Research on the Vehicle Turnover Equipment Inventory Demand Forecasting Based on System Dynamics

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Abstract. The method of system dynamics was applied to the forecasting of the vehicle turnover equipment inventory demand. This paper first analyzed the key indicators affecting inventory demand forecasting and their causality, then established the dynamic model of the vehicle turnover equipment inventory demand forecasting. Finally, the accuracy and applicability of the method was validated, which can provide reference for inventory demand forecasting of army turnaround equipment.

1. Introduction
The accurate prediction of the vehicle turnover equipment demand is the key basis for the troops to make inventory control decisions. Its demand is affected by many complicated factors, showing a nonlinear or linear law, which is a common system dynamic feedback complexity problem. Equipment can be divided into continuous demand equipment and intermittent demand equipment [1] according to the frequency of demand. The research object of this paper is mainly the continuous demand equipment with more statistical data. At present, the prediction methods for the continuous equipment demand usually include time series method, regression analysis method, exponential smoothing method and neural network prediction method. However, these methods take relatively few factors into account and are difficult to predict accurately and systematically.

Using the qualitative analysis of system dynamics and the quantitative analysis of mathematical methods, a dynamic model for predicting the inventory demand of vehicle turnover equipment is established, which takes into account various major influencing factors more comprehensively and systematically, making the prediction results more accurate and reasonable.

2. Analysis of key indicator factors of inventory demand
Through the analysis of the relevant factors affecting the inventory demand, combined with the field research and expert assessment of the troops, the three key indicators of vehicle equipment scale, new increment and equipment scrap quantity of equipment units are selected to predict the inventory demand.

2.1. Unit vehicle equipment scale
The unit vehicle equipment scale refers to the number of equipment used by the troops to complete the mission, which is the most basic factor affecting the inventory demand. At the same time, the size of the vehicle equipment will also affect the number of faulty equipment and new demand, further affecting the amount of equipment scrap. Through the historical data research on the factors affecting
the inventory demand, the larger the unit vehicle equipment scale is, the more equipment and corresponding inventory are required. Especially when the scale of the unit vehicle equipment suddenly expands due to some irregular changes such as the outbreak of war, natural disasters and emergency tasks granted by superiors, the demand for equipment inventory will also rise rapidly.

2.2. New increments
The new increment refers to the quantity of more vehicles and vehicle equipment to meet the increasing needs of military training and temporary tasks, and at the same time will generate new equipment demand. It is related to the increase of vehicle equipment scale and inventory adjustment. The more the equipment scale of unit vehicles increases, the more the equipment will be equipped, and the demand for inventory will increase. Therefore, the new increment is an important factor affecting the inventory demand [2]. In recent years, with the increasing frequency of military training and exercise tasks undertaken by our army, the new increment of equipment is also increasing, but the overall growth rate is relatively smaller and smaller, tending to be stable.

2.3. Equipment scrap
The quantity of equipment scrap refers to the quantity of equipment that does not meet the technical standards, loses the repair significance after the failure, or can be directly replaced after the damage due to the low value. It is related to the quantity of the failure equipment and the scrap rate, which is the key factor affecting the inventory demand. As the years of use become longer, the service life of equipment will gradually decrease, the rate of equipment scrap will increase, and the amount of equipment scrap will increase, and the demand for inventory will also increase.

3. Construction of system dynamics prediction model for inventory demand
Based on the system dynamics problem solving steps, the main flow of the system dynamics model for vehicle turnover equipment inventory demand forecasting is developed, as shown in Figure 1.
3.1. Analysis of the causal relationship between factor variables of the system

Based on the analysis of the actual working conditions and key indicators of vehicle equipment, the basic causal relationship diagram of the inventory demand forecasting system is established, as shown in Figure 2. The two factor variables in the causal map are connected by a single arrow indicating a causal relationship, "+" means positively closed, and "-" means negative correlation.
Among them, the variables and the specific causal relationship are:

1. The amount of scrapped equipment increases with the increase of the number of faulty equipment and the scrapping rate of equipment, whereas decreases.

2. Equipment scrap rate refers to the amount of equipment scrapped during the unit study period. It is related to the level of maintenance and the length of service years. With the development of science and technology, the level of maintenance technology continues to increase, and the number of repairable and refurbished equipment also increases, so the scrap rate will also decrease. At the same time, the longer the equipment is used, the faster the scrap rate will be.

3. The new demand for equipment refers to the number of equipment that needs to be increased under certain security requirements after the unit vehicle equipment scale is increased. The new demand is mainly affected by the scale of the unit vehicle equipment and increases with the increase of the scale.

4. The number of faulty equipment is related to the size of the vehicle equipment and the failure rate of the equipment. The larger the unit vehicle equipment scale, the more the base number of possible failures that need to be repaired or eliminated, and the more the number of faulty equipment.

5. The new increment of equipment is determined by the new demand and inventory adjustment. As the scale of the unit vehicle equipment increases, more equipment needs to be stored to cope with it, that is, the new demand for equipment will increase, and the amount of new equipment will increase. As the inventory demand increases, the number of equipment purchases will increase. But at the same time, it cannot be increased indefinitely. In order to meet certain ideal inventory requirements without generating inventory backlog, it is necessary to make reasonable adjustments to reduce the number of equipment purchases, which also inhibits the increase of new increments [3].

6. The inventory demand of equipment is mainly affected by the new increment, equipment scrap quantity and post-repair quantity. The more new increment of equipment, the more inventory demand will inevitably be; at the same time, the increase of equipment scrap will lead to the increase of inventory demand; after repair, the amount can be put back into use, which reduces the consumption of equipment, so the inventory demand will be reduced.

Analysis of the main feedback loop:

1. New increment → + inventory demand → - inventory adjustment → + new increment

As the number of new equipment increases, the demand for stocks will increase. In order to achieve a certain ideal inventory demand while preventing backlog waste, it is necessary to adjust its inventory. Reducing inventory adjustment means reducing the number of equipment purchases, thus restraining the increase of new increments.

2. New increment → + equipment scrap → + inventory demand → inventory adjustment → + new increment

As the number of new equipment increases, the amount of equipment scrap will increase after a period of time; with the increase of equipment scrap, the demand for equipment will increase, which will lead to the increase of inventory demand; as the demand for inventory increases, in order to achieve a certain degree of security requirements and avoid inventory backlog, it is necessary to adjust its inventory. The reduction of inventory adjustment means a relative reduction in the number of equipment purchases, which also inhibits the increase of new increments [4].

4. Flow diagram design of the system

The system flow diagram is based on the full understanding of the causality diagram and clearly reflects the overall picture of the system material flow, information flow and feedback. According to the causal relationship between the variables in the system causality diagram, the system dynamics model of inventory demand forecasting can be obtained. It mainly includes the flow diagram of the inventory demand forecasting system and the correlation equation of the model. A complete system dynamics model for inventory demand forecasting is constructed, as shown in Figure 3.
Figure 3. Flow diagram of the inventory demand forecasting system.

The system dynamics model equation is as follows:

\[ N \text{ Unit vehicle equipment scale} = \text{INTEG (Increased number of vehicle equipment, } X) \]

\[ T \text{ Increased number of vehicle equipment} = \text{WITH LOOKUP (time, array)} \]

\[ L \text{ New increment} = \text{New demand} + \text{Equipment adjustment} \]

\[ A \text{ Inventory deviation} = (\text{Ideal inventory} - \text{Equipment demand}) \times (1 - \text{Guarantee rate}) \]

\[ A \text{ Inventory adjustment amount} = \text{Inventory deviation} \]

\[ L \text{ Ideal inventory} = \text{SMOOTH (Demand, Moving smoothing time)} \]

\[ L \text{ Equipment scrap amount} = \text{Number of faulty equipment} \times \text{Scrap rate} \]

\[ L \text{ Scrap rate} = \text{Natural scrap rate} + \text{Artificial scrap rate} \]

The \textit{scrap rate}, represents the scrap rate of XX equipment after \( t \) years of use. Because the equipment will be replaced and supplemented immediately when the equipment is discarded in the whole vehicle equipment system, there will be equipment used for 1-\( t \) years in the system in the year \( t \), so the scrap rate in the year \( t \) can be solved by using the idea of queuing theory in mathematical statistics and the tool of matlab.

\[ R \text{ Natural scrap rate} = \beta(t-1) - \beta(t) \]

The scrap rate includes the natural scrap rate and the artificial scrap rate. Natural scrap refers to the scrap that occurs when the life of equipment reaches its limit with the increase of years, which is mainly related to the length of use. The two-parameter \textit{Weibull} distribution function is used as the function for calculating the intact ratio of equipment[5], i.e. \( \beta(t) = \exp\left(\frac{-t}{T}\right)^k \). Among them, \( \beta(t) \) denotes the intact ratio of the equipment after \( t \) years of use; \( T \) denotes the average service life of the equipment; \( k \) denotes the characteristic parameters.

\[ R \text{ Artificial scrap rate} = \sigma \times \text{Equipment failure rate} \]

Artificial scrap refers to the scrap that cannot be repaired artificially in the faulty equipment, which is mainly affected by the maintenance level and the failure rate of the equipment. When the equipment is less critical and the value is lower, the faulty parts are generally replaced immediately. The artificial scrap rate at this time is the equipment failure rate, that is, \( \sigma = 1 \); When the equipment has a certain repair significance, the artificial scrap rate has a great relationship with the maintenance level, that is

\[ T \text{ Equipment failure rate} = \text{Failure rate table (time) } \times \text{Use intensity influence factor } \times \text{Operating environmental impact factor } \times \text{Operational level impact factor} \]
T Maintenance level impact factor = WITH LOOKUP (maintenance level, array)
L Inventory demand = New increment + Equipment scrap

Among them, L is the state variable equation, R is the rate equation, A is the auxiliary equation, T is the table function, N is the equation that gives the initial value to the state variable equation, and X is the initial value.

5. Instance verification

Taking the XX of the main transport vehicle Liberation CA1121 in the vehicle equipment warehouse of the 21st group army as the research object, the number of bicycles installed is 2, which has certain repairing significance. The demand data and failure data of the 10 years since the deployment of troops in 2005 were collected and used as data samples. Due to the uninterrupted nature of the military support tasks, the equipment must be replenished immediately after the consumption has generated demand, and there is no shortage of goods and out of stock. Therefore, the time delay is not considered. Moreover, the support level of each unit in the army is required to be high, and the guarantee rate is 0.99.

At the present stage, in order to achieve the goal of "being able to fight and win the battle", our army has relatively more major activities such as military training and exercises every year, and the tasks accepted by military units in peacetime are also basically on the rise. Therefore, the use rate of vehicle equipment has increased year by year, that is, the annual working hours of the corresponding equipment have increased year by year. This paper uses the vehicle equipment working time to measure the impact factor of its use intensity. The supplement of equipment for military units is basically a one-year procurement cycle. In the one-year procurement cycle, the ideal inventory of XX equipment is the annual expected demand. This paper uses the moving smoothing method, i.e. the moving average of the equipment demand in the first five years to express the ideal inventory of the equipment in the next year [6].

The scale of the unit vehicle equipment changes with the occurrence of uncertainties such as tasks accepted by the troops and natural disasters. The equipment scale of the 21st Group Army Vehicle Equipment Warehouse 2005-2015 transport vehicle Liberation CA1121 and its xx annual demand and the number of faults are shown in Table 1. After analyzing the collected data, investigating and researching the warehouse on the spot, it is known that the scale of this type of vehicle equipment is basically increasing. However, in recent years, there has been no obvious change in military situation, only a small increase in some manoeuvres, training and support tasks, so the increase of vehicle equipment scale gradually decreases. The specific form of the growth rate table function of the number of vehicle equipment is shown in Figure 4, the abscissa indicates the year, and the ordinate indicates the number of vehicle equipment increases.

![Figure 4. Vehicle equipment number growth rate table function.](image-url)
Table 1. The equipment scale of the 21st Group Army vehicle equipment warehouse Liberation CA1121 from 2005 to 2015.

| years | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| Vehicle equipment scale / tai | 290  | 328  | 360  | 378  | 393  | 404  | 414  | 424  | 432  | 439  | 446  |
| XX equipment demand / piece | 24   | 22   | 27   | 32   | 34   | 81   | 29   | 30   | 34   | 37   | 38   |
| Fault data / piece | 202  | 181  | 176  | 178  | 180  | 175  | 172  | 164  | 155  | 157  | 160  |
| Annual working hours / h | 1116 | 1050 | 1225 | 1248 | 1270 | 1335 | 1447 | 1453 | 1657 | 1730 | 1745 |

For XX equipment of Liberation CA1121, its scrap rate is not only affected by the years of use, but also restricted by the failure rate of equipment and the level of maintenance ability. According to Professor Zhang Peng's research content in "Research on Management Strategies of Air Material Inventory Based on System Dynamics" and the actual investigation of the 21 Group Army Vehicle Equipment Warehouse [7], the table functions of maintenance level impact factor and failure rate are shown in Figure 5 and Figure 6 respectively. With the development of science and technology and the improvement of equipment support capability, the level of equipment maintenance and support in our army has been continuously improved. According to the fuzzy comprehensive evaluation method, the maintenance level of the 21st Group Army vehicle equipment warehouse is good, with a value of 0.75, and the influence factor of the maintenance level corresponding to the data of the table function in Figure 5 is 0.7.
Because the vehicle equipment that has just been equipped with the unit usually needs time to run in, and many maintenance and storage personnel are not very clear about the performance of the new equipment, some minor faults often cannot be eliminated in time and cause big problems, so the failure rate of the equipment itself is generally higher when the units were equipped in the previous years. After several years of running-in and familiarity, the failure rate of the equipment itself will gradually decrease and tend to be stable. Then, the failure rate of the equipment is determined by combining the intensity impact factor, the operating environmental impact factor, and the operational level impact factor. The specific value is shown in the following figure [8].

According to the “Regulations on Vehicle Maintenance of the People's Liberation Army”, the vehicle equipment is basically overhauled every six years. Under normal circumstances, the equipment that has been used for 6 years should also be replaced[9]. Therefore, when calculating the natural scrap rate, take the average service life of XX equipment as 6 years and the characteristic parameter $k$ as 3. At the same time, the idea of queuing theory in mathematical statistics and the tool of matlab are used in calculating the equipment scrap rate in year $t$. Then the specific data of the scrap rate of XX in Liberation CA1121 varying with time is shown in Table 2 below.
Table 2. XX's intact ratio and scrap rate.

| Year (year) | Naturally intact ratio (%) | Natural scrap rate (%) | Artificial scrap rate (%) | Scrap rate, (%) | Scrap rate (%) |
|-------------|---------------------------|------------------------|---------------------------|----------------|---------------|
| 2005        | 0.995381                  | 0.004619               | 0.105                     | 0.109619       | 0.109619      |
| 2006        | 0.968259                  | 0.031741               | 0.079                     | 0.110741       | 0.110618      |
| 2007        | 0.882497                  | 0.085762               | 0.074                     | 0.159762       | 0.149431      |
| 2008        | 0.743567                  | 0.138930               | 0.071                     | 0.209930       | 0.180817      |
| 2009        | 0.560625                  | 0.182942               | 0.068                     | 0.250942       | 0.195758      |
| 2010        | 0                        | 0.560625               | 0.065                     | 0.625625       | 0.481818      |
| 2011        | 0.995381                  | 0.004619               | 0.062                     | 0.066619       | 0.152893      |
| 2012        | 0.968259                  | 0.031741               | 0.058                     | 0.089741       | 0.170297      |
| 2013        | 0.882497                  | 0.085762               | 0.054                     | 0.139762       | 0.200991      |
| 2014        | 0.743567                  | 0.138930               | 0.054                     | 0.192930       | 0.231326      |
| 2015        | 0.560625                  | 0.182942               | 0.054                     | 0.236942       | 0.231599      |
| 2016        | 0                        | 0.560625               | 0.056                     | 0.616625       | 0.333645      |
| 2017        | 0.995381                  | 0.004619               | 0.058                     | 0.062619       | 0.182696      |
| 2018        | 0.968259                  | 0.031741               | 0.059                     | 0.090741       | 0.202465      |
| 2019        | 0.882497                  | 0.085762               | 0.060                     | 0.145762       | 0.222569      |

The coefficients and parameters are calculated according to the actual data of the 21 Group Army Vehicle Equipment Warehouse and the mathematical model method. The simulation of the system model and the data results are carried out by using the special simulation software Vensim for system dynamics. The specific simulation results of the inventory demand are shown in the following figure.

Figure 8. Simulation results of xx equipment inventory demand.

According to the 2005-2019 inventory demand simulation data, the demand will increase suddenly every six years. This is because the service life of the equipment set in this paper is 6 years, and the equipment must be replaced after 6 years cumulative work, so the inventory demand will increase suddenly every 6 years [10]. Secondly, the inventory demand generally shows an increasing trend. This is because in order to meet the requirements of modern and information warfare, military training, exercises and other tasks continue to increase, the use intensity of vehicle equipment and equipment and the probability of failure also continue to increase, so the demand for equipment inventory is increasing.

The relative error between the simulated predicted value and the actual demand of the inventory demand forecasting system dynamics model is shown in Figure 9 and Table 3. The maximum error is 9.09%, less than 10%. After testing, the inventory demand forecasting system dynamics model
established in this paper meets the accuracy requirements and is suitable for the demand forecasting of continuous demand equipment. Therefore, the forecast value of inventory demand from 2016 to 2019 is 57 pieces, 32 pieces, 38 pieces and 42 pieces respectively.

![Graph](image)

Figure 9. The error between the simulated predicted value and the actual demand of the inventory demand system dynamics model.

Table 3. Model simulation prediction results and error table.

| Year (year) | Actual demand (piece) | Simulated predictive value (piece) | Relative error (%) | Remarks |
|------------|-----------------------|-----------------------------------|--------------------|---------|
| 2005       | 24                    | 22                                | 8.33               |         |
| 2006       | 22                    | 20                                | 9.09               | MAX     |
| 2007       | 27                    | 26                                | 3.70               |         |
| 2008       | 32                    | 32                                | 0.00               |         |
| 2009       | 34                    | 36                                | 5.88               |         |
| 2010       | 81                    | 84                                | 3.70               |         |
| 2011       | 29                    | 27                                | 6.89               |         |
| 2012       | 30                    | 28                                | 6.66               |         |
| 2013       | 34                    | 33                                | 2.94               |         |
| 2014       | 37                    | 35                                | 5.40               |         |
| 2015       | 38                    | 37                                | 2.63               |         |

Average error (%) 5.522 <10%
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