Location Planning of Field Ammunition Depot for Multi-stage Supply Based on Dijstra Algorithm

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Abstract. The location of field ammunition depots is related to the efficiency and effectiveness of ammunition supply and support, and is affected by the changing needs of different stages of operations. In response to complex situations such as damage to transportation roads, repairs, and dynamic changes in demand in the course of combat, the fastest supply speed is the primary goal, while the satisfaction rate, balance, and cost factors of the ammunition supply at each demand point are taken into account to build a multi-stage supply Site selection planning model for field ammunition depot. Use Dijstra algorithm's hierarchical sequence method to determine the shortest supply time, gradually increase the supply time, find the relationship between supply time, satisfaction rate, balance and cost, and find a satisfactory location plan. Finally, the simulation case calculations show that the model can cover some key dynamic changes during wartime, with strong adaptability and more scientific site selection.

1. Introduction
The field ammunition depot is a strong support to ensure the continuous supply of ammunition in wartime, and its setting must consider many factors. In the course of combat, there are often complicated factors such as the enemy's damage to transportation and the dynamic changes in our ammunition demand, which have a greater impact on the punctual supply of ammunition. As an important part of the rapid ammunition supply system, the field ammunition warehouse is responsible for ammunition storage under wartime conditions, and can provide fast and accurate ammunition support for combat troops [1]. It plays a key role in the process of combat. The location and construction of field ammunition depots greatly affect the level of rapid ammunition support and quality assurance. The method of site selection for field ammunition depots and the method of forecasting ammunition demand are both important parts of ammunition guarantee theory, and both greatly improve the on-time supply capability of ammunition [2-3]. In this regard, it is urgent to find a rapid location method for field ammunition depots suitable for multiple stages of the combat process.

The role of the field ammunition depot is similar to that of the distribution center in local logistics, but compared to the distribution center, the field ammunition depot is more flexible and will adjust and change with the battlefield situation. The scientific nature of the location of the distribution center in local logistics can effectively improve the on-time supply of materials. For example, many automobile manufacturers pay more attention to the research on the location of auto parts distribution centers in order to improve the level of parts supply [4]. In addition, many methods have emerged in the research on the location of distribution centers. The more classic location problem is solved by lingo, genetic algorithm, and particle swarm algorithm [5-7]. At present, many more advanced location selection methods have been developed, such as improved immune algorithm, cuckoo search algorithm, etc. [8-9]. However, these methods are mainly aimed at the site selection research under the single-stage
situation, and are not applicable to the site selection problem of field ammunition depots under multi-stage and changing conditions. Regarding the location of the emergency material distribution center, although changes in demand have been considered, the relationship between supply time, cost, and satisfaction rate has not been explored [10-12].

Aiming at the problem of field ammunition selection under multi-stage changes, this paper uses the layered sequence method coupled with Dijkstra algorithm to solve the shortest supply time. The labeling method is used to determine the fastest path from each ammunition demand site to the field ammunition depot and the location of the field ammunition depot. Then adjust the supply time in turn, select the location of the field ammunition depot, explore the relationship between supply time, satisfaction rate, balance and cost, and find a satisfactory location plan.

2. Multi-stage Supply Model of Field Ammunition Location Selection

2.1. Problem Background Description

During the course of the battle, due to changes in the battlefield conditions, the ammunition transportation road in the rear was damaged to varying degrees and the road was rushed to repair by our troops. At the same time, the demand for our ammunition in the course of combat has also shown phase changes. In this case, quickly determine the location of the field ammunition depot from the candidate points of each ammunition depot, and determine the level of the field ammunition depot to maximize the demand for combat ammunition and reduce the waste of resources. The background process is shown in Figure 1.

Among them, the thicker the transportation line indicates that the road transportation capacity is stronger under normal circumstances, and the dashed transportation line indicates that the line is attacked by the enemy, which will cause the traffic capacity of the route to be weakened. The dashed ellipse indicates that there is no ammunition warehouse at this location. At the same time, in order to simplify the model, suppose:

1. The dynamic demand of ammunition for each combat unit at each stage of the war is known.
2. The damage and repair of the road are known.
3. There are sufficient ammunition transportation vehicles, and the transportation cost is linearly related to the load and time.
4. The opening time of the ammunition warehouse and the time of ammunition loading and unloading can be ignored.

![Figure 1. The background map of the site selection of the field ammunition depot in wartime.](image)

2.2. Site Selection Model Construction

Based on the above analysis of the characteristics of wartime ammunition supply, the coupled Dijkstra algorithm is used to model the location of the field ammunition depot. The coupled Dijkstra algorithm
can use the label to gradually find the location and path of the field ammunition depot that is the fastest from the combat unit, which can be adapted to the solution of this model. After the battle begins, quickly collect road network information in the combat area. Include:

1. \( d_{ij} \): The actual distance from the location node \( i \) to the path \( l \) to the node \( j \).
2. \( v_i \): Traffic speed on road when road is undamaged.
3. \( \rho_i \): Traffic efficiency of road \( l \) in the \( t \)-stage of the operation. \( \rho_i \in [0, 1] \). The lower the \( \rho_i \)-value, the more severe the road damage. \( \rho_i \) takes 0, indicating that the road is completely destroyed. \( \rho_i \) is 1, indicating the road is not attacked by the enemy. And \( \rho_i \) will increase by repairing the road.

Due to the high requirements for the on-time supply of ammunition under wartime conditions, the shortest supply time of ammunition should be the primary goal for the site selection of field ammunition depots. In this regard, establish a model with the shortest supply time as the primary goal:

\[
\min W_1 = \sum_{i \in Q^s} \sum_{j \in M} d_{ij} y_{ij} \rho_i
\]

\[
y_{ij} = \begin{cases} 
1, & \text{At stage } t, \text{ select route } l \text{ from field ammunition} \\
0, & \text{At stage } t, \text{ do not select route } l \text{ from field ammunition} 
\end{cases}
\]

Among them, \( W_1 \) is the total transportation time of ammunition. \( Q^s \) is the assembly of the open ammunition depot in the first stage, and \( M \) is each combat unit. With the advancement of the combat process, the positions of the combat forces, the demand for ammunition, and the transportation road conditions are in a process of constant change. Therefore, the established target model can reflect this situation in wartime.

Within a short period of time after the war, the supply of ammunition could not meet the needs of all combat troops. Therefore, the built model needs to make full use of the ammunition in the ammunition supply base to maximize the ammunition demand of the combat troops. At the same time, in order to avoid a situation where some combat troops are in sufficient supply of ammunition while others are in short supply. In this regard, the supply of ammunition should consider the balance of demand satisfaction. A model that targets the rate of ammunition supply satisfaction and the rate of ammunition supply imbalance should be established:

\[
\max W_2 = \sum_{i \in Q^s} \sum_{j \in M} \sum_{t = T} S_{ij}^t D_j^t
\]

\[
\min W_3 = \sum_{i \in Q^s} \sum_{j \in M} \sum_{t = T} \left[ \left( S_{ij}^t / D_j^t \right) - \min \left( S_{ij}^t / D_j^t \right) \right]
\]

Among them, \( W_2 \) is the ammunition demand satisfaction rate, which reflects the satisfaction of the ammunition demand. \( W_3 \) is the supply imbalance value, which reflects the imbalance in the supply of ammunition; \( T \) is the \( n \) stages in the battle process; \( D_j^t \) is the demand for ammunition at the combat location \( j \) in the \( T \) stage. \( S_{ij}^t \) is the supply of field ammunition depot \( i \) to the combat site \( j \) in the \( T \) stage.

The location of field ammunition depots should also consider the cost of ammunition supply, which mainly includes: ammunition transportation costs, ammunition depot setup costs, ammunition depot reconstruction costs, and ammunition depot maintenance costs. In this regard, a cost-oriented model can be established.

\[
\min W_4 = \sum_{i \in Q^s} \sum_{t = T} (E_{ij} x_{ij}^t + M_j z_{ij}^t) + \sum_{i \in Q^s} \sum_{j \in M} \sum_{t = T} \omega S_{ij}^t d_{ij} y_{ij}^t
\]
Among them, $W_i$ is the total supply cost; $E_{ij}$ is the construction cost required to expand the $e$-class ammunition depot to $f$-class, $\{e,f\} = \{0, 1, 2, 3\}$ and $f \geq e$, if there is no field ammunition depot originally set up, then $e = 0$; $M_i$ is the maintenance cost of the $f$-class ammunition depot. It is related to the size of the field ammunition depot and the amount of ammunition dispatch; $w$ is the cost of transporting a unit amount of ammunition per unit distance.

$$x^t_i = \begin{cases} 1, & \text{At stage } t, \text{an } f - \text{level ammunition depot needs to be built at } i \\ 0, & \text{Do not use the ammunition depot at } i \text{ at stage } t, \text{or an ammunition depot that satisfies the scale has been built} \end{cases} \quad (6)$$

$$z^t_i = \begin{cases} 1, & \text{In phase } t, \text{the ammunition depot with the scale of } f \text{ at } i \text{ is activated} \\ 0, & \text{In phase } t, \text{the ammunition depot with the scale of } f \text{ at } i \text{ is not activated} \end{cases} \quad (7)$$

$$\begin{align*}
\sum_{i \in U^t} z^t_i & \geq \sum_{i \in U^t} x^t_i > 0, \ t \in T \\
S_{j}^{t}_c & \leq Q_{j}^{t}, \ \forall j \in D, \ c \in C
\end{align*} \quad (8)$$

Among them: Formula (8) indicates that the field ammunition warehouse $i$ is activated, and there must be a road from the ammunition warehouse to other locations. If the ammunition depot is not activated, the road from the ammunition depot to other places must not be selected. Equation (9) indicates that the traffic efficiency is between 0 and 100%. Equation (10) indicates that in any period, the number of ammunition depots to be built is greater than or equal to 0, and the number of ammunition depots constructed in this phase must be less than the number of ammunition depots activated in this phase. Equation (11) indicates that the supply of ammunition cannot be higher than the demand for ammunition.

3. Location Model Solution

The punctual supply of ammunition is the key to winning the war, so the ammunition supply time should be as short as possible. At the same time, for the overall stability of the war, it is not only necessary to consider the satisfaction of the ammunition demand of combat troops, but also to consider the balance of ammunition supply. Moreover, due to the limitations of the human and material resources of the ammunition support department, these limitations are converted into cost constraints. The solution process of this paper is as follows:

(1) Collect information at each stage of the combat process, use Dijkstra's method to solve the fastest transportation path from the field ammunition depot to each combat unit, mark each combat unit as the initial point, gradually mark to find the fastest transportation path, and at the same time determine the field that needs to be developed Ammunition warehouse, get the initial opening plan of the ammunition warehouse.

(2) Based on the initial starting plan, the supply time will be adjusted upwards. At the same time, considering the balance of ammunition supply and the cost of supply, and considering the use of the established field arsenal, the initial model is adjusted.

(3) Based on the above analysis, a diagram of the "time-balance-cost" relationship of ammunition supply under wartime conditions is established. According to the existing conditions, the site selection plan of the field ammunition depot should be carried out reasonably.
4. Case Simulation Site Selection

4.1. Simulation Case Description

With a simulation combat exercise as the background, the dynamic information of the battlefield is collected to provide design basis for ammunition support. No. 1-2 is the ammunition supply base, No. 3-8 is the waiting point for the field ammunition depot, and No. 9-18 is the combat unit. In order to simplify the calculation, this case has the following assumptions:

(1) Taking into account the convenience of supply, the No. 1 ammunition supply base is only suitable for supplying ammunition to the field ammunition depots at the candidate points 3, 4, and 8, and the No. 2 ammunition supply base is only suitable for the candidate points 5, 7, and 6. The field ammunition storehouse supplies ammunition.

(2) Regardless of the level of ammunition storage, the cost of field ammunition storage is only divided into fixed costs and variable costs.

(3) The transportation cost and management cost per unit of ammunition are only directly proportional to the supply time at this stage.

The ammunition storage volume of each stage of the ammunition supply base 1 and 2 and the ammunition demand of each stage of the combat troops 9-18 are shown in Table 1, and the road traffic conditions of each stage are shown in Table 2:

Table 1. Storage/demand scale.

|                | Stage 1 | Stage 2 | Stage 3 |
|----------------|---------|---------|---------|
| Supply base 1  | 4800    | 5300    | 1400    |
| Supply base 2  | 5300    | 4500    | 2800    |
| Combat troops 9| 2300    | 0       | 0       |
| Combat troops 10| 2800   | 1800    | 0       |
| Combat troops 11| 0      | 1100    | 500     |
| Combat troops 12| 0      | 1200    | 400     |
| Combat troops 13| 3200   | 1000    | 0       |
| Combat troops 14| 0      | 600     | 0       |
| Combat troops 15| 0      | 800     | 200     |
| Combat troops 16| 0      | 0       | 800     |
| Combat troops 17| 0      | 0       | 500     |
| Combat troops 18| 0      | 0       | 800     |

Table 2. Road traffic time conditions at each stage.

| Road   | Stage 1 | Stage 2 | Stage 3 | Road   | Stage 1 | Stage 2 | Stage 3 |
|--------|---------|---------|---------|--------|---------|---------|---------|
| 3-9    | 4       | 5       | 3       | 8-15   | 4       | 4       | 3       |
| 4-10   | 2       | 6       | 2       | 8-11   | -       | 5       | 4       |
| 5-9    | 6       | 6       | 3       | 9-10   | 8       | 6       | 4       |
| 5-13   | 7       | -       | 5       | 11-15  | 9       | 6       | 4       |
| 6-14   | 4       | 3       | 5       | 11-12  | -       | 7       | 3       |
| 6-16   | 6       | 4       | 6       | 11-17  | -       | 3       | 3       |
| 6-18   | 4       | 4       | 4       | 12-15  | -       | 4       | 4       |
| 7-9    | 5       | 5       | 6       | 12-18  | 7       | -       | 2       |
| 7-10   | 3       | -       | 6       | 14-15  | 3       | 8       | 2       |
| 7-13   | 3       | 5       | 6       | 15-16  | 3       | 10      | 6       |
| 7-15   | 4       | 6       | 2       | 17-18  | 4       | 3       | 2       |
4.2. Solving the Simulation Case
The coupling Dijkstra algorithm is used to find the fastest path from the field ammunition depot to the combat unit, and the supply time is adjusted upwards to determine the location of the field ammunition depot and its supply route. Consider the situation of demand satisfaction and supply imbalance, remove the site selection plan with long time, low demand satisfaction rate, and high supply imbalance, and further adjust the site selection plan. The site selection plan shown in Table 3 can be obtained:

| Program | Phase 1 Open the ammunition depot number | Phase 2 Open the ammunition depot number | Phase 3 Open the ammunition depot number | Total supply time | Consume guarantee resources | Demand satisfaction | Supply imbalance |
|---------|------------------------------------------|------------------------------------------|------------------------------------------|------------------|-----------------------------|---------------------|------------------|
| 1       | 3, 4, 7                                  | 4, 7, 8, 6                               | 8, 7, 6                                  | 68               | 32262                       | 0.9834              | 0.117            |
| 2       | 4, 7                                     | 4, 7, 8, 6                               | 8, 7, 6                                  | 69               | 27442                       | 0.989               | 0.0727           |
| 3       | 3, 7                                     | 4, 7, 8                                 | 8, 7, 6                                  | 69               | 32342                       | 0.9613              | 0.233            |
| 4       | 3, 4, 7                                  | 4, 7, 8, 6                               | 8, 6                                     | 70               | 32390                       | 0.9834              | 0.117            |
| 5       | 4, 7                                     | 4, 7, 8, 6                               | 8, 6                                     | 71               | 27570                       | 0.989               | 0.0727           |
| 6       | 3, 7                                     | 4, 7, 8, 6                               | 8, 6                                     | 71               | 27471                       | 0.9613              | 0.233            |
| 7       | 3, 4, 7                                  | 7, 8, 6                                 | 8, 7, 6                                  | 73               | 33072                       | 0.9834              | 0.117            |
| 8       | 4, 7                                     | 7, 8, 6                                 | 8, 7, 6                                  | 74               | 28092                       | 0.989               | 0.0727           |
| 9       | 3, 7                                     | 7, 8, 6                                 | 8, 7, 6                                  | 74               | 27993                       | 0.9613              | 0.233            |
| 10      | 3, 4, 7                                  | 4, 7, 8, 6                               | 7, 8                                     | 75               | 32710                       | 0.9834              | 0.117            |
| 11      | 3, 4, 7                                  | 7, 8, 6                                 | 8, 6                                     | 75               | 33040                       | 0.9834              | 0.117            |
| 12      | 4, 7                                     | 4, 7, 8, 6                               | 7, 8                                     | 76               | 27890                       | 0.989               | 0.0727           |
| 13      | 4, 7                                     | 7, 8, 6                                 | 8, 6                                     | 76               | 28220                       | 0.989               | 0.0727           |
| 14      | 4, 7                                     | 4, 7, 8                                 | 7, 8                                     | 85               | 23904                       | 0.9781              | 0.2537           |

From this, the relationship change diagram shown in the following figure can be obtained:

**Figure 2. Diagram of relationship changes.**

From the above analysis, it can be found that Scheme 2 has a slight increase in time compared with Scheme 1, but the cost is drastically reduced. The reason is that Scheme 2 does not open a field ammunition depot. At the same time, Option 2 is also better than Option 1 in terms of demand satisfaction rate and balance, so Option 2 can be given priority. In addition, from the above research results, it is found that position 7 appears more frequently in various stages, indicating that position 7 is the focus of the construction of field ammunition depots and plays an important role. Key consideration should be given to building a field ammunition depot at position 7.
5. Conclusion
The field ammunition depot is an important part of ammunition protection, and its construction must change with the changes of the battlefield stage to ensure the rapid supply of ammunition. In this regard, from the perspective of the fastest supply time, this article considers the balance of supply and the limitation of guarantee resources, establishes a 0-1 planning model, and uses the layered sequence method coupled with the Dijsstra algorithm to solve the model, and uses the Dijsstra labeling method to determine operations. The fastest distance from the troops to the field ammunition depot, and considering the supply capacity of the field ammunition depot, determine the relationship between the supply time and the consumption of resources, and at the same time find the key construction location, to provide help for the site selection of the field ammunition depot under wartime conditions.

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