings "Accessibility to public facilities and resources", "Cost and economy", "Population density", "Value and benefits", "Competition and capacity", "Environmental risks" and "Distance and suitability" in the literature on FLS criteria related to multi-criteria placement problems. When studies in the literature covering the specified criteria are examined, cost (Land, Rent, Transportation, Installation, Investment, Operation, Maintenance) [14-15], value and benefits (Product and Land Value, Income) [16], natural and environmental risks (Climate, Weather, Disaster, Health, Traffic, Pollution and Waste Collection) [14], accessibility to resources and utilization of facilities [17], population density [18], physical characteristics of the depots [19], accessibility to public facilities (Airway, Highway, Railway, Accommodation Facilities, Parks and Recreation Areas) [17] criteria are considered as criteria affecting FLS.

The second stage of the literature review was conducted on FLS studies of hazardous substances with the integration of GIS and MCDM. The literature summary of the studies is presented in Table 1.

**Table 1**
Literature Summary for Hazardous Material Facility Location Selection using GIS and MCDM

| Year | References | Sector | Methods | Year | References | Sector | Methods |
|---|---|---|---|---|---|---|---|
| 2016 | [20] | Ammunition | DEMATEL-ANP, MAIRCA | 2021 | [27] | Waste | ANP |
| 2018 | [21] | Ammunition | Mathematical Modelling, AHP | 2021 | [28] | Waste | AHP-TOPSIS |
| 2019 | [22] | Waste | DEMATEL-FANP | 2022 | [29] | Energy | AHP-TOPSIS |
| 2019 | [23] | Ammunition | AHP-TOPSIS | 2022 | [30] | Waste | SWARA-WASPAS |
| 2020 | [24] | Fire | FAHP | 2023 | [31] | Waste | FAHP-FMULTIMOORA |
| 2020 | [25] | Waste | FAHP | 2023 | [32] | Energy | FAHP-CRITIC-VIKOR |
| 2021 | [26] | Fire | BWM | 2023 | [33] | Waste | AHP-SAW |

Additionally, the WASPAS method is used for ranking in different studies [34-39].

## 3. Methodology

### *3.1 Pythagorean Fuzzy Sets*

Pythagorean fuzzy sets (PFS) were developed by Yager and Abbasov [40] as an extension of the Intuitionistic fuzzy sets (IFS). PFSs are characterized by the degree of membership and non-membership. In PFSs unlike IFSs, the sum of the two membership degrees can be less or more than 1, however, the sum of the squares of two degrees has to be ≤ 1 [41]. PFSs are defined as follows [42]:

Let X be a non-empty set. A PFS P̂ in X is defined by:

$$\hat{P} = \{(x, a_{\hat{P}}(x), \beta_{\hat{P}}(x)) | x \in X\} \quad (1)$$

Where $a_{\hat{P}}, \beta_{\hat{P}}: \rightarrow [0,1]$ represent the degree of membership and nonmembership of the element $x \in X$ to the set $\hat{P}$, respectively. PFS in X must satisfy the condition as:

$$0 \leq \left(a_{\hat{P}}(x)\right)^2 + \left(\beta_{\hat{P}}(x)\right)^2 \leq 1 \quad (2)$$

With the degree of hesitancy given by:

$$\gamma_{\hat{P}}(x) = \sqrt{1 - \left(a_{\hat{P}}(x)\right)^2 + \left(\beta_{\hat{P}}(x)\right)^2} \quad (3)$$

where $\gamma_{\hat{P}}(x)$ denotes the degree of hesitancy.

Let $\hat{S}_1 = \langle a_{\widehat{S_1}}, \beta_{\widehat{S_1}} \rangle$ and $\hat{S}_2 = \langle a_{\widehat{S_2}}, \beta_{\widehat{S_2}} \rangle$ be two Pythagorean fuzzy numbers (PFNs). The basic arithmetic operations of these two PFNS are defined as follows:

$$\hat{S}_1 \otimes \hat{S}_2 = \left(\sqrt{a_{\widehat{S_1}}^2 + a_{\widehat{S_2}}^2 - a_{\widehat{S_1}}^2\, a_{\widehat{S_2}}^2},\ \beta_{\widehat{S_1}}\beta_{\widehat{S_2}}\right) \quad (4)$$

$$\hat{S}_1 \otimes \hat{S}_2 = \ a_{\widehat{S_1}}a_{\widehat{S_2}}, \sqrt{\beta_{\widehat{S_1}}^2 + \beta_{\widehat{S_2}}^2 - \beta_{\widehat{S_1}}^2\, \beta_{\widehat{S_2}}^2} \quad (5)$$

$$\omega\hat{S} = \left(\sqrt{1 - \left(1 - a_{\hat{S}}^2\right)^{\omega}}, \beta_{\hat{S}}^{\omega}\right), \omega > 0 \quad (6)$$

$$\hat{S}^{\omega} = \left(a_{\hat{S}}^{\omega}, \sqrt{1 - \left(1 - \beta_{\hat{S}}^2\right)^{\omega}}\right), \omega > 0 \quad (7)$$

*3.2 WASPAS*

WASPAS (Weighted Aggregated Sum Product Asessment) technique is a combination of methods called WSM (Weighted Sum Model) ve WPM (Weighted Product Model). The method was introduced to the literature in 2012 by Zavadskas et al. [43]. The strength of the method is that the application process is short and easy, and it does not require specific computer programming to perform the calculations. The steps of the method are as follows [44-45]:

Step 1: Creating the decision matrix

The decision matrix (x) is created as Eq.(8) by determining the alternatives and criteria.

$$X = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} i = 1,2,\dots,m\ j = 1,2,\dots,n \quad (8)$$

Step 2: Weighting of criteria

Step 3: Defuzzification and normalization of the decision matrix

Eq.(9) and (10) are used for normalization separately for the benefit and cost criteria.

$$For\ benefit\ criteria: x_{ij}^{*} = \frac{x_{ij}}{maksx_{ij}} \quad (9)$$

$$For\ cost\ criteria: x_{ij}^{*} = \frac{minx_{ij}}{x_{ij}} \quad (10)$$

Step 4: Calculation of total relative importance

The total relative importance according to WSM is given in Eq.(11), and the total relative importance according to WPM is given in Eq.(12).

According to WSM, total relative importance of the i. alternative:

$$\left(Q_i^{(1)}\right) = \sum_{j=1}^{n} x_{ij}^{*}\, w_j \quad (11)$$

According to WPM, total relative importance of the i. alternative:

$$\left((Q)_i^{(2)}\right) = \prod_{j=1}^{n} x_{ij}^{*w_j} \quad (12)$$

Step 5: Calculation and ranking of the combined optimal value ($Q_i$)
The calculation of the combined optimal value is given in Eq. (13).

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)} \tag{13}$$

$\lambda$: the combined optimality coefficient is generally 0,5 ve $0 \leq \lambda \leq 1$.
If $\lambda = 0$, WASPAS method turns into WPM,
If $\lambda = 1$, WASPAS method turns into WSM.
In terms of ranking, the alternative with the largest $Q_i$ values is selected as the best alternative.

## 4. Application

### *4.1. Determining candidate depot locations with GIS*

GIS is widely used when making decisions such as where facilities, supply points, depotss and base areas should be established [23, 46-49]. GIS is an important tool used in creating a decision support system with its ability to evaluate spatial and non-spatial data together. Decision analyzes created with GIS enable the rapid and effective evaluation of complex data (mathematical and statistical) compared to other methods [50]. First of all, the FLS criteria discussed in the literature and the factors that should be taken into consideration for dangerous substance FDL were examined. The criteria for ammunition depot selection will be determined by consider the opinions of military experts among the determined criteria. According to these criteria, positional analyzes were made in GIS and candidate places were determined.

Chou et al. [12] has been classified under three headings: important and critical (presence of public services, public attitude, land suitability, etc.), objective (investment and labor costs, land value, etc.), subjective (proximity to the market, political risk, ease of transportation, proximity to schools, etc.). Akyol [51] emphasized that some characteristics were sought in the location selection of military depots, that the location to be selected should support the operation, be at a central distance from the supported troops, be established as far ahead and on the main road as possible, and that heavy tonnage supply depots should be placed on railway routes. To determine the location selection criteria for ammunition depots; It was observed that main criteria such as "military criteria", "capacity criteria" and "environmental criteria" were used. In the study of Altuntaş [52] increased the scope of these criteria as a result of survey studies and expert opinions and stated that 86 sub-criteria were determined under 6 main criteria by examining the studies in the literature. Locating the ammunition depots are is a very complex decision-making process that includes criteria based on military, logistics, natural, environmental, social, economic and capacity issues expressed in the study. However, since many of the 86 criteria are within the scope of civilian FLS, considering the opinions of military experts, not all of these criteria are applicable to ammunition depots. In this study, 86 criteria were reduced to 18 criteria that will affect the FLS for ammunition. Table 2 shows the main and sub-criteria to be used in GIS analyses.

**Table 2**
Selection criteria of ammunition depot

| Criteria | Subcriteria | References |
|---|---|---|
| Military | Proximity to the place of duty/region, Terrorist zones in the region, Distance to the border line, Proximity to the troops on duty | [14,15,17,18, 53] |
| Capacity | Area/size (m2), proximity of depotss to demand areas | [17,54] |
| Economic | Presence of a military area in the region, transportation distance to operation/shooting areas and the units it will support | [14,15] |
| Natural and Environmental | Suitability of the land structure - suitability for hiding and natural obstacles, Distance from the possible disaster area and/or earthquake line, Positive/negative impact on the environment and natural life, Proximity/distance to water resources in the region, Suitability of the climatic conditions of the region for the depots location | [14,55] |

| Criteria | Subcriteria | References |
|---|---|---|
| Logistics | Traffic density - proximity to the highway (main transportation) network, Proximity to the railway station, Proximity to the sea and port | [16,17,53] |
| Social | Distance/proximity to city/district and settlement centers, Population density of the region (km2) | [18,53] |

The 18 specified criteria was examined in GIS within certain limit values in accordance with AASTP-1 in terms of storing and transporting ammunition and reducing possible negative effects on the environment. Some sample values are presented in Table 3. When these limit values and the analyzes for each criterion were combined as a whole, it was determined that the number of candidate places remained very low due to the limit values determined for some criteria. In addition, it was observed that candidate places were concentrated in certain regions due to some criteria. The criteria that cause this have been relaxed in accordance with AASTP-1 and lower and upper limits have been determined. Apart from this, if depots is to be done, the conditions under which it should be stored have been determined with the opinions of military experts, without going beyond the directive [56].

**Table 3**
Sample criteria values relaxed in GIS Analysis

| Criterion | Number of Fires | Population Density(km$^2$) | Distance to Border Line(≥) | Transportation Modes | | | Distance to Fault Line (≥) |
|---|---|---|---|---|---|---|---|
| | | | | Highway | Railway | Seaport (≤) | |
| Start | 200 | 200 | 100 km | 5km-20km | 5km-50km | 300km | 5km |
| Relaxed | 250 | 300 | 50 km | 3km-40km | 3km-90km | 400 km | - |

Seven candidate depots locations were determined as a result of the analysis according to relaxed criteria. These newly identified candidate depots locations are shown in red in Figure 1 below.

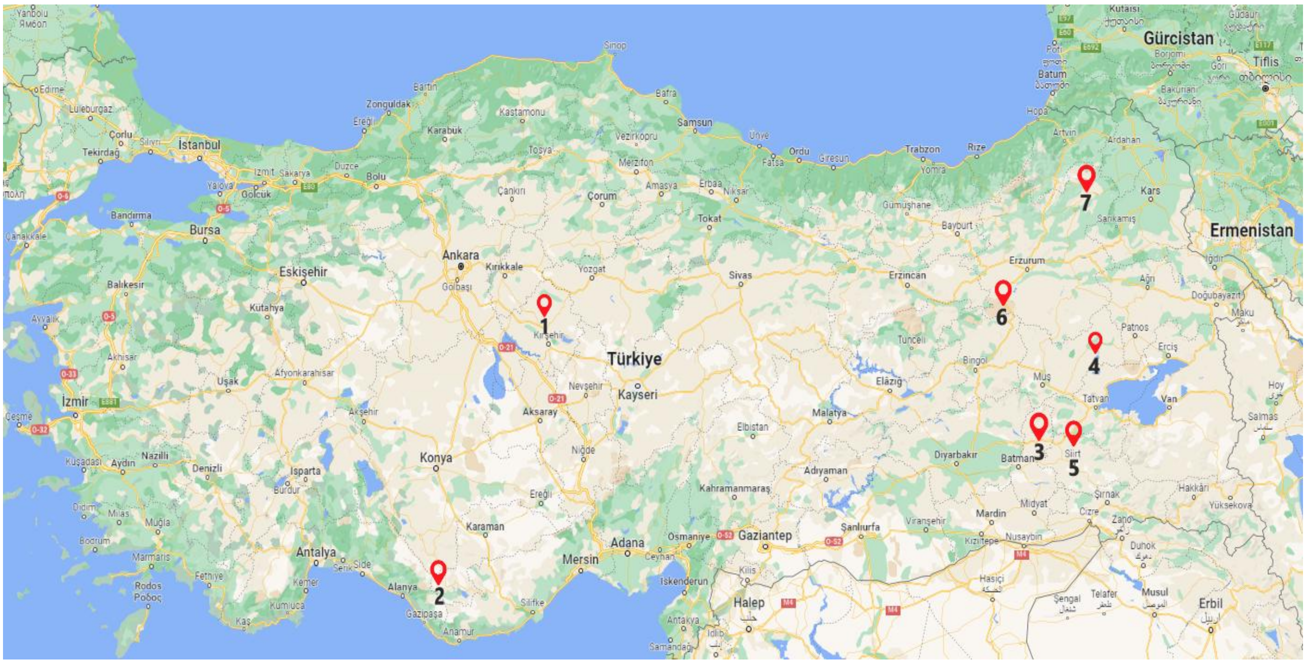


**Fig. 1.** New candidate depot locations identified based on relaxed criteria

### *4.2. Application of Pythagorean Fuzzy WASPAS*

In this section of the study, 7 candidate depotss obtained from GIS were analyzed according to 6 Main criteria using the Pythagorean Fuzzy WASPAS method. The method is given below step by step:

Step 1. Linguistic evaluations about the candidates are converted into Pythagorean fuzzy numbers through the comparison scale given in Table 4 and a combined decision matrix is created (Table 5).

**Table 4**
Linguistic scale for ratings of alternatives

| Linguistic terms | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
|---|---|---|---|---|
| Extremely low (EL) | 0.03 | 0.18 | 0.75 | 0.90 |
| Very low (VL) | 0.12 | 0.27 | 0.66 | 0.81 |
| Low (L) | 0.21 | 0.36 | 0.57 | 0.72 |
| Medium low (ML) | 0.30 | 0.45 | 0.48 | 0.63 |
| Medium (M) | 0.39 | 0.54 | 0.39 | 0.54 |
| Medium high (MH) | 0.48 | 0.63 | 0.30 | 0.45 |
| High (H) | 0.57 | 0.72 | 0.21 | 0.36 |
| Very high (VH) | 0.66 | 0.81 | 0.12 | 0.27 |
| Extremely high (EH) | 0.75 | 0.90 | 0.03 | 0.18 |

Step 2. Maximum defuzzified values are obtained through Eq.(14) (Table 6). Using the maximum defuzzified values, a normalized decision matrix is created in the form of Pythagorean fuzzy numbers with Eq.(17) (Table 7). In this process, the values obtained using Eq.15 and 16 are used, depending on whether all criteria are benefit or cost based.

$$p = \frac{\lambda_L + \lambda_U + \sqrt{1-v_L^2} + \sqrt{1-v_U^2} + \lambda_L\lambda_U - \sqrt{\sqrt{1-v_L^2}\sqrt{1-v_U^2}}}{4} \quad (14)$$

$$\tilde{r}_{ij} = \frac{\tilde{x}_{ij}}{max_i p_{ij}} \quad (15)$$

$$\tilde{r}_{ij} = \frac{min_i p_{ij}}{\tilde{x}_{ij}} \quad (16)$$

$$\lambda\tilde{p} = \left(\left[\sqrt{1-(1-\mu_L^2)^\lambda}, \sqrt{1-(1-\mu_U^2)^\lambda}\right], \left[v_L^\lambda, v_U^\lambda\right]\right) \quad (17)$$

**Table 5**
Consolidated Decision Matrix

| Criteria | C1 | | | | C2 | | | | C3 | | | | C4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.66 | 0.81 | 0.12 | 0.27 | 0.57 | 0.72 | 0.21 | 0.36 | 0.48 | 0.63 | 0.30 | 0.45 | 0.75 | 0.90 | 0.03 | 0.18 |
| $A_2$ | 0.30 | 0.45 | 0.48 | 0.63 | 0.66 | 0.81 | 0.12 | 0.27 | 0.48 | 0.63 | 0.30 | 0.45 | 0.48 | 0.63 | 0.30 | 0.45 |
| $A_3$ | 0.30 | 0.45 | 0.48 | 0.63 | 0.66 | 0.81 | 0.12 | 0.27 | 0.57 | 0.72 | 0.21 | 0.36 | 0.21 | 0.36 | 0.57 | 0.72 |
| $A_4$ | 0.57 | 0.72 | 0.21 | 0.36 | 0.66 | 0.81 | 0.12 | 0.27 | 0.57 | 0.72 | 0.21 | 0.36 | 0.39 | 0.54 | 0.39 | 0.54 |
| $A_5$ | 0.30 | 0.45 | 0.48 | 0.63 | 0.57 | 0.72 | 0.21 | 0.36 | 0.57 | 0.72 | 0.21 | 0.36 | 0.21 | 0.36 | 0.57 | 0.72 |
| $A_6$ | 0.30 | 0.45 | 0.48 | 0.63 | 0.66 | 0.81 | 0.12 | 0.27 | 0.57 | 0.72 | 0.21 | 0.36 | 0.39 | 0.54 | 0.39 | 0.54 |
| $A_7$ | 0.12 | 0.27 | 0.66 | 0.81 | 0.21 | 0.36 | 0.57 | 0.72 | 0.39 | 0.54 | 0.39 | 0.54 | 0.30 | 0.45 | 0.48 | 0.63 |

| Criteria | **C5** | | | | **C6** | | | |
|---|---|---|---|---|---|---|---|---|
| Alt | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.57 | 0.72 | 0.21 | 0.36 | 0.66 | 0.81 | 0.12 | 0.27 |
| $A_2$ | 0.57 | 0.72 | 0.21 | 0.36 | 0.75 | 0.90 | 0.03 | 0.18 |
| $A_3$ | 0.48 | 0.63 | 0.30 | 0.45 | 0.57 | 0.72 | 0.21 | 0.36 |
| $A_4$ | 0.48 | 0.63 | 0.30 | 0.45 | 0.66 | 0.81 | 0.12 | 0.27 |
| $A_5$ | 0.48 | 0.63 | 0.30 | 0.45 | 0.57 | 0.72 | 0.21 | 0.36 |
| $A_6$ | 0.48 | 0.63 | 0.30 | 0.45 | 0.66 | 0.81 | 0.12 | 0.27 |
| $A_7$ | 0.30 | 0.45 | 0.48 | 0.63 | 0.48 | 0.63 | 0.30 | 0.45 |

**Table 6**
Maximum Defuzzified Values

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| $A_1$ | 0.746 | 0.664 | 0.584 | 0.829 | 0.664 | 0.746 |
| $A_2$ | 0.428 | 0.746 | 0.584 | 0.584 | 0.664 | 0.829 |
| $A_3$ | 0.428 | 0.746 | 0.664 | 0.352 | 0.584 | 0.664 |
| $A_4$ | 0.664 | 0.746 | 0.664 | 0.506 | 0.584 | 0.746 |
| $A_5$ | 0.428 | 0.664 | 0.664 | 0.352 | 0.584 | 0.664 |
| $A_6$ | 0.428 | 0.746 | 0.664 | 0.506 | 0.584 | 0.746 |
| $A_7$ | 0.274 | 0.352 | 0.506 | 0.428 | 0.428 | 0.584 |
| Max | 0.746 | 0.746 | 0.664 | 0.829 | 0.664 | 0.829 |

**Table 7**
Normalized Decision Matrix

| Criteria | C1 | | | | C2 | | | | C3 | | | | C4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.73 | 0.87 | 0.06 | 0.17 | 0.64 | 0.79 | 0.12 | 0.25 | 0.57 | 0.73 | 0.16 | 0.30 | 0.79 | 0.93 | 0.01 | 0.13 |
| $A_2$ | 0.34 | 0.51 | 0.37 | 0.54 | 0.73 | 0.87 | 0.06 | 0.17 | 0.57 | 0.73 | 0.16 | 0.30 | 0.52 | 0.68 | 0.23 | 0.38 |
| $A_3$ | 0.34 | 0.51 | 0.37 | 0.54 | 0.73 | 0.87 | 0.06 | 0.17 | 0.67 | 0.82 | 0.10 | 0.21 | 0.23 | 0.39 | 0.51 | 0.67 |
| $A_4$ | 0.64 | 0.79 | 0.12 | 0.25 | 0.73 | 0.87 | 0.06 | 0.17 | 0.67 | 0.82 | 0.10 | 0.21 | 0.42 | 0.58 | 0.32 | 0.48 |
| $A_5$ | 0.34 | 0.51 | 0.37 | 0.54 | 0.64 | 0.79 | 0.12 | 0.25 | 0.67 | 0.82 | 0.10 | 0.21 | 0.23 | 0.39 | 0.51 | 0.67 |
| $A_6$ | 0.34 | 0.51 | 0.37 | 0.54 | 0.73 | 0.87 | 0.06 | 0.17 | 0.67 | 0.82 | 0.10 | 0.21 | 0.42 | 0.58 | 0.32 | 0.48 |
| $A_7$ | 0.14 | 0.31 | 0.57 | 0.75 | 0.24 | 0.41 | 0.47 | 0.64 | 0.47 | 0.64 | 0.24 | 0.40 | 0.33 | 0.49 | 0.41 | 0.57 |

| Criteria | C5 | | | | C6 | | | |
|---|---|---|---|---|---|---|---|---|
| Alt | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.67 | 0.82 | 0.10 | 0.21 | 0.71 | 0.85 | 0.08 | 0.21 |
| $A_2$ | 0.67 | 0.82 | 0.10 | 0.21 | 0.79 | 0.93 | 0.01 | 0.13 |
| $A_3$ | 0.57 | 0.73 | 0.16 | 0.30 | 0.61 | 0.77 | 0.15 | 0.29 |
| $A_4$ | 0.57 | 0.73 | 0.16 | 0.30 | 0.71 | 0.85 | 0.08 | 0.21 |
| $A_5$ | 0.57 | 0.73 | 0.16 | 0.30 | 0.61 | 0.77 | 0.15 | 0.29 |
| $A_6$ | 0.57 | 0.73 | 0.16 | 0.30 | 0.71 | 0.85 | 0.08 | 0.21 |
| $A_7$ | 0.36 | 0.54 | 0.33 | 0.50 | 0.52 | 0.68 | 0.23 | 0.38 |

**Step 3.** Linguistic evaluations about the importance levels of the criteria are converted into Pythagorean fuzzy numbers through the comparison scale given in Table 8. Thus, criterion weights are obtained in the form of Pythagorean fuzzy numbers (Table 9).

**Table 8**
Linguistic Scale for Weighting of Criteria

| Linguistic terms | $\mu_L$ * | $\mu_U$* | $v_L$ * | $v_U$* |
|---|---|---|---|---|
| Extremely Important (EI) | 0.70 | 0.90 | 0.06 | 0.26 |
| Important (I) | 0.54 | 0.74 | 0.22 | 0.42 |
| Medium (M) | 0.38 | 0.58 | 0.38 | 0.58 |
| Medium low (ML) | 0.22 | 0.42 | 0.54 | 0.74 |
| Low (L) | 0.06 | 0.26 | 0.70 | 0.90 |

**Table 9**
Pythagorean Fuzzy Number Representation of Criterion Weights

| Criteria | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
|---|---|---|---|---|
| $C_1$ | 0.7 | 0.9 | 0.06 | 0.26 |
| $C_2$ | 0.38 | 0.58 | 0.38 | 0.58 |
| $C_3$ | 0.7 | 0.9 | 0.06 | 0.26 |
| $C_4$ | 0.54 | 0.74 | 0.22 | 0.42 |
| $C_5$ | 0.7 | 0.9 | 0.06 | 0.26 |
| $C_6$ | 0.22 | 0.42 | 0.54 | 0.74 |

**Step 4.** The values in the normalized decision matrix are producted by the weights of the criteria using Eq.(19) (Table 10). These values are then added together through Eq. (20) and Pythagorean fuzzy weighted total values are obtained (Table 11).

$$Q_i^{(1)} = \sum_{j=1}^{n} \tilde{r}_{ij}\,\widetilde{w}_{ij} \tag{18}$$

$$p_1 \otimes p_2 = \left([\mu_L\mu_L^*, \mu_U\mu_U^*], \left[\sqrt{(v_L)^2 + (v_L^*)^2 - (v_L)^2(v_L^*)^2}, \sqrt{(v_U)^2 + (v_U^*)^2 - (v_U)^2(v_U^*)^2}\right]\right) \tag{19}$$

$$p_1 \oplus p_2 = \left(\left[\sqrt{(\mu_L)^2 + (\mu_L^*)^2 - (\mu_L)^2(\mu_L^*)^2}, \sqrt{(\mu_U)^2 + (\mu_U^*)^2 - (\mu_U)^2(\mu_U^*)^2}\right], [v_L\mu_L^*, v_U v_U^*]\right) \tag{20}$$

**Table 10**
Weighted Normalized Decision Matrix

| Criteria | $C_1$ | | | | $C_2$ | | | | $C_3$ | | | | $C_4$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.80 | 0.88 | 0.01 | 0.09 | 0.84 | 0.87 | 0.08 | 0.19 | 0.68 | 0.75 | 0.04 | 0.16 | 0.88 | 0.95 | 0.01 | 0.08 |
| $A_2$ | 0.47 | 0.55 | 0.09 | 0.29 | 0.89 | 0.92 | 0.04 | 0.13 | 0.68 | 0.75 | 0.04 | 0.16 | 0.70 | 0.75 | 0.11 | 0.25 |
| $A_3$ | 0.47 | 0.55 | 0.09 | 0.29 | 0.89 | 0.92 | 0.04 | 0.13 | 0.75 | 0.83 | 0.02 | 0.11 | 0.45 | 0.50 | 0.25 | 0.47 |
| $A_4$ | 0.73 | 0.81 | 0.03 | 0.13 | 0.89 | 0.92 | 0.04 | 0.13 | 0.75 | 0.83 | 0.02 | 0.11 | 0.63 | 0.67 | 0.15 | 0.32 |
| $A_5$ | 0.47 | 0.55 | 0.09 | 0.29 | 0.84 | 0.87 | 0.08 | 0.19 | 0.75 | 0.83 | 0.02 | 0.11 | 0.45 | 0.50 | 0.25 | 0.47 |
| $A_6$ | 0.47 | 0.55 | 0.09 | 0.29 | 0.89 | 0.92 | 0.04 | 0.13 | 0.75 | 0.83 | 0.02 | 0.11 | 0.63 | 0.67 | 0.15 | 0.32 |
| $A_7$ | 0.25 | 0.35 | 0.15 | 0.44 | 0.58 | 0.60 | 0.30 | 0.52 | 0.59 | 0.67 | 0.06 | 0.21 | 0.55 | 0.59 | 0.20 | 0.39 |

| Criteria | $C_5$ | | | | $C_6$ | | | |
|---|---|---|---|---|---|---|---|---|
| Alt. | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| $A_1$ | 0.75 | 0.83 | 0.02 | 0.11 | 0.93 | 0.93 | 0.06 | 0.18 |
| $A_2$ | 0.75 | 0.83 | 0.02 | 0.11 | 0.95 | 0.97 | 0.01 | 0.11 |
| $A_3$ | 0.68 | 0.75 | 0.04 | 0.16 | 0.90 | 0.89 | 0.11 | 0.25 |
| $A_4$ | 0.68 | 0.75 | 0.04 | 0.16 | 0.93 | 0.93 | 0.06 | 0.18 |
| $A_5$ | 0.68 | 0.75 | 0.04 | 0.16 | 0.90 | 0.89 | 0.11 | 0.25 |
| $A_6$ | 0.68 | 0.75 | 0.04 | 0.16 | 0.93 | 0.93 | 0.06 | 0.18 |
| $A_7$ | 0.49 | 0.57 | 0.08 | 0.27 | 0.87 | 0.85 | 0.17 | 0.33 |

**Table 11**
Pythagorean Fuzzy Weighted Total Values of Alternatives

| A1 | | | | A2 | | | | A3 | | | | A4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\boldsymbol{\mu_L}$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| 0.95 | 1.55 | 0.00 | 0.01 | 0.79 | 1.36 | 0.00 | 0.02 | 0.74 | 1.28 | 0.00 | 0.03 | 0.86 | 1.43 | 0.00 | 0.01 |

| A5 | | | | A6 | | | | A7 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\boldsymbol{\mu_L}$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| 0.73 | 1.26 | 0.00 | 0.03 | 0.77 | 1.32 | 0.00 | 0.02 | 0.48 | 0.95 | 0.01 | 0.08 |

**Step 5.** Eq.(22) is applied by using the values in the normalized decision matrix and the criterion weights and the weighted normalized decision matrix is obtained. Then, these values are multiplied with each other via Eq.(19). Thus, the Pythagorean fuzzy weighted product values given in Table 12 are obtained.

$$Q_i^{(2)} = \prod_{j=1}^{n} \tilde{r}_{ij}^{\widetilde{w}_{ij}} \tag{21}$$

$$p^{\lambda} = \left( [\mu_L^{\lambda}, \mu_U^{\lambda}], \left[ \sqrt{1-(1-v_L^2)^{\lambda}}, \sqrt{1-(1-v_U^2)^{\lambda}} \right] \right) \tag{22}$$

**Table 12**
Pythagorean Fuzzy Weighted Product Values of Alternatives

| A1 | | | | A2 | | | | A3 | | | | A4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\boldsymbol{\mu_L}$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| 0.28 | 0.43 | 0.11 | 0.35 | 0.14 | 0.23 | 0.16 | 0.46 | 0.09 | 0.14 | 0.30 | 0.65 | 0.19 | 0.29 | 0.18 | 0.45 |

| A5 | | | | A6 | | | | A7 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\boldsymbol{\mu_L}$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| 0.08 | 0.13 | 0.30 | 0.67 | 0.13 | 0.20 | 0.20 | 0.52 | 0.02 | 0.04 | 0.44 | 0.92 |

**Step 6.** Pythagorean fuzzy weighted sum values and Pythagorean fuzzy weighted product values are defuzzified using Eq.(14) (Table 13). Then, the two values are integrated through Eq.(13) and the total relative importance values of the alternatives are obtained (Table 13). At this stage, the $\boldsymbol{\lambda}$ value was accepted as 0.5, assuming that the results obtained from the two values are of equal importance.

**Table 13**
Refined Values and Relative Importance Values of Alternatives

| Alt. | Weighted Sum Value | Weighted Product Value | Total Relative Importance Value |
|---|---|---|---|
| A1 | 1.244 | 0.450 | 0.847 |
| A2 | 1.055 | 0.336 | 0.695 |
| A3 | 0.990 | 0.276 | 0.633 |
| A4 | 1.128 | 0.371 | 0.750 |
| A5 | 0.975 | 0.271 | 0.623 |
| A6 | 1.028 | 0.317 | 0.672 |
| A7 | 0.725 | 0.190 | 0.457 |

**Step 7.** The alternative with the highest total relative importance value is determined as the most suitable candidate. When Table 13 is examined, candidates are listed as A1> A4> A2> A6> A3> A5> A7. In current practice, depot 1 is preferred as depot location.

## 5. Conclusions

Today, many developed countries focus on the recycling of ammunition, which is an indispensable military concept, especially stocked for hot conflict situations, without harming people and the environment. This study focused on an important problem area in the literature. Additionally, facility location selection, which is important in the recycling of ammunition, was evaluated.

Due to the great risks posed by ammunition depots locations, it is of great importance to determine them according to various criteria that will minimize the impact of a possible explosion and the possibility of an accident. In the second step, the criteria that can be used in ammunition depots location decision were determined from the hazardous material FLS criteria determined in studies conducted in the literature. The determined criteria were analyzed in GIS and the districts that met these criteria were determined. As a result of the analysis, it is shown generically on the map where depots can be established on a district basis.

In the study, an original methodology using GIS and fuzzy MCDM is proposed in accordance with the characteristics of the FLS problem. Candidate depots locations were determined by examining some criteria that cannot be considered with decision models in GIS. The effectiveness of the proposed methodology has been tested on a generic application. A sample study was conducted in Turkey to determine the depot locations where end-of-life ammunition will be protected before being sent to recycling facilities. In terms of the criteria to be used for ammunition warehouse location selection, the best warehouse location was determined as A1.

The criteria determined in the study can be used in all ammunition depot location selection studies. In future research, different MCDM methods can be integrated for the importance levels of criteria. Various fuzzy logic approaches can be adapted to the WASPAS method. Moreover, the proposed methodology can be combined with optimization models in which the recycling plant is included.

## Author Contributions

Conceptualization, H.A.D. and K.G.K.; methodology, H.A.D.; software, H.A.D.; validation, H.A.D. and K.G.K.; formal analysis, H.A.D. and K.G.K.; investigation, H.A.D. and K.G.K.; resources, H.A.D.; data curation, H.A.D. and K.G.K.; writing—original draft preparation, H.A.D.; writing—review and editing, H.A.D.; visualization, H.A.D.; supervision, K.G.K.; project administration, K.G.K.; funding acquisition, K.G.K. All authors have read and agreed to the published version of the manuscript.

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## Data Availability Statement

The datasets generated during and/or analysed during the current study are not publicly available due to the privacy-preserving nature of the data. However, they can be obtained from the corresponding author upon reasonable request.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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