A Method for Dividing Line Replaceable Unit

Guo Zhiming\textsuperscript{1*}, Liu Ying\textsuperscript{1}, Li Changfu\textsuperscript{1}, Qiao Hu\textsuperscript{2}

\textsuperscript{1}China Research and Development Academy of Machinery Equipment, Beijing 100089
\textsuperscript{2}School of Mechatronic Engineering, Xi’an Technological University, Xi’an 710021
gzmnwpu@163.com

Abstract. The problem of dividing the line replaceable unit (LRU) is one of the urgent problems to be solved in the RMS field in recent years. This paper proposes a method of line replaceable unit division, based on actual needs, to study the need of LRU division trade-off. On this basis, the indicators and parameters of LRU division trade-offs are studied to realize the scientific division of LRU, which provides support for product reliability, maintainability, supportability and test engineering design and analysis.

1. Introduction
The concept of LRU was first formally proposed in the Logistics Management Information Performance Specification promulgated by the US Department of Defense in 1996, it referred to the necessary support unit that can be used to restore the product preparation status by removing or replacing it in the field \cite{1}. The purpose of equipment LRU division is mainly to facilitate on-site maintenance. It is necessary to combine the basic requirements of product functions, and fully consider the requirements of product reliability, maintainability, supportability, testability and economy, and scientifically classify the LRU of the product.

For the LRU division, many scholars at home and abroad have done a lot of research \cite{2-3}. Zhang et al based on the relationship between LRU planning design and product design, and combined with the RMS design guidelines, to build the overall framework of the LRU planning and design and the method flow of the technical implementation, through a combination of qualitative and quantitative methods, and comprehensive analysis and evaluation of LRU planning and design; Yang et al based on the research of LRU partitioning method to improve the level of system-level observability. For the first time, the concept of average failure quality, average failure repair time, and average failure failure miss detection rate was proposed innovatively to LRU division.

In summary, the current research focuses on the application of the LRU concept. Based on the design criteria of the relevant LRU, LRU partitioning is carried out, and little research on the theoretical method of LRU partitioning is carried out. Therefore, this paper proposes a method for line replaceable unit division. The LRU partitioning trade-off is to comprehensively consider various factors and constraints affecting LRU partitioning for different objectives in the process of LRU partitioning, the impact of each target on the LRU partitioning is balanced according to actual needs to optimize the LRU partitioning scheme. In the process of LRU division, objective, accurate and intuitive quantitative indicators are proposed as the basis for division, on the one hand, the quantitative indicators can accurately reflect the influencing factors and target needs of the LRU division; On the
other hand, there is no strong positive correlation between the indicators and the indicators, and the indicators are easy to obtain.

2. LRU division trade-offs demand analysis

Combined with the definition of LRU, the LRU division trades off demand mainly from functions, equipment reliability, equipment maintainability, equipment support, equipment testability and economy. At the same time, several aspects of the LRU partitioning requirements are not isolated and influential to each other. The LRU division trades off the demand relationship as shown in Figure 1.

![LRU division trade-offs analysis framework](image)

Figure 1. LRU division trade-offs needs analysis framework

(1) Functional requirements

Based on the definition of LRU, LRU is an integral part of the product and should first meet the functional requirements of the product. Functional requirements come mainly from three aspects: component geometry, structural parameters, and connection methods. Structural requirements are mainly to meet the requirements of strength, stiffness and stability; The connection requirements are mainly the composability and interchangeability of the interfaces. Different parts of the equipment have different geometrical shapes, structural parameters, and connection methods. It is also necessary to carry out LRU division and balance detailed functional requirements analysis with specific equipment.

(2) Reliability requirements

The impact of equipment reliability on LRU is reflected in the failure rate of each component of the product, the reliability level is a prerequisite for determining whether the equipment component structure is LRU. The highly reliable component structure is generally not determined as LRU. For parts with high failure rate, because the maintenance frequency is higher than the maintenance frequency of parts with low failure rate, when constructing LRU, attention should be paid to those components with high failure rate. The reliability of the equipment will have an impact on maintenance. If the reliability index of the equipment is high, the equipment will have less demand for maintenance.

(3) Maintenance requirements

Most modern products are complex in structure and have a long service life. The maintenance and repair activities throughout the life cycle are the main means to effectively prevent damage and restore the specified status of faulty parts. The need for maintenance to balance the LRU is naturally derived from problems in actual use, that is to shorten the repair time, reduce the frequency of maintenance, reduce maintenance costs. Increased maintenance requirements will also increase test and support requirements. The need for maintenance is a requirement that needs to be focused on in the LRU division, and it takes a lot of weight in the trade-off analysis. In terms of maintenance, the demand analysis of LRU
trade-offs is mainly through the following ways: on the one hand, through research and analysis, visit the maintenance bases at all levels of typical weapons and equipment, analyze the existing maintenance support resources and maintenance support mode of the equipment, analyze the fault problem information and failure modes and impacts of the equipment, and determine the requirements during the use and maintenance of the equipment; On the other hand, the product structure function analysis, based on the basic product structure tree, according to the failure mode analysis, maintenance work project demand analysis, fault diagnosis and detection mode analysis, maintenance mode analysis and so on, determine the maintenance requirements of the equipment, and determine the LRU division trade-off requirements from the maintenance analysis.

(4) Security requirements

The purpose of the LRU division is to make the product easy to repair, and the maintenance process necessarily involves safeguarding resources. Safeguarding the size of maintenance support resources by rationally configuring the structure of spare parts, it can improve the mobility of equipment and even the entire force deployment. The need for safeguards to balance the LRU is mainly portability, including quality, volume and scale. The LRU division will also have a greater impact on the security. For example, if the granularity is too coarse, the difficulty will be increased; The details will reduce the efficiency of on-site maintenance. Assurance can be used both as a goal of balancing trade-offs and as a constraint on trade-offs. The maintenance support program is a prerequisite for the development of weapons and equipment design, combined with the specific equipment maintenance guarantee program to carry out demand analysis.

From a mathematical point of view, LRU partitioning is also a multi-dimensional knapsack problem, that is, under the constraints of limited resources, a set of items with the largest "value" is selected from a certain number of items. The mathematical model of the multi-dimensional knapsack problem from the perspective of security is:

\[
\begin{align*}
\text{max } & f(x) = \sum_{i=1}^{m} v_i x_i \\
\text{s.t. } & \sum_{i=1}^{m} w_{ij} x_i \leq c_j, i = 1, 2, \ldots, m \\
& x_i \in \{0, 1\}, j = 1, 2, \ldots, k
\end{align*}
\]

Where: \( m \) is the number of units of equipment; \( v_i \) is the "value" of the \( i \)-th equipment component, that is, the contribution to a certain target; \( c_j (j = 1, 2, 3, \ldots, k) \) is a constraint of resources (quality, volume, length, width, height, etc); \( w_{ij} \) is the consumption of the \( j \)-th resource by the \( i \)-th LRU; \( x_i \) indicates whether the \( i \)-th product unit is divided into LRU.

(5) Test requirements

From the perspective of test requirements, the LRU needs to be able to accurately determine the status of the LRU and isolate its internal faults in a timely manner. According to statistics, 60% of the time in the maintenance of equipment is used for fault diagnosis and positioning. The equipment is well tested and can reduce the average repair time of the equipment.

(6) Economic requirements

In the LRU division, the economic cost of the LRU should be taken into account, and economic needs should be considered during the life cycle of the equipment to avoid short-term cost behavior. If the one-sided demand for maintenance, security, testing, etc., will lead to a large cost, resulting in too high cost to the enterprise can not afford.

In summary, the LRU division trade-off requirement analysis is the premise of scientific division of LRU and the basis of subsequent related work. This paper analyzes the requirements from functions, equipment reliability, maintainability, supportability, testability and economy. At the same time, in the research process, the effects of various requirements are considered comprehensively, which lays a foundation for the subsequent determination of quantitative indicators and parameters.
3. LRU division trade-off indicators and parameter determination

The LRU partition factor set and the LRU partition trade-off indicator and the demand reflected by the parameter set are the true subset of the LRU partition trade-off requirement, and there is an intersection between the two sets. The area of the LRU partitioning factor set and the LRU partitioning trade-off indicator and the parameter set are variable, and the more comprehensive and accurate the demand can reflect, the larger the area that can be covered, as shown in Figure 2.

![LRU division trade-off requirement and LRU division trade-off indicator parameter relationship](image)

(1) LRU partition factor set

According to the actual demand, the factors used in the trade-off demand analysis for LRU division are divided into fault test diagnosis class, maintenance replacement class, supply guarantee class and other factors. Each type of factor contains multiple sub-factors that break down the factors into sub-factor sets. As shown in Figure 3.

![LRU partition factor set](image)

(2) LRU division weight measurement indicators and parameter sets
Based on the above, the LRU division weight measurement indicators and parameter sets that can comprehensively reflect the testability, maintainability, supportability and economy of the equipment after failure or replacement are proposed. In terms of testability, the quantitative indicators are proposed to reflect the timeliness and accuracy of the on-site diagnostic test; In terms of maintainability, quantitative indicators are proposed to reflect the time of on-site maintenance, personnel, tools, etc; In terms of security, quantitative indicators are provided to reflect the faulty spare parts load to reflect the burden of spare parts; In terms of economics, the life cycle maintenance cost indicator is used to estimate the cost from the aspects of security, maintenance and scrapped LRU disposal fees. Figure 4 shows the framework for building the LRU partitioning trade-off indicator.

![LRU partitioning trade-off indicator set construction framework](image)

Figure 4. LRU partitioning trade-off indicator set construction framework

According to the framework in Figure 4, to determine the scientific definition and mathematical description of the four indicators at the unit level, and combined with the actual maintenance engineering, consider the two situations of preventive maintenance and repair maintenance, and give the matrix expression of four indicators and parameters at the system level.

4. Conclusion
Aiming at the current situation that the weapon equipment LRU division has many influencing factors and lacks effective quantitative indicators. This paper proposes a method for dividing the line replaceable units by providing LRU divisional trade-offs based on the requirements of quick and convenient maintenance guarantee and rapid and accurate test diagnosis. Focus on solving the need for LRU division trade-offs and the indicators and parameters of LRU division trade-offs, realize the
scientific division of LRU, and provide support for product reliability, maintainability, supportability and test engineering design and analysis.

Acknowledgment
The project was supported by the Pre-Research Fund Project of the Armed Forces Equipment Development Department (61400040101)

References
[1] MIL-PRF-49506. Logistics Management Information Performance Specification [S]. U.S. Department of Defense, 1996
[2] Li Xiaoquan. Research on Wartime Military Machinery Maintenance Devices Modularization Based on ISM[J]. Armament Automation, 2007, 26(12): 26-27 (in chinese)
[3] Basten R J I. Defining line replaceable units[J]. European Journal of Operational Research, 2015, 247(1): 310-320
[4] Zhang Ce. RMS Oriented LRU Planning[D]. Beijing: Beihang University, 2006 (in chinese)
[5] Lv Chuan. Design, Analysis and Verification of Maintainability[M]. Beijing: National Defense Industry Press, 2012 (in chinese)
[6] Yang Yongmin. Research on Some Key Technologies of Observability Analysis and Application of Dynamic System[D]. Changsha: National University of Defense Technology, 2014 (in chinese)
[7] Yang Yongmin, Ge Zhecxue, Luo Xu, et al. A Survey of Maintainability Design and Analysis Technology of Equipment[J]. National Defense Science & Technology, 2015, 36(1): 4-9 (in chinese)