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Model Proposal for Ammunition Demand Forecasting and Ammunition Distribution Network Design: Military Unit Application

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ABSTRACT

During the war, the safe provision of the required ammunition at the desired place and time can affect the fate of the war and even the country. Determining the amount of ammunition to be needed in the war is as important as planning its distribution. Two problems are important research topics in the field of military logistics. A two-stage methodology is presented in the study to solve these problems. In the first stage, an analytical approach based on conformity tests is presented to estimate the amount of ammunition that military artillery units will need based on generic data, and ammunition requirements for possible battles are estimated. In the second stage, a distribution network design is carried out for the distribution of ammunition from the ammunition depot to the deployed artillery units. This distribution network also includes reverse logistics activities, as it is necessary to collect the waste left by the ammunition used by the artillery units. In order to achieve this in the study, a Multi-Period Multi-Depot Simultaneous Collect Distribute Vehicle Routing Problem Model is developed. The results obtained as a result of the solution of the model are examined in detail and analyzed by comparing with the current situation.

1. Introduction

During a battle, the safe provision of the required ammunition at the desired place and time can affect the fate of the battle and even the country. Determining the amount of ammunition that will be needed in a battle is as important as planning its distribution [1, 2]. These two issues are directly related to each other. Countries calculate these needs and complete their preparations before a battle by benefiting from their past war experiences and the experiences of other countries. Combat units can use various transportation lines and vehicles to reach the materials they need in the operational environment. During this process, the distribution of the materials needed from factories, main depots and secondary depots can be done by land, air and sea.

One of the most consumed and most needed materials in a combat environment is ammunition. Accurately estimating ammunition needs during combat and delivering this ammunition to units on time is an important military logistics problem [3, 4]. The success of

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ammunition distribution directly affects the success of the battle. A unit that runs out of ammunition is doomed to surrender in a combat environment. Artillery ammunition is also an indispensable part of the battlefield as a fire support element in combat. Engaging the enemy in fire from a distance makes it an important element of combat. The safe transportation of materials with weight and carrying limitations, such as artillery ammunition, require detailed planning. Therefore, ammunition distribution network design and planning are an important area of research in military logistics [5].

In recent operations, the duration of battles and the amount of ammunition used have changed due to technological developments and changes in military tactics. These changes have necessitated a recalculation of the amount of ammunition expected to be spent. These replannings cause delays in combat activities and reduce the rate of combat success [6]. Therefore, the implementation of the plans with analytical methods, their reliance on objective factors rather than subjective factors, and the evaluation of this problem within a broad framework are indispensable factors for the success of countries in combat and the reduction of costs [7, 8].

In order to solve these problems, a two-stage methodology is presented in the study. In the first stage, the amount of ammunition that military artillery units that previously participated in a general battle will need is estimated by obtaining generic data and an analytical approach is presented for calculating the ammunition needs of the units that will take part in the conflicts. Ammunition requirements for future battles are estimated by performing the least squares method-based suitability tests on generic data determined from past battles. In the second stage, a distribution network design is carried out for the distribution of ammunition from the ammunition depot to the deployed artillery units. This distribution network also includes reverse logistics activities since the waste left by the ammunition used by the artillery units must be collected. In order to achieve this in the study, a Multi-Period Multi-Depot Simultaneous Collect-Distribute Vehicle Routing Problem Model is developed.

After the introduction part of the study, the literature review was given in the second part and the application was presented in the third part. In the application part, firstly the demand forecast study was carried out and then the distribution network was created. In the fourth and last part, the results were emphasized and the study was concluded by making suggestions for future studies.

2. Literature Review

Ammunition supply has always been a force multiplier for military units. Although the timely delivery of ammunition to the unit is not sufficient for success alone, it is an important force multiplier [9, 10]. In order for the supply activity to be considered fully effective, the accuracy of the amount to be distributed is as important as a correct distribution network [11]. In the study, firstly, the future ammunition usage amounts were estimated based on generic data and the distribution amounts of ammunition required were determined from here and then the distribution network was created by adding the constraints specific to the problem to the Simultaneous Collection Distribution Vehicle Routing Problem model. A methodology that will estimate the ammunition that a unit will need according to the data used in similar conflicts and provide ammunition distribution accordingly was presented. Generic data was used in this study. However, when this methodology is applied based on the ammunition data used by a unit in a conflict environment, the number of ammunition and vehicles required can be estimated. Therefore, in the literature review, 91 Vehicle Routing Problem studies conducted since 1969 were examined and classified according to the type they belong to and whether demand estimation was made or not. The classification is given in Table 1.

Table 1. Literature Review

Author	Year	Determ.	Stochastic	Single Depot	Multi Depot	Only Distrubiton	Pick-Up Delivery	Sim.P&D	Demand Forecast
Tillman ve Hering [12]	1969		+		+	+			
Laporte ve Louveaux [13]	1990		+	+		+			
Bertsimas et al. [14]	1995		+	+		+			
Salhi ve Nagy [15]	1999	+		+	+			+	
Yang et al. [16]	2000		+	+		+			
Dethloff [17]	2001	+		+				+	
Giosa et al. [18]	2002	+			+	+			
Tang et al. [19]	2002		+	+		+			
Polacek et al. [20]	2004	+			+	+			
Crispim ve Brandoa [21]	2005	+		+				+	
Chang [22]	2005		+	+		+			
Lim ve Wang [23]	2005	+			+	+			
Bianchi et al. [24]	2006		+	+		+			
Montane ve Galveo [25]	2006	+		+				+	
Dondo ve Cerdá [26]	2006	+			+	+			
Wassan et al. [27]	2007	+		+				+	
Haugland ve Ho [28]	2007		+	+		+			
Ho et al. [29]	2008	+			+	+			
Sungur et al. [30]	2008		+	+		+			
Gajpal ve Abad [31]	2009	+		+				+	
Secomandi ve Margot [32]	2009		+	+		+			
Ombuki-Berman ve Hanshar [33]	2009	+			+	+			
Mingyong ve Erbao [34]	2010	+		+				+	
Hou ve Zhou [35]	2010		+	+				+	
Erera et al. [36]	2010		+	+		+			
Minis ve Tatarakis [37]	2011		+	+			+		
Zachariadis ve Kiranoudis [38]	2011	+		+				+	
Subramanian et al. [39]	2011	+		+				+	
Tasan et al. [40]	2012	+		+				+	
Cruz et al. [41]	2012	+		+				+	
Goodson et al. [42]	2012		+	+		+			
Zuhori et al. [43]	2013		+		+	+			
Juan et al. [44]	2013		+	+		+			
Göksal et al. [45]	2013	+		+				+	
Zhang et al. [46]	2013		+	+		+			
Jabali et al. [47]	2014		+	+		+			
Salhi et al. [48]	2014	+			+	+			
Gauvin et al. [49]	2014		+	+		+			
Contardo ve Martinelli [50]	2014	+			+	+			
Kunnapapdeelert et al. [51]	2015	+			+		+		
Avcı ve Topaloğlu [52]	2015	+		+			+	+	
Gschwind [53]	2015	+		+				+	
Soonpracha et al. [54]	2015		+	+		+			
Dimitrakos ve Kyriakidis [55]	2015		+	+			+		
Biesinger et al. [56]	2015		+	+		+			

Balaprakash et al. [57]	2015		+	+		+			
Mancini [58]	2016	+			+	+			
Kalaycı ve Kaya [59]	2016	+		+				+	
Christiansen et al. [60]	2016		+		+	+			
Marinaki ve Marinakis [61]	2016		+	+		+			
Berhan [62]	2016		+	+				+	
Ghilas et al. [63]	2016		+	+			+		
Mendoza et al. [64]	2016		+	+		+			
Jabir et al. [65]	2017	+			+		+		
Kartal et al. [66]	2017	+		+				+	
Uslu et al. [67]	2017		+		+	+			
Pasha et al. [68]	2017		+	+		+			
Bayrak ve Özyörük [69]	2017	+		+				+	
Bolanos et al. [70]	2018	+			+	+			
Belgin et al. [71]	2018	+		+				+	
Bertazzi ve Secomandi [72]	2018		+	+				+	
Zhou et al. [73]	2018		+	+				+	
Dinh et al. [74]	2018		+	+		+			
Calvet et al. [75]	2019		+		+	+	+		
Wang et al. [76]	2019	+			+	+			
Lahyani et al. [77]	2019	+			+	+			
Madankumar ve Rajendran [78]	2019	+		+				+	
Soeanu et al. [79]	2020	+			+	+			
Stodola [80]	2020	+			+	+			
Hornstra et al. [81]	2020	+		+				+	
Aydoğdu ve Özyörük [82]	2020	+		+				+	
Keçeci et al. [83]	2021	+		+			+	+	
Santos et al. [84]	2021	+		+			+	+	
Tamke ve Buscher [85]	2021	+			+	+			
Zhou et al. [86]	2022	+			+	+			
Ji et al. [87]	2022	+			+	+			+
Jiang et al. [88]	2022	+		+				+	
Mara et al. [89]	2022	+			+	+			
Kabadurmuş ve Erdoğan [90]	2023	+			+	+			
Gu et al. [91]	2023	+			+	+			
Vincent et al. [92]	2023	+		+			+	+	
Teng et al. [93]	2024		+		+	+			
Al Theeb et al. [94]	2024	+			+	+			
Debnath et al. [95]	2024	+			+	+			
Zhou et al. [96]	2024	+			+	+			
Zhang et al. [97]	2024	+			+	+			
Borges et al. [98]	2024	+		+		+			
Jasim et al. [99]	2024	+		+		+			
Faiz et al. [100]	2024	+			+	+			
Caballero et al. [101]	2024	+			+	+			
Wen et al. [102]	2024	+			+	+			

The graph of the studies included in the literature review by year is given in Figure 1.

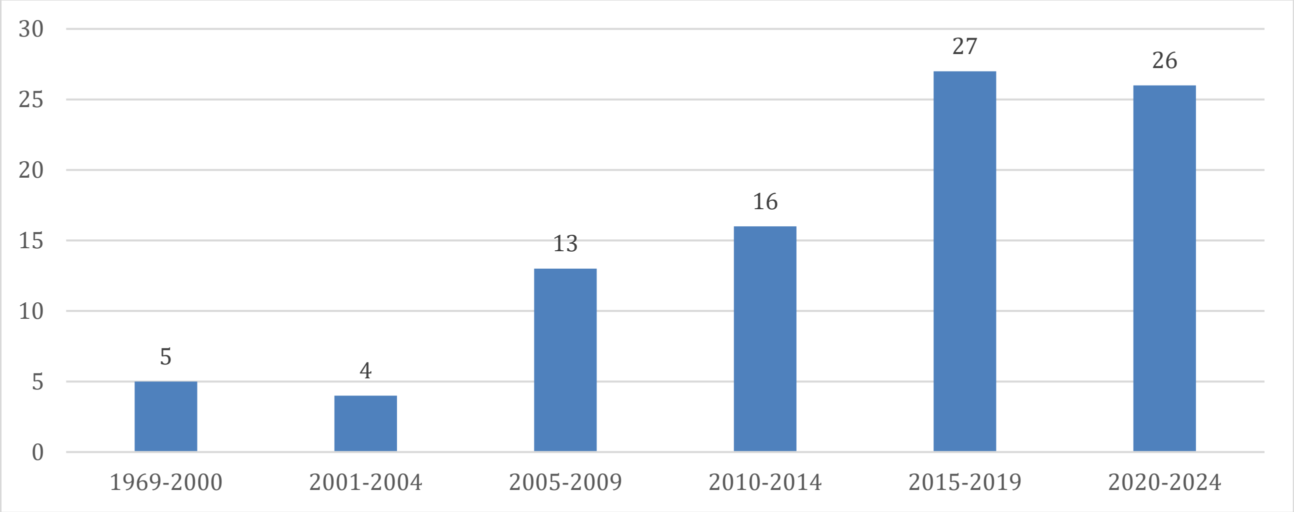

Fig.1. Distribution of Examined Studies by Year

When Figure 1 is examined, it is seen that Vehicle Routing Problem studies are increasing due to their applicability to real-life problems. The number of studies conducted reached its highest level in 2019. It remained at the same levels in 2024. The graph showing the classification distribution of the studies examined is presented in Figure 2.

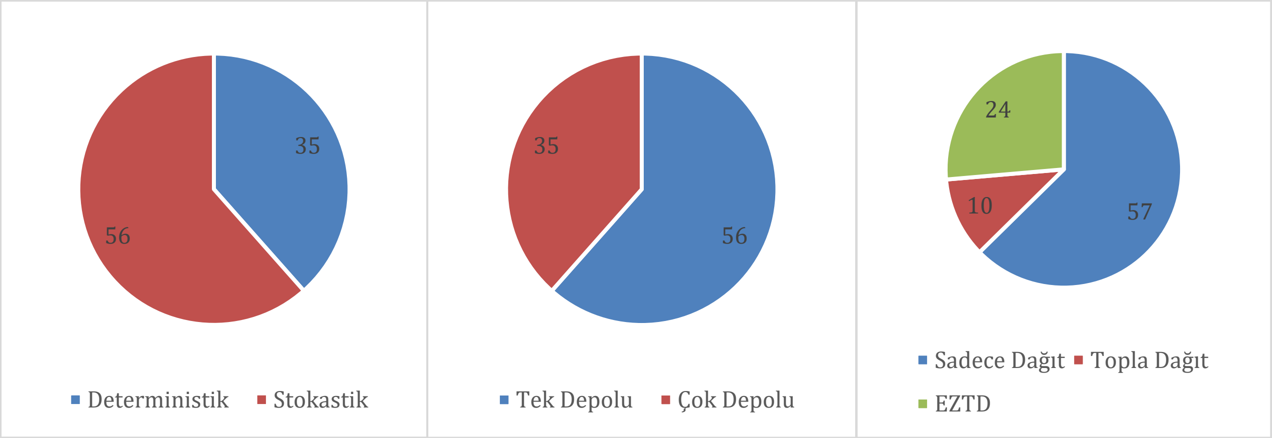

Fig.2. İncelenen Çalışmaların Sınıflandırması

In the first graph of Figure 2, the red color is deterministic, the blue color is stochastic; in the second graph, the red color is multi-warehouse, the blue color is single-warehouse; in the third graph, the red color is collection and distribution, the blue color is only distribution, and the green color is simultaneous collection and distribution studies. When Figure 2 is examined, it is seen that the vast majority of the studies conducted are deterministic, single-warehouse and studies that only address distribution. As can be seen from Table 1, only 1 of the studies also performed demand estimation and in that study, a problem in which only distribution is performed was studied. Within the scope of all the studies conducted, no study was encountered in the literature that focused on a multi-period multi-warehouse problem in which both distribution and collection are performed, where the amount to be distributed is determined by making demand estimation with analytical methods. In the literature research conducted, it was seen that military issues and especially the ammunition issue were not addressed much.

3. Developed 2-Stage Methodology

Ammunition supply has always been a force multiplier for military units. Although the timely delivery of ammunition to the unit is not sufficient for success on its own, it is an important force multiplier. Artillery units are positioned along a certain line in a way that they can support the operational area with their fire. Estimating the ammunition that these units, which are dispersed over a wide area, will need and not delivering the required ammunition on time poses a high cost and a vital risk, such as losing the war. For this reason, proper planning and more effective use of resources are of great importance in terms of winning the war. After artillery ammunition is used, there is a certain amount of ammunition left that needs to be returned to the depot. These leftovers are returned to the depot, evaluated within the scope of recycling, and can be used in ammunition production and storage again. For this reason, after the ammunition is distributed, the remaining ones must also be returned to the depot in accordance with the vehicle capacity. Considering this entire process, it should not be overlooked that reverse logistics activities can also be carried out in the ammunition distribution network created and that the vehicle to be transported should be designed in accordance with its physical capacities, such as weight and volume, for both distribution and collection.

In the study, firstly, demand estimation was performed with the least squares method based suitability tests to determine the amount of ammunition to be distributed and then the Multi-Period Multi-Depot Simultaneous Collection and Distribution Vehicle Routing Problem model was developed for the distribution network design.

3.1. Ammunition Demand Forecasting

In military logistics, determining the amount of supply materials is an important problem area as much as determining the supply routes. Ammunition stock is divided into two as ammunition campaign stock and ammunition campaign requirement. Ammunition campaign requirement is the amount of ammunition that will be needed by the unit according to a certain scenario, considering the type of current battle to be carried out, terrain structure, tactics and duration. It is calculated separately for each type of weapon. Ammunition campaign stock is the stocking that is evaluated to be needed in the support of combat and is made starting from peace conditions. This is usually the amount of ammunition that will be needed in a 20-25 day operation. Ammunition campaign stock consists of the continental load and the war reserve stock. The continental load ammunition is the ammunition to be carried on the personnel and vehicle in a unit. It is calculated based on the first 5 days of a war. War reserve stock is the ammunition other than the continental load ammunition. It usually covers a period of 20 days. In the study, a demand forecast was performed on a generic war scenario lasting 30 days. The ammunition numbers planned for the first 25 days of a generic war were considered generically and a forecast for the next 30 days was obtained by performing the least squares method-based suitability tests on them. The 25-day ammunition quantities used for the forecast are presented in Table 2.

Table 2. Ammunition Consumed for 25 Days

Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed
1.	288	6.	172	11.	126	16.	94	21.	86
2.	262	7.	164	12.	120	17.	96	22.	82
3.	254	8.	140	13.	114	18.	86	23.	78

4.	232	9.	130	14.	102	19.	90	24	84
5.	190	10.	122	15.	104	20.	88	25.	78

Suitability tests were performed based on the available ammunition quantities using linear functions, exponential functions, exponential functions and parabolic functions. The graphs obtained as a result of the suitability tests are given in Figure 3, and the functions and significance coefficients are given in Table 3.

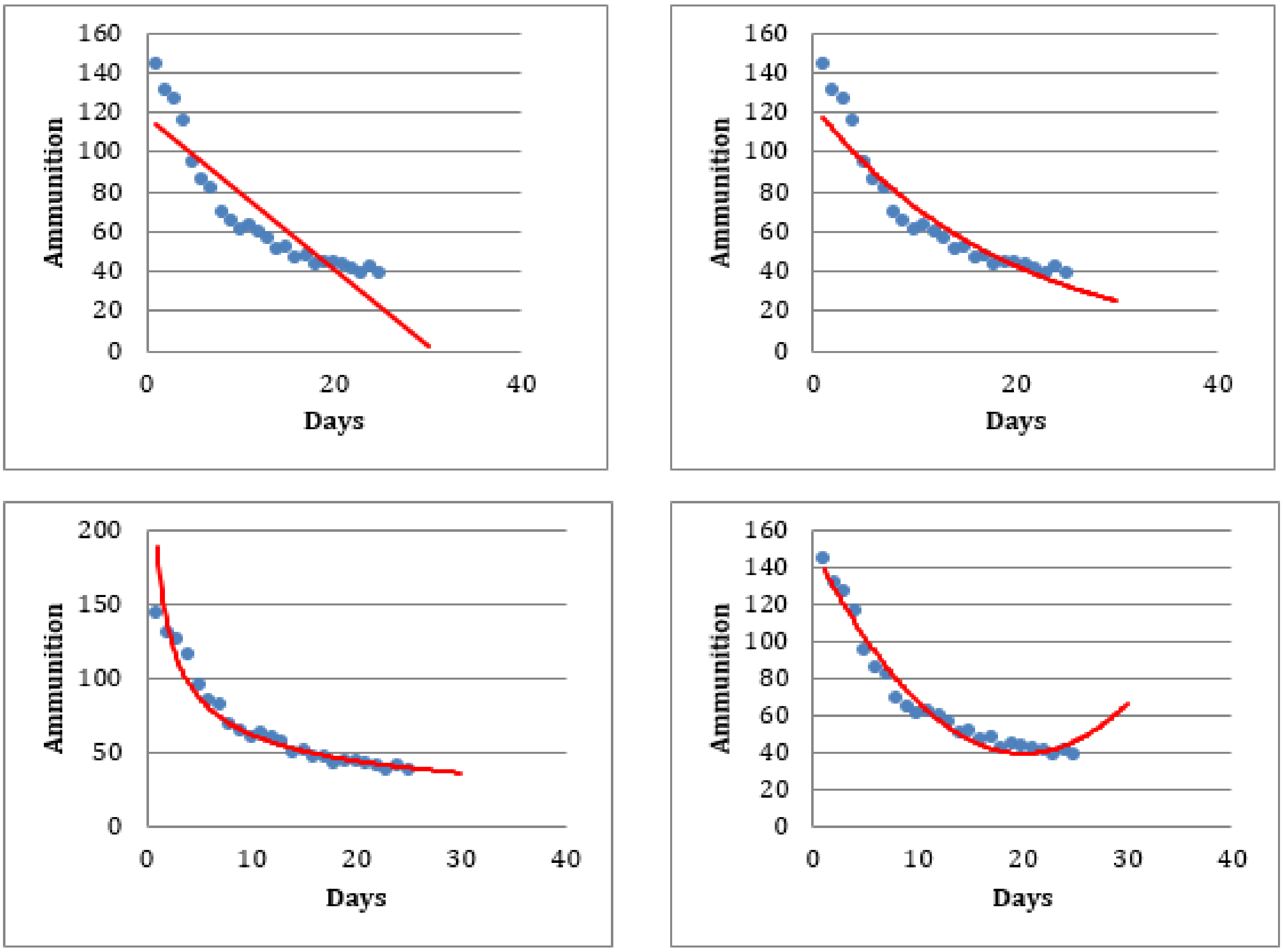

Fig.3. Suitability Test Graphs

The upper left graph of Figure 3 shows the suitability of the linear function, the upper right graph shows the suitability of the Exponential function, the lower left graph shows the suitability of the power function, and the lower right graph shows the suitability of the polynomial function.

Table 3. Suitability Test Results

Function Type	Equation	Coefficient of Determination (R^2)
Linear Trend Function	$y = -3{,}847x + 117{,}6$	0,806
Exponential Trend Function	$y = 123{,}5e^{-0{,}05x}$	0,909
Power Trend Function	$y = 288{,}6x^{-0{,}48}$	0,956
Polynomial Trend Function	$y = 0{,}271x^2 – 10{,}91x + 149{,}4$	0,972

When Figure 3 and Table 3 are examined, it is seen that the most suitable function for estimating the amount of ammunition demand is the parabolic function with a significance coefficient of 0.972. However, the structure of the parabolic function, which first decreases and then increases, is contrary to the general course of the war. Because the amount of ammunition in battles does not increase towards the end of the war, on the contrary, less ammunition is used than it was used until then. Therefore, the exponential function with the second best significance coefficient of 0.956 was used for ammunition demand estimation. The ammunition demand estimates obtained as a result of using the obtained function are given in Table 4.

Table 4. 30-Day Ammunition Consumption Estimates

Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed	Days	Number of Ammunition Consumed
1.	289	7.	114	13.	85	19.	71	25.	62
2.	207	8.	107	14.	82	20.	69	26.	61
3.	171	9.	101	15.	79	21.	67	27.	60
4.	149	10.	96	16.	77	22.	66	28.	59
5.	134	11.	92	17.	75	23.	65	29.	58
6.	123	12.	88	18.	73	24.	63	30.	57

When Table 4 is examined, an approach to scientifically estimate demand for a 30-day generic war is presented. It is evaluated that the estimate made with a probability function here can be made with different methods in other studies. Here, a generic approach to ammunition estimation, which has not been discussed much in the literature, is presented.

3.2. Ammunition Pick Up&Delivery Network Design

After determining the quantities to be distributed and collected with the ammunition demand estimation, which is the first stage of the study, the second stage, the ammunition distribution network design, was started. This distribution network design was created using the Simultaneous Collection and Distribution Vehicle Routing model. A new model proposal was developed by incorporating the features and assumptions of the problem itself into the classical Simultaneous Collection and Distribution Vehicle Routing model in the literature. With this model, it is aimed to determine the shortest path for the transportation of the required ammunition amount calculated by demand estimation methods from the existing depots to the artillery units and the ammunition residues to be collected from the artillery units to the depots, and to find the number of vehicles that should be in the depots on a daily basis. This methodology was tested for an imaginary situation where the geographical location and numerical information of the depots and artillery units are generated generically. The model of the Multi-Periodic Multi-Depot Simultaneous Collection and Distribution Problem used in the study is given below;

Sets
N_s: Depots $N_s = \{1,\ldots,D\}$
N_c: Units $N_c = \{D+1,\ldots,N\}$
N: Nodes $\{i,j \in N_s \cup N_c\}$
Z_d: Ammunition to be distributed $Zd = \{1,\ldots,P\}$
Z_t: Ammunition to be collected $Z_t = \{P+1,\ldots,C\}$
Z: Ammuniton $\{m \in Z_d \cup Z_t\}$

T: Periods T = {1,…,T}

Parameters

Q_1: Vehicle weight capacity (kg)

Q_2: Vehicle volume capacity (m^3)

c_{ij}: Distance between node i and node j, i,j ∈ N

d_{imt}: The quantity of distribution to be made from the units for ammuniton m in period t, $m \in Z_d$

q_{imt}: The quantity of collection to be made from the units for ammunition m in period t, $m \in Z_t$

w_m: weight of ammunition m, m∈Z

h_m: volume of ammunition m, m∈Z

$B1_k$: Maximum weight capacity of the depot k, $k \in N_s$

$B2_k$: Maximum volume capacity of the depot k, $k \in N_s$

Decision Variables

X_{ijt}: If in period t the edge (i,j) is on any tour then 1, other 0

Y_{ikt}: If in period t, unit i is served from warehouse k then 1, other 0

M_k: Number of vehicles departing from depot k, $k \in N_s$

Auxilary Decision Variables

$U1_{it}$: Total ammunition weight to be deployed in the vehicle just before entering node i in period t

$V1_{it}$: Total ammunition weight to be collected in the vehicle at the exit of node i in period t

$U2_{it}$: Total ammunition volume to be deployed in the vehicle just before entering node i in period t

$V2_{it}$: Total ammunition volume to be collected in the vehicle at the exit of node i in period t

Objective Function

$$min\ Z = \sum_{\substack{i \in \mathrm{N} \\ i \neq j}} \sum_{j \in \mathrm{N}} \sum_{t \in \mathrm{T}} c_{ij} x_{ijt} \qquad (\mathbf{1})$$

subject to

$$\sum_{j \in \mathrm{N}} x_{ijt} = 1 \qquad \forall i \in \mathrm{N}_c, i \neq j, t \in \mathrm{T} \qquad (\mathbf{2})$$

$$\sum_{j \in \mathrm{N}} x_{jit} = \sum_{j \in \mathrm{N}} x_{ijt} \qquad \forall i \in \mathrm{N}_c, i \neq j, t \in \mathrm{T} \qquad (\mathbf{3})$$

$$\sum_{j \in \mathrm{Nc}} x_{kjt} = M_k \qquad \forall \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{4})$$

$$\sum_{i \in \mathrm{Nc}} x_{ikt} = M_k \qquad \forall \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{5})$$

$$\sum_{k \in \mathrm{Ns}} y_{ikt} = 1 \qquad \forall \mathrm{i} \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{6})$$

$$x_{ikt} \leq y_{ikt} \qquad \forall \mathrm{i} \in \mathrm{N}_c, \forall \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{7})$$

$$x_{kit} \leq y_{ikt} \qquad \forall \mathrm{i} \in \mathrm{N}_c, \forall \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{8})$$

$$x_{ijt} + y_{ikt} + \sum_{\substack{m \in Ns \\ m \neq k}} y_{jmt} \leq 2 \qquad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}_c, \mathrm{i} \neq \mathrm{j}, \forall \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{9})$$

$$U1_{jt} - U1_{it} + Q_1 * x_{ijt} + (Q_1 - \textstyle\sum_{m \in Zd} W_m * d_{imt} - \sum_{m \in Zd} W_m * d_{jmt}) * x_{jit} \leq Q_1 - \sum_{m \in Zd} W_m * d_{imt} \quad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}_\mathrm{c}\ \mathrm{i} \neq \mathrm{j}, t \in \mathrm{T} \qquad (10)$$

$$V1_{it} - V1_{jt} + Q_1 * x_{ijt} + (Q_1 - \textstyle\sum_{m \in Zt} W_m * q_{imt} - \sum_{m \in Zt} W_m * q_{jmt}) * x_{jit} \leq Q_1 - \sum_{m \in Zt} W_m * q_{jmt} \quad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}_\mathrm{c}\ \mathrm{i} \neq \mathrm{j}, t \in \mathrm{T} \qquad (11)$$

$$U1_{it} + V1_{it} - \sum_{m \in Zd} \mathrm{W}_m * d_{imt} \leq \mathrm{Q}_1 \qquad \forall \mathrm{i} \in N_c, t \in \mathrm{T} \qquad (\mathbf{12})$$

$$U1_{it} \geq \sum_{m \in Zd} \mathrm{W}_m * d_{imt} + \sum_{j \in Nc} \sum_{m \in Zd} \mathrm{W}_m * d_{jmt} * x_{ijt} \qquad \mathrm{i} \neq \mathrm{j}\,, \forall \mathrm{i} \in N_c, t \in \mathrm{T} \qquad (\mathbf{13})$$

$$V1_{it} \geq \sum_{m \in Zt} \mathrm{W}_m * q_{imt} + \sum_{j \in Nc} \sum_{m \in Zt} \mathrm{W}_m * q_{jmt} * x_{jit} \qquad \mathrm{i} \neq \mathrm{j}\,, \forall \mathrm{i} \in N_c, t \in \mathrm{T} \qquad (\mathbf{14})$$

$$V1_{it} \leq \mathrm{Q}_1 - (\mathrm{Q}_1 - \sum_{m \in Zt} \mathrm{W}_m * q_{imt})(\sum_{k \in Ns} x_{kit}) \qquad \forall i \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{15})$$

$$U1_{it} \leq \mathrm{Q}_1 - \left(\mathrm{Q}_1 - \sum_{m \in Zd} \mathrm{W}_m * d_{imt}\right)\left(\sum_{k \in Ns} x_{ikt}\right) \qquad \forall i \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{16})$$

$$\sum_{i \in Nc} \sum_{m \in Zd} \mathrm{W}_m * d_{imt} * y_{ikt} \leq B1_k \qquad \forall k \in Ns, t \in \mathrm{T} \qquad (\mathbf{17})$$

$$U2_{jt} - U2_{i\,t} + \mathrm{Q}_2 * x_{ijt} + (\mathrm{Q}_2 - \textstyle\sum_{m \in Zd} h_m * d_{imt} - \sum_{m \in Zd} h_m * d_{jmt}) * x_{jit} \leq \mathrm{Q}_2 - \sum_{m \in Zd} h_m * d_{imt} \ \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}_c \ \mathrm{i} \neq \mathrm{j}, t \in \mathrm{T} \qquad (18)$$

$$V2_{it} - V2_{jt} + \mathrm{Q}_2 * x_{ijt} + (\mathrm{Q}_2 - \textstyle\sum_{m \in Zt} h_m * q_{imt} - \sum_{m \in Zt} h_m * q_{jmt}) * x_{jit} \leq \mathrm{Q}_2 - \sum_{m \in Zt} h_m * q_{jmt} \ \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}_c \ \mathrm{i} \neq \mathrm{j}\,, t \in \mathrm{T} \qquad (19)$$

$$U2_{it} + V2_{it} - \sum_{m \in Zd} h_m * d_{imt} \leq \mathrm{Q}_2 \qquad \forall i \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{20})$$

$$U2_{it} \geq \sum_{m \in Zd} h_m * d_{imt} + \sum_{j \in Nc} \sum_{m \in Zd} h_m * d_{jmt} * x_{ijt} \qquad \mathrm{i} \neq \mathrm{j}\,, \forall \mathrm{i} \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{21})$$

$$V2_{it} \geq \sum_{m \in Zt} h_m * q_{imt} + \sum_{j \in Nc} \sum_{m \in Zt} h_m * q_{jmt}\, x_{jit} \qquad \mathrm{i} \neq \mathrm{j}\,, \forall \mathrm{i} \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{22})$$

$$V2_{it} \leq \mathrm{Q}_2 - \left(\mathrm{Q}_2 - \sum_{m \in Zt} h_m * q_{imt}\right)\left(\sum_{k \in Ns} x_{kit}\right) \qquad \forall i \in \mathrm{N}_c\,, t \in \mathrm{T} \qquad (\mathbf{23})$$

$$U2_{it} \leq \mathrm{Q}_2 - \left(\mathrm{Q}_2 - \sum_{m \in Zd} h_m * d_{imt}\right)\left(\sum_{k \in Ns} x_{ikt}\right) \qquad \forall i \in \mathrm{N}_c\,, t \in \mathrm{T} \qquad (\mathbf{24})$$

$$\sum_{i \in Nc} \sum_{m \in Zd} h_m * d_{imt} * y_{ikt} \leq B2_k \qquad \forall k \in \mathrm{N}_s\,, t \in \mathrm{T} \qquad (\mathbf{25})$$

$$x_{ijt} \in \{0,1\} \qquad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N}, t \in \mathrm{T} \qquad (\mathbf{26})$$

$$y_{ikt} \in \{0,1\} \qquad \forall \mathrm{i} \in \mathrm{N}_c, \mathrm{k} \in \mathrm{N}_s, t \in \mathrm{T} \qquad (\mathbf{27})$$

$$U1_{it}, U2_{it} \geq 0 \qquad \forall \mathrm{i} \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{28})$$

$$V1_{it}, V2_{it} \geq 0 \qquad \forall \mathrm{i} \in \mathrm{N}_c, t \in \mathrm{T} \qquad (\mathbf{29})$$

$$M_k \geq 0 \qquad \forall k \in \mathrm{N}_s \qquad (\mathbf{30})$$

Equation 1 is the objective function, the aim is to find the shortest route where the vehicle distributes ammunition. Equality 2 ensures that each unit is visited at least once in each period. Equality 3 equalizes the number of entry and exit lines to all nodes in each period. Equality 4 ensures that the number of vehicles to leave depot k in each period is Mk. Equality 5 ensures that vehicles leaving depot k in each period return to depot k. Equality 6 ensures that each unit is assigned to a depot in each period. Equalities 7 - 9 ensure that a vehicle leaving for distribution in each period returns to the depot it started from. Equality 10 and Equality 11, respectively, ensure that the pick up and delivery demands in each period do not exceed the vehicle weight capacity while on a route, and prevent the formation of sub-tours. Equality 12 ensures that the weight of the load carried on a route does not exceed the vehicle capacity in each period. Equalities 13 - 16 determine the lower/upper limits of the auxiliary decision variables for weight in each period. Equation 17 ensures that the total demand of the units assigned to a depot in each period does not exceed the depot capacity. Equations 18 and 19 ensure that the combination of pick up/delivery demands on a vehicle on a route does not exceed the volume capacity separately in each period and do not allow the formation of sub-tours. Equation 20 ensures that the volumetric load carried on a vehicle on a route in each period does not exceed the volumetric capacity of the vehicle. Equations 21-24 determine the lower and upper bounds of the decision variables U2i, V2i. Equation 25 ensures that the total volumetric demand of the batteries assigned to a depot does not exceed the depot capacity. Equations 26-30 are constraints indicating the type of the decision variable.

3.3. Application

Artillery units are positioned along a certain line in a way that they can support the operation area with their fire. Timely delivery of ammunition to these units, which are scattered over a wide area, poses a high cost and risk. In the application, an ammunition distribution network was created from 2 different depots to 12 artillery units whose geographical locations were determined generically. The generic locations of the artillery units and depots on the map are shown in Figure 4.

Fig.4. Depots and Units Points

It is assumed that there are a certain number of vehicles in each depot. In the example discussed here, distribution is made by assuming that there are different numbers of vehicles. Information on the vehicles that will make distribution, the number of vehicles in each depot and the information on the ammunition to be distributed are given in Table 5. The distribution of the amount of ammunition found with the demand estimate by a certain number of vehicles is presented generically. Accordingly, the number of vehicles that each depot should have, the number of surplus vehicles and the distribution route are determined.

Table 5. Model Parameter Information

Ammunition Container Features		
Max Loading Weight	21,710 kg	
Max Loading Volume	33.0 m^3	
Ammunition Type	**Unit Ammunition Weight (Kg)**	**Unit Ammunition Volume (M$^{3)}$**
Ammuniton A	58,220	0,020
Number of Vehicles	20 (Depot 1-10, Depot 2-10)	
Unit Distrubiton Request	Estimated Values	
Unit Collection Request	The value distributed the day before was determined as the total value for that day.	

The developed mathematical model was solved on a computer with an Intel Core i7-9700 CPU 3.00 GHz processor and 16 GB RAM by coding it in the GAMS 24.1 program under the Windows 10 operating system. The information about the obtained solutions and the representation of the routes on the map are given in Figure 5 and Table 6, respectively. The routes that the vehicles will follow and the number of vehicles are shown here.

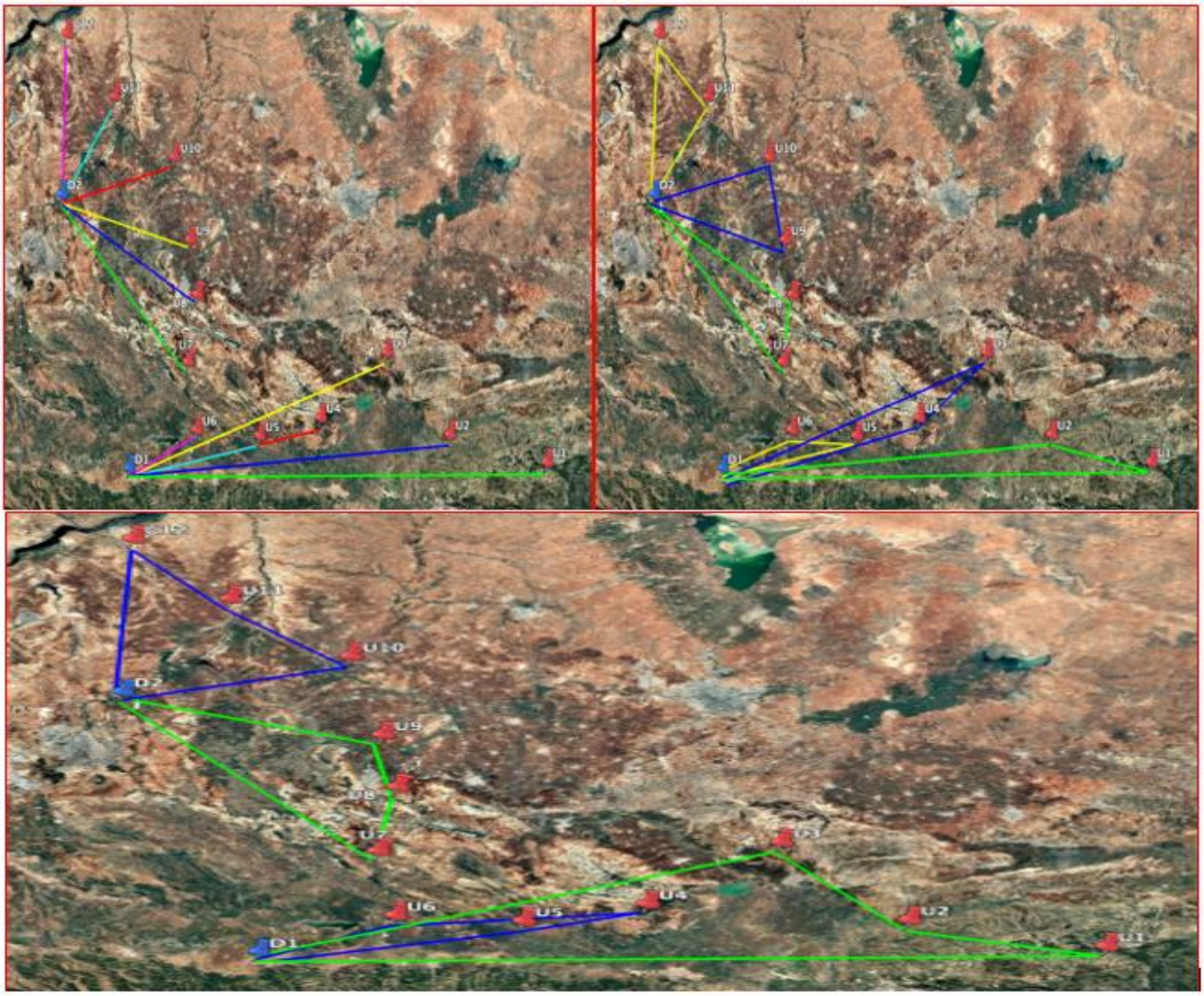

Fig 5. Day Based Ammunition Distribution and Collection Routes Map Display

In Figure 5, the upper left corner shows days 1-8, the upper right corner shows days 9-17, and the lower corner shows days 18-30.

Table 6. Day-Based Ammunition Pick Up&Delivery Routes

Days	**Routes**
1-8	1-3-1, 1-4-1, 1-5-1, 1-6-1, 1-7-1, 1-8-1, 2-9-2, 2-10-2, 2-11-2, 2-12-2, 2-13-2, 2-14-2
9-17	1-3-4-1, 1-5-6-1, 1-7-8-1, 2-9-10-2, 2-11-12-2, 2-13-14-2
18-30	1-3-4-5-1, 1-6-7-8-1, 2-9-10-11-2, 2-12-13-14-2

Initially, it was assumed that there were 10 ammunition vehicles in Warehouse 1 and 10 in Warehouse 2 and the solution was made accordingly. When the generic model was solved, the days when the most vehicles were needed were between the 2nd and 8th days, and 1 vehicle was planned for each unit on these days. 12 ammunition vehicles were calculated as the maximum number of vehicles that should be kept in the warehouses. As seen in Table 4, it seems that the number of vehicles in the warehouses can be reduced and shifted to other regions where needed in the following days. In order for the distribution request and collection request to be made completely, there should be 6 vehicles in Warehouse 1 and 6 vehicles in Warehouse 2 as of the 2nd day.

The objective function value of the solution found using the model is 34.112. According to the generic data with this model, 10,086 ammunition was distributed from 2 depots to 12 unit points for 30 days and ammunition waste was collected.

During the distribution, while 1 vehicle was planned for each unit point between the 2nd and 8th days, distribution and collection were completed with 1 vehicle for 2 unit points between the 9th and 17th days, and 1 vehicle for 3 unit points between the 18th and 30th days. A solution was found that covered the least distance during the distribution and used the vehicles in the most efficient way.

It was determined that 4 out of 10 vehicles in each depot between the 2nd and 8th days were not needed, 7 vehicles were not needed between the 9th and 17th days, and 8 vehicles were not needed between the 18th and 30th days. With this model, the number of vehicles to be placed in each depot or the situations of shifting excess vehicles in the depot to other depots can be analyzed.

5. Conclusion and Recommendations

This study focuses on the optimization of ammunition distribution, which is a critical logistics problem in the combat environment. Using a two-stage methodology, first the ammunition requirements of artillery units were estimated with historical generic data and analytical methods, then the ammunition distribution network was designed with the simultaneous collection-distribution vehicle routing problem model. The developed model was created by adding the constraints and assumptions specific to the problem to the classical simultaneous collection-distribution vehicle routing model in the literature. The model has a multi-period and multi-depot structure, and optimizes the distribution of ammunition determined according to the demand estimation results to the units and the return of collected ammunition residues to the depots. The number of vehicles to be distributed is calculated after finding the routes from the model. In this way, the number of vehicles required to be in the depot and the excess amount are revealed.

The most important finding of the study is that the developed model provides significant efficiency in ammunition distribution. The model distributed 10,086 ammunition from 2 depots to 12 unit points over 30 days using the shortest route and minimum vehicle usage. In addition, the model allowed the number of vehicles in the depots to be reduced in the following days and to be shifted to other areas where needed. This is of great importance in terms of more efficient use of resources and reduction of logistics costs.

The literature review has shown that ammunition supply is always a force multiplier for military units and that on-time delivery is an important factor, although not sufficient for success. The vast majority of studies conducted are deterministic, single-depot and only distribution-oriented. Only one study has made a demand forecast, but it only focused on the distribution problem. This study, on the other hand, presents an ammunition distribution network design that has not been studied in the literature, is both distributed and collected, has multiple depots, is multi-period and includes demand forecasting. In this respect, it stands out from the literature and makes a difference.

Estimating the amount of ammunition that will be needed in a war environment is as important as the distribution of ammunition. In this study, a methodology for estimating the amount of ammunition required is presented by considering generic data. In this study, the probability function that the usage amounts fit into is calculated and the demand estimate is made accordingly. It is thought that different methods such as machine learning can be used in other future studies. In the application phase, first of all, suitability tests were performed for ammunition demand estimate. As a result of the tests performed using linear, exponential, exponential and parabolic functions, the exponential function with the highest significance coefficient (0.972) did not fit the general course of the war, so the exponential function with the significance coefficient of 0.956 was used for demand estimate. This is important in terms of the model's compliance not only with mathematical accuracy but also with the realistic situation in the field.

As a result of the application of the model, while there were initially 10 vehicles in each depot, 1 vehicle was planned for each unit point between the 2nd and 8th days, when the most vehicles were needed. In the following days, it was observed that the distribution could be completed with 1 vehicle for 2 unit points between the 9th and 17th days, and 1 vehicle for 3 unit points between the 18th and 30th days. These results show that the model has a dynamic structure and can revise the planning according to changing needs. In addition, it was determined that 4 of the 10 vehicles in each depot between the 2nd and 8th days were not needed, 7 vehicles between the 9th and 17th days, and 8 vehicles between the 18th and 30th days. This proves that the model optimizes resource usage and prevents unnecessary vehicle usage.

There are also some limitations to this study. First of all, the data used are generic data from past battles. In future studies, the validity and reliability of the model can be increased by using data specific to more specific scenarios and geographical regions. The model can be expanded to include different ammunition types and their properties.

The following suggestions can be offered for future research:

- Stochastic Demand Forecast: In this study, a deterministic demand forecast was made. In future studies, stochastic demand forecast methods that better reflect uncertainty and variability can be used.
- Dynamic Routing: The combat environment is a dynamic and variable environment. In future studies, dynamic routing algorithms can be developed that take into account real-time data flow and update routes according to instant changes.

- Multi-Objective Optimization: In this study, only distance minimization is used as the objective function. In future studies, multi-objective optimization models that take into account other factors such as cost, risk, and time can be developed.
- Artificial Intelligence and Machine Learning: Artificial intelligence and machine learning techniques can be used in areas such as demand forecasting, route optimization, and resource management. Future studies can investigate the integration of these techniques into ammunition distribution network design.

In conclusion, this study shows that analytical methods can be used for ammunition demand estimation and distribution network design and that these methods can provide a significant logistic advantage in the battlefield. The developed model contributes to the timely and safe delivery of ammunition to the troops by ensuring the efficient use of resources. The studies to be carried out in line with the presented suggestions will enable the optimization of ammunition estimation and distribution and the effective and efficient use of resources by improving logistic capabilities in the battlefield.

Conflicts of Interest

The author declare no conflicts of interest.

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