# Location Planning of Field Ammunition Depot for Just in Time

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**Abstract.** The location of the field ammunition warehouse is the key step to optimizing the ammunition supply support system, and it is also one of the steps to effectively reduce the ammunition supply cost. All along, previous studies on ammunition supply support have been divided into two categories, one is ammunition support based on JIT, and the other is how to effectively select the site, which can effectively combine JIT and site selection, but few people have done it. These two factors are mutually restrictive, interactive, and complimentary. The research on JIT-oriented field ammunition warehouse location will be of great significance to the development of our military ammunition supply support system. This paper focuses on this issue.

**Keywords:** field ammunition depot · Just in Time (JIT) · location planning · ammunition supply

## 1 Introduction

Field ammunition depot is a powerful guarantee for the continuous supply of ammunition in wartime, and many factors must be considered in its setting. In the course of combat, there are often complex factors such as the destruction of transportation by the enemy and the dynamic change of ammunition demand of our army, which have a great influence on the timely supply of ammunition. As an important part of the rapid ammunition supply system, the field ammunition warehouse is responsible for ammunition storage in wartime, which can provide fast [1] and accurate ammunition support for combat troops. It plays a key role in the combat process. The site selection and construction of field ammunition depot have a great influence on the level and quality assurance of rapid ammunition. The site selection method of field ammunition depot and ammunition demand prediction method are both important components of ammunition support theory, which greatly improve the ability of ammunition supply on time [2, 3]. In this respect, it is urgent to find a quick positioning method for the field ammunition depot which is suitable for multiple stages of the battle.

The role of a field ammunition depot in local logistics is similar to that of the distribution center, but compared with a distribution center, a field ammunition depot is


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more flexible and will adjust and change with the changes in a battlefield situation. The scientific location of a distribution center in local logistics can effectively improve the on-time supply of materials. For example, to improve the supply level of auto parts, many auto manufacturers pay more and more attention to the research on the location of auto parts distribution centers [4]. In addition, there are many methods in the study of distribution center location. More classical positioning problems are solved by lingo, genetic algorithm, and particle swarm optimization [5–7]. At present, many more advanced location selection methods have been developed, such as improved immune algorithms and cuckoo search [8]. However, these methods are mainly aimed at the site selection research of field ammunition depot quick positioning methods which are suitable for multi-stage operations in a single stage.

The timing of field ammunition warehouse configuration should be determined according to the requirements of the combat style and support tasks of the troops, and the preset configuration or accompanying configuration should be implemented. Therefore, it is necessary to focus on the research on the location of the field ammunition depot facing JIT(Just in Time). When the JIT(Just in Time)-oriented field ammunition depot location is preset, the terrain should be surveyed and the depot location selected in advance, to ensure that the troops arrive at the designated allocation area before the combat troops [9, 10]. The field ammunition warehouse should arrive at the designated area at the same time as the combat troops and support forces, and be set up in the designated area.

## 2 Establishment of Location Planning Model of Field Ammunition Depot for JIT

### 2.1 Problem Background Description

During the battle, due to the change in the battlefield situation, the rear ammunition transportation road was damaged to varying degrees and the road was repaired by our troops. At the same time, the demand for ammunition in our country has also shown a phased change in the course of combat. In this case, the location of the field ammunition depot can be quickly determined from the alternative points of each ammunition depot, and the level of opening the field ammunition depot can be determined, to maximize the demand for combat ammunition and reduce the waste of resources.

### 2.2 Problem Analysis

This paper will take the field ammunition depot as the research object, introduce the concept of time window into the site selection model, embody the meaning of JIT, fully consider the wartime setting principle and safety management of our army's current field ammunition depot, and based on in-depth and systematic research on existing models and algorithms, it is proposed to analyze the site selection of field ammunition depot from the method of operational research, quantify the factors affecting the site selection and set the corresponding parameters, establish a 0–1 programming model with the lowest total cost, analyze the principle of genetic algorithm, and finally verify and determine the specific examples. In the planning process, affected by wartime conditions, it is necessary to comprehensively consider the traffic network, topography, climate and hydrology, and other factors, and analyze the constraint conditions, site selection process, and example verification to realize site selection optimization. For the location problem of multiple field ammunition warehouses, we should not only consider the optimal location of the node itself but also consider whether its location layout can make the whole ammunition supply support system have the highest efficiency and the best benefit.

### 2.3 Location Planning Model

To build the model, make the following assumptions.

(1) The ammunition storage capacity of the ammunition supply base is known;
(2) The capacity and number of field ammunition depots at each alternative point are limited;
(3) The unit ammunition transportation cost from the ammunition supply base to the field ammunition depot and from the field ammunition depot to combat troops is known;
(4) The demand per unit time (quarter) of each combat unit is known;
(5) The fixed cost and unit ammunition management cost of the field ammunition depot at the alternative point are certain and known constants;
(6) The time when the transport vehicle arrives at the combat troops is known;
(7) The earliest and latest allowable time for transport vehicles to arrive at combat troops is known;
(8) The opportunity cost of the vehicle waiting at the task point per unit of time is known;
(9) The loss value of the transport vehicles arriving at the unit time after the required time is infinite (failure to supply ammunition on time will cause great harm to the battlefield situation).

Under the above assumptions, the costs to be considered in this model research include:

(1) the management expenses of ammunition passed through the field ammunition depots and the fixed investment expenses of the field ammunition depots.
(2) Transport costs from ammunition supply base to field ammunition depots and transport costs from field ammunition depots to combat troops.
(3) The opportunity cost of waiting for the transport vehicle at the mission point and the penalty for the transport vehicle arriving after the required time.

Meaning of symbols in the model

$A$ is the assembly of the ammunition supply base.
$B$ is the collection of field ammunition depots.
$C$ is the collection of combat troops.
$G_{ab}$ is the transportation cost of unit ammunition from the ammunition supply base $a$ to the field ammunition depot $b$;
$H_{ab}$ is the transport volume from the ammunition supply base $a$ to the field ammunition depot $b$;
$W_{bc}$ is the transportation cost of unit ammunition from the field ammunition depot $b$ to the combat unit $c$;

$X_{bc}$ is the transport volume from the field ammunition depot $b$ to the combat unit $c$;
$F_b$ is the fixed cost of field ammunition depot $b$;
$Q_b$ is the management cost of $b$ unit ammunition of field ammunition depot;
$D_c$ is the unit time demand of $c$ combat forces;
$E_a$ is the ammunition reserve of $a$, the ammunition supply base;
$I_b$ is the capacity of the field ammunition depot $b$;
$ET_c$ is the earliest allowed time for transport vehicles to reach the combat unit $c$;
$LT_c$ is the latest allowable time for transport vehicles to reach combat force $c$;
$t_c$ is the time when the transport vehicle arrives at the customer node $c$;
$j$ is the opportunity cost of the vehicle waiting unit time at the task point;
$k$ is the penalty value imposed per unit of time when the vehicle arrives after the required time;
$m$ is the maximum number of ammunition magazines set in the field;

Decision variables:

$z_b$: If a field ammunition depot is opened at $b$, $z_b = 1$, otherwise $z_b = 0$;

Establish a mathematical model:

1) Cost of opening a field ammunition depot

The establishment cost includes the fixed cost and management cost of the construction of field ammunition depots, namely:

$$\sum_{b \in B} F_b z_b + \sum_{a \in A} \sum_{b \in B} Q_b H_{ab} \tag{1}$$

2) Ammunition transportation cost

Transportation costs include transportation costs from the ammunition supply base to field ammunition depots and logistics costs from field ammunition depots to customers, namely:

$$\sum_{a \in A} \sum_{b \in B} G_{ab} H_{ab} + \sum_{b \in B} \sum_{c \in C} W_{bc} X_{bc} \theta \tag{2}$$

3) Punishment cost

The penalty cost includes the opportunity cost of the vehicle waiting at the task point and the loss cost imposed by the vehicle arriving after the required time, which is simplified into the following model after processing:

$$j \sum_{c \in C} \max[(ET_c - t_c), 0] + k \sum_{c \in C} [(t_c - LT_c), 0] \tag{3}$$

Objective functions and constraints can be obtained as follows:

$$
\begin{aligned}
\min = & \sum_{b \in B} F_b z_b + \sum_{a \in A} \sum_{b \in B} Q_b H_{ab} \\
& + \sum_{a \in A} \sum_{b \in B} G_{ab} H_{ab} + \sum_{b \in B} \sum_{c \in C} W_{bc} X_{bc} \theta \\
& + j \sum_{c \in C} \max[(ET_c - t_c), 0] + k \sum_{c \in C} [(t_c - LT_c), 0]
\end{aligned} \tag{4}
$$

s.t.

$$
\begin{aligned}
& \sum_{b \in B} H_{ab} \le E_a \\
& \sum_{b \in B} X_{bc} = \sum_{a \in A} H_{ab} \\
& \sum_{b \in B} X_{bc} = D_c \\
& \sum_{a \in A} H_{ab} \le I_b z_b \\
& 1 \le \sum_{b \in B} z_b \le m \\
& z_b \in \{0, 1\}
\end{aligned}
$$

Equation 1 is the objective function, where the first part is the management cost of ammunition passing through the field ammunition depots and the fixed investment cost of the field ammunition depots. The second part is the transport cost of the ammunition supply base to field ammunition depots and the transport cost of field ammunition depots to combat troops; The third part is the opportunity cost of the vehicle waiting at the task point and the loss cost of the vehicle arriving after the required time.

Constraints (1) Ensure that the total amount of auto parts supplied from the ammunition supply base to the field ammunition depot cannot exceed the ammunition reserve of the ammunition supply base itself; Constraints (2) ensure that the amount of ammunition collected by the field ammunition depot from the ammunition supply base is equal to the amount of ammunition delivered to the combat troops; Constraint (3) to ensure that the needs of each combat force can be met; Constraint condition (4) ensure that the total amount of ammunition distributed to combat troops by field ammunition depots cannot exceed their capacity; Constraint condition (5) specifies the maximum number of allowed field ammunition depots and the minimum number of field ammunition depots; Constraint condition (6) is the constraint of the decision variable.

At present, the research on the location of the distribution center is relatively mature software lingo, Matlab, and so on. The common methods are 0–1 integer programming solution, genetic algorithm, particle swarm optimization algorithm, and so on. Aiming at the establishment of the field ammunition depot location model, this paper uses the fastest solution lingo software to solve.

With the progress of the operation, the position of each combat unit, the demand for ammunition, and transport road conditions are in the process of constant change. Therefore, the target model needs to reflect the wartime situation. Therefore, the site selection of field ammunition depots should take the shortest supply time of ammunition as the primary objective. In this regard, a model with the shortest supply time as the primary objective is established:

$$\min W_2 = \sum_{k=1}^{l}\sum_{i=1}^{n} c_{ki} l_{ki} d_i + \sum_{i=1}^{n}\sum_{j=1}^{m} v_{ij} x_{ij} d_j + \sum_{k=1}^{l}\sum_{i=1}^{n} p_i l_{ki} + \sum_{i=1}^{n} b_i F_i$$

$$s.t.\begin{cases} \sum_{i\in n} l_{ki} \le B_k (k = 1, 2, 3, ..., l) \\ \sum_{k\in K} l_{ki} \le N_i (i = 1, 2, 3, ..., n) \\ \sum_{i\in I} x_{ij} \ge D_j (j = 1, 2, 3, ..., m) \\ \sum_{i\in I} b_i \le H_p \\ \sum_{j\in J} y_{ij} = 1 \\ \sum_{j\in J} x_{ij} = \sum_{k\in K} l_{ki} \\ b_i = \begin{cases} 1, \text{located at this point} \\ 0, \text{not located at this point} \end{cases} \\ l_{ki} \ge 0, x_{ij} \ge 0, k \in K, i \in N, j \in M \end{cases} \tag{5}$$

$$d^t_{\widehat{ilj}} = \begin{cases} 1, \textit{At stage } t, \text{select route } l \text{ from field ammunition} \\ \text{library } i \text{and deliver it to combat unit } j \\ 0, \textit{At stage } t, \textit{do not } \text{select route } l \text{ from field ammunition} \\ \text{library } i \text{and deliver it to combat unit } j \end{cases} \tag{6}$$

where $W_1$ is the total transport time of ammunition;
$Q^t$ opens the collection of field ammunition depots for phase $t$;
$d_{\widehat{ilj}}$ is the actual path $l$ from the node $i$ to node $j$;
$v_l$ is the traffic speed of the road $l$ without damage;
$\rho_l^t$ is the traffic efficiency of phase $t$, $\rho_l^t \in [01]$. A value of 0 indicates that the road is destroyed. A value of 1 indicates that the road is not under enemy attack.

According to the hypothesis, the field ammunition depot location model with the minimum cost as the secondary objective is obtained:

$$\min W_2 = \sum_{k=1}^{l}\sum_{i=1}^{n} c_{ki} l_{ki} d_i + \sum_{i=1}^{n}\sum_{j=1}^{m} v_{ij} x_{ij} d_j + \sum_{k=1}^{l}\sum_{i=1}^{n} p_i l_{ki} + \sum_{i=1}^{n} b_i F_i \tag{7}$$

where $W_2$ -- Total ammo replenishment cost;
$c_{ki}$ - the rate of transport per unit distance from the supply center to the field ammunition depot;
$l_{ki}$ -- Traffic from supply centers to field ammunition depots;
$d_i$ -- Transport distance from supply center to field ammunition depot;
$v_{ij}$ - The transport rate for the unit distance from the field ammunition depot to the combat unit;
$x_{ij}$ - The amount of transport from field ammunition depots to combat units;
$d_j$ -- Transportation distance from field ammunition depots to supply centers
$p_i$ -- unit processing cost of ammunition in field ammunition depots;
$b_i$ -- Whether to build a field ammo depot at this point;
$F_i$ -- Fixed construction cost for a field ammo depot;

$$\min W_2 = \sum_{k=1}^{l}\sum_{i=1}^{n} c_{ki} l_{ki} d_i + \sum_{i=1}^{n}\sum_{j=1}^{m} v_{ij} x_{ij} d_j + \sum_{k=1}^{l}\sum_{i=1}^{n} p_i l_{ki} + \sum_{i=1}^{n} b_i F_i$$

$$s.t. \begin{cases} \sum\limits_{i \in n} l_{ki} \le B_k (k = 1, 2, 3, ..., l) \\ \sum\limits_{k \in K} l_{ki} \le N_i (i = 1, 2, 3, ..., n) \\ \sum\limits_{i \in I} x_{ij} \ge D_j (j = 1, 2, 3, ..., m) \\ \sum\limits_{i \in I} b_i \le H_p \\ \sum\limits_{j \in J} y_{ij} = 1 \\ \sum\limits_{j \in J} x_{ij} = \sum\limits_{k \in K} l_{ki} \\ b_i = \begin{cases} 1, \text{located at this point} \\ 0, \text{not located at this point} \end{cases} \\ l_{ki} \ge 0, x_{ij} \ge 0, k \in K, i \in N, j \in M \end{cases}$$

$\sum_{i \in n} l_{ki} \le B_k$ -- The amount of ammunition transported from the supply center to the field ammunition depot is not greater than its maximum replenishment, $B_k$ is the maximum replenishment of the supply center;
$\sum_{k \in K} l_{ki} \le N_i$ --The quantity of ammunition transported from the supply center to the field ammunition depot is not greater than the maximum stock of the field ammunition depot, $N_i$ is the maximum stock;
$\sum_{i \in I} x_{ij} \ge D_j$ -- the ammunition supply from the field ammunition depot can meet the demand of the combat troops, $D_j$ is the ammunition demand of the combat troops;
$\sum_{i \in I} b_i \le H_p$ -- Maximum build value of field ammo depots, $H_p$ is the maximum value;

$\sum_{j \in J} y_{ij} = 1$ -- Each combat unit is resupplied by only one field ammunition depot, which equals 1 if the field ammunition depot supplies ammunition to combat units, 0 otherwise; $\sum_{j \in J} x_{ij} = \sum_{k \in K} l_{ki}$-- The field ammo depot only completes warehousing tasks, regardless of transportation losses.

## 3 Example Analysis

The following is an example validation of the location model, which involves 6 ammunition supply bases, 4 field ammunition depots, and 7 combat units. The total supply and storage of the ammunition supply base, related parameters of field ammunition depots, the demand of combat troops, transportation cost from ammunition supply base to field ammunition depots and transportation cost from field ammunition depots to combat troops are assumed, as shown in Tables 1, 2, 3, 4, and 5. In order to simplify the operation, according to the assumptions of the model in 2.2, set shipping time $t_0 = 2$, earliest time $ET_0 = 5$, latest time $LT_0 = 6$.

**Table 1.** Total supply of the supply center

| Ammunition supply center | The total supply |
|---|---|
| A1 | 60000 |
| A2 | 40000 |
| A3 | 50000 |
| A4 | 80000 |
| A5 | 40000 |
| A6 | 70000 |

**Table 2.** Parameters of field ammunition depots

| Field ammunition depot | Capacity | Fixed construction charge | Overhead charge/per issue |
|---|---|---|---|
| W1 | 70000 | 500000 | 5 |
| W2 | 60000 | 300000 | 1 |
| W3 | 70000 | 400000 | 3 |
| W4 | 50000 | 400000 | 4 |

**Table 3.** Combat force requirements

| Combat troops | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|
| Demand for | 300 | 700 | 1000 | 500 | 400 | 800 | 200 |

**Table 4.** Transportation costs from supply centers to field ammunition depots

| | W1 | W2 | W3 | W4 |
|---|---|---|---|---|
| A1 | 6 | 4 | 2 | 5 |
| A2 | 4 | 3 | 9 | 4 |
| A3 | 7 | 6 | 8 | 2 |
| A4 | 6 | 7 | 4 | 3 |
| A5 | 4 | 5 | 1 | 2 |
| A6 | 3 | 1 | 4 | 7 |

**Table 5.** Transportation costs of field ammunition depots to combat troops

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|
| W1 | 3 | 7 | 4 | 5 | 6 | 4 | 3 |
| W2 | 6 | 1 | 3 | 5 | 7 | 4 | 5 |
| W3 | 2 | 4 | 5 | 3 | 6 | 5 | 6 |
| W4 | 5 | 6 | 3 | 7 | 4 | 8 | 5 |

Using the above data, combined with the established mathematical model, using lingo software to solve. Lingo program is as shown in Figs. 1 and 2.

It can be seen from the above results that the total cost of the optimal objective function is 319,084 yuan when the alternative address No. 2 is chosen as the best field ammunition depot location.

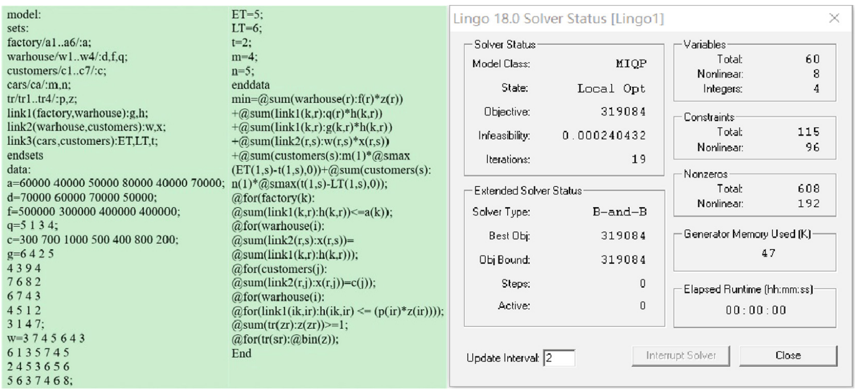


**Fig. 1.** Lingo program code and Lingo program running interface

```
      C( C5)        400.0000        0.000000
      C( C6)        800.0000        0.000000
      C( C7)        200.0000        0.000000
      M( CA)        4.000000        0.000000
      N( CA)        5.000000        0.000000
     P( TR1)        925.3038        0.000000
     P( TR2)        3900.000        0.000000
     P( TR3)        808.8057        0.000000
     P( TR4)        1549.115        0.000000
     Z( TR1)        0.000000        0.000000
     Z( TR2)        1.000000        0.000000
     Z( TR3)        0.000000        0.000000
     Z( TR4)        0.000000        0.000000
  G( A1, W1)        6.000000        0.000000
  G( A1, W2)        4.000000        0.000000
  G( A1, W3)        2.000000        0.000000
  G( A1, W4)        5.000000        0.000000
  G( A2, W1)        4.000000        0.000000
  G( A2, W2)        3.000000        0.000000
  G( A2, W3)        9.000000        0.000000
```

**Fig. 2.** Results of the running of the Lingo program

## 4 Conclusion

Based on optimizing the JIT-oriented ammunition supply strategy, this paper studies and analyzes the problem of field ammunition warehouse setting. Based on analyzing the location principle of field ammunition warehouse, a planning model of ammunition warehouse setting based on cost optimization is established with the address and type of possible ammunition warehouse in the combat area as the location constraint, and LINGO is used as an example to verify that the location result is lower in cost. The site selection of a field ammunition depot involves many factors, and its function is to ensure that ammunition is delivered to combat troops on time and safely. Therefore, future research can be done from the aspect of punctuality.

## References

1. Y. Li, R. Zhao, X. Shi, "Simulation of ammunition consumption conversion factor considering damage degree," Journal of Physics: Conference Series, vol.5, no.2, pp. 19–25, 2020. https://doi.org/10.1088/1742-6596/1533/2/022127.
2. Yu Xinyong, Gao Xiaohua, Wang Lei, Wang Xinwei, Ding Yu, Lu Chen, Zhang Sheng. Cooperative Multi-UAV Task Assignment in Cross-Regional Joint Operations Considering Ammunition Inventory[J]. Drones, 2022, 6(3). https://www.mdpi.com/2504-446X/6/3/77
3. Zuo Zhaojun, Pan Shaoqing, Xiong Chun. Based on the grey situation decision problem of site selection of aviation ammunition study [J]. Journal of Changsha aviation professional technology institute, 2006 (3): 25–27. https://doi.org/10.13829/j.cnki.issn.1671-9654.2006.03.008
4. Liu Zeyang, Xu Guangan, Gong Cheng, Qiu Yanyu. Analysis of key factors of safety distance of soil-covered ammunition depot [J]. Protection Engineering, 2021, 43(06):22–28. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7iJTKGjg9uTdeTsOI_ra5_XfJ0MWAwaNLhyWz1phjV07RGTjYq0JLpS6dT8Zlk1G4i&uniplatform=NZKPT&src=copy
5. Fu Zhiyin, Tian Baofa, Liu Wenchao, Cao Wanlin, Liu Wenyong, Niu Toshihi. Firearms ammunition in the structure of concrete wall design study [J]. Journal of natural disasters, 2017, 26 (01): 123–128. https://doi.org/10.13577/j.jnd.2017.0115
6. JIANG Xiaoyi. Location selection of emergency medical supplies Warehouse based on SIR Model [C]//. The 13th China steel conference proceedings (paper) - conference guest report & venue guest., 2022:154. https://doi.org/10.26914/c.cnkihy.2022.018039

7. Huo Xuemi, Fu Hang. Research on Logistics Distribution Center location based on Lingo [J]. Logistics Engineering and Management, 2020, 42(02):111–112. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7i8oRR1PAr7RxjuAJk4dHXot_pPCNktGMFrWXzPDUTmAaVxiWHa6IW1GoG3hOiNqk&uniplatform=NZKPT&src=copy
8. Qinglin Ding, Hong Liu. Research on Location Selection of Dairy Products Logistics Distribution Center Based on Mixed Integer Programming Model[J]. Academic Journal of Engineering and Technology Science, 2020, 3(5). https://schlr.cnki.net/Detail/index/GARJ2020/SJIW83B8FCCF982C7BDBFAD0E4EBBAF6AAAB
9. Ding Yujiao. Study on location of fresh agricultural products logistics park based on multi-objective programming [J]. Value Engineering, 2019, 38(12):83–85. https://doi.org/10.14018/j.cnki.cn131085/n.2019.12.026.
10. Chen ai-wen. Study on location of fresh produce distribution center based on multi-objective sparrow search algorithm [D]. Anhui Agricultural University, 2022. https://doi/https://doi.org/10.26919/d.cnki.gannu.2022.000720.