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Configuration model of partial repairable spares under batch ordering policy based on inventory state

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Abstract Rational planning of spares configuration project is an effective approach to improve equipment availability as well as reduce life cycle cost (LCC). With an analysis of various impacts on support system, the spares demand rate forecast model is constructed. According to systemic analysis method, spares support effectiveness evaluation indicators system is built, and then, initial spares configuration and optimization method is researched. To the issue of discarding and consumption for incomplete repairable items, its expected backorders function is approximated by Laplace demand distribution. Combining the $(s-1, s)$ and (R, Q) inventory policy, the spares resupply model is established under the batch ordering policy based on inventory state, and the optimization analysis flow for spares configuration is proposed. Through application on shipborne equipment spares configuration, the given scenarios are analyzed under two constraint targets: one is the support effectiveness, and the other is the spares cost. Analysis reveals that the result is consistent with practical regulation; therefore, the model's correctness, method's validity as well as optimization project's rationality are proved to a certain extent.

1. Introduction

Spares, which are closely accompanied with the whole life cycle of equipment, are supportability material for equipment maintenance and emergency repair and are also the material basis for equipment support and supply,[1] for it directly impacts the life cycle cost (LCC) as well as the equipment readiness posture. Currently, military mainly rely on "excessive procurement and reserves" to meet the spares support demand, which leads to a large amount of spares stock putting off. In this case, spares may be damage or failure during storage and cause a lot of waste; in addition, the actual needed spares are of serious shortage, which seriously affect the equipment support effectiveness.

The above-mentioned issue involves the spares configuration and optimization. Firstly, spares need to be classified as repairable or consumable items so as to determine the reasonable inventory strategy.[2] For repairable items of high failure rate, low consumption and expensive cost, $(s-1, s)$ inventory policy is introduced, which is the basic assumption for multi-echelon technique for recoverable item control (METRIC). Under this assumption, Cesaro and Pacciarelli[3] and Lee et al.[4]

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researched the issues of aviation spares optimization; Sleptchenko[5] and Rustenburg et al.[6] proposed spares configuration method for naval warship based on METRIC; Ruan et al.[7] established three-echelon inventory optimization model of repairable spares, and proposed the concept of system support degree; in addition, he researched the optimization method of carrying spares support project for warship equipment under multi-constraints.[8] Diaz and Fu[9] and Ruiz-Castro and Li[10] relaxed METRIC assumptions of "unlimited maintenance overall", and researched spares optimization method under the maintenance resource constraints. For non-repairable spares of low failure rate and high consumption, (R, Q) inventory policy is usually applied,[11] that is, determine reasonable ordering point R and economic ordering quantity Q based on spares stock state. Gumus and Guneri[12] studied inventory management system framework under the random demand and fuzzy supply chain environment; Topan et al.[13] and Darwish and Odah[14] researched the economic ordering policy of two-echelon inventory system that consists of a central warehouse and several point-of-sale; Olsson[15] and Tiacci and Saetta[16] studied the optimal inventory policy of consumable spares with lateral transshipment; Al-Rifai and Rossetti[17] built heuristic optimization model of two-echelon ordering system under the (R, Q) inventory policy, Mao et al.[18] studied the consumable spares optimization methods centered equipment availability.

For military equipment, most of the spares are partial repairable items, that is, the increase of repairing times will lead to spares performance degradation. But in the majority of the related literature, repairable items are always assumed to be repaired, and after each repair, it will recover the initial state; some actual cases and impact factors, such as spares service life and its discarding consumption, are not considered. In addition, periodically ordering or planned procurement from external supplier, spares project will appear to be poor robustness, and it is difficult to meet the randomness and uncertainty phenomenon of spares failure and consumption. In this paper, we will focus on incomplete recoverable equipment and take into account the factors that items performance become degradation after repair as well as its discarding and consumption. Under the batch ordering mode based on inventory state, we establish an optimal configuration model of partial repairable items through organic combination of ($s-1$, s) and (R, Q) inventory policy, so as to make the spares project more reasonable and the calculation result close to the actual situation.

2. Description of spares support process

Spare parts, according to its indenture, can be classified into line replaceable units (LRU) and shop replaceable units (SRU).[19] If equipment fails in grass-root station, then detect and locate the fault, disassemble the failure item and install the spare in equipment. The process is shown in Fig. 1. If there are spares in stock, we can replace the failure item by its spares, and then the failure equipment can be recovered. If there are no spares in stock, one time of LRU shortage will occur. Considering the repair capacity restrictions, the failure item has certain repair probability in grass-root station; after repair, the recovered item will be stored in grass-root station and can be used for the next demand. If the failure item cannot be repaired, it will be sent to repair at higher echelon location (intermediate station); at the same time, the grass-root depot orders one spare from intermediate depot. The spares support process at intermediate station is similar to that of grass-root station.

According to equipment fault tree structure, the failure LRU is caused by its sub-assembly SRU. If there are SRU spares in stock, it will be installed in LRU to replace the failure SRU. Then, we complete the repair of the failure LRU. If there are no SRU spares in stock, it will delay the repair time. When we complete the repair and supply of failure LRU, a spare shortage is resolved.

In support system, the top-echelon site (base station) is usually constituted by industrial factory or military region repair shop and equipped with complete repair device, tools, and technical document; it has a strong repair capacity and can undertake all of the repair work. Actually, apart from the whole-life item, most of repairable parts have a certain service life; besides, its working performance will decline with the increase of their repair times, so the failure item may has a certain discarding rate at the top-echelon site. With the spares' discarding and consumption, the base station needs to purchase spares from external supplier based on the current inventory state. Considering the long supply cycle of some items (such as special, imported, or temporary production items, etc.), as well as the order fees and transportation costs, the base station needs to take batch ordering policy, thus, the amount of spares stock in the whole support system can meet the needs of equipment repair.

3. Spares demand rate

3.1. Analysis of spares demand

In order to quickly restore the combat effectiveness of failed equipment, the repair mode that replaces the failure items by its spares is usually used, in the way that spares demand rate equals its replacement rate, which is an important input parameter for spares optimization model. The main factors

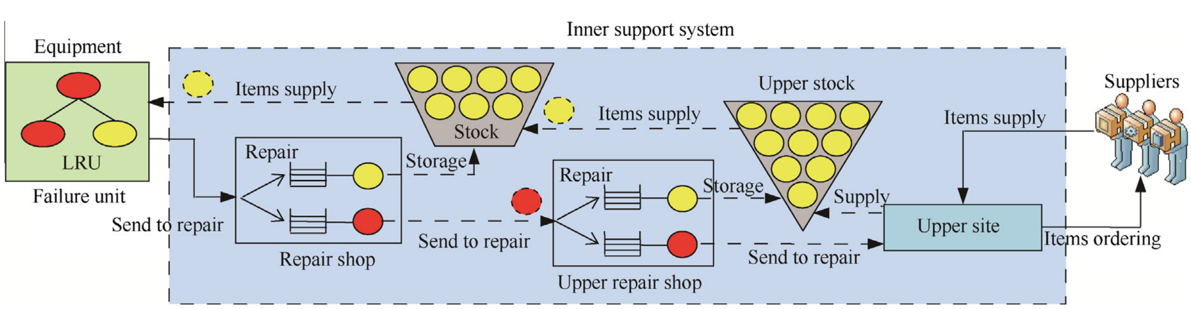

Fig. 1 Process of failure, repair, ordering and supply for spare parts.