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MAINTAINABILITY ALLOCATION METHOD BASED ON TIME CHARACTERISTICS FORCOMPLEX EQUIPMENT

METODA ALOKACJI OBSŁUGIWALNOŚCI ZŁOŻONYCH URZĄDZEŃ OPARTA NA CHARAKTERYSTYKACH CZASOWYCH

Maintainability allocation is an important step in product quality design. Traditional allocation methods are limited such that the allocated mean time to repair for each unit design apartment cannot be totally controlled by the corresponding design apartment. This paper proposesa new time characteristics-based maintainability allocation method to solve the aforementioned problem. The relationship between design content and repair time is considered in this method, and repair time is divided into common and individual repair time. Common repair time, which isdetermined by the overall system design,is deducted from the total repair time. Individual repair time is allocated to the specific unit through proper traditional allocation method. A case study is performed,and results demonstrate that the new method is more suitable and effective than original methods in terms ofmaintainability allocation.

Keywords: maintainability, maintenance, allocation method, MTTR.

Alokacja obsługiwalności jest ważnym krokiem w projektowaniu jakości produktów. Tradycyjne metody alokacji są ograniczone w takim sensie, że alokowany średni czas do naprawy dla każdego działu projektowania jednostki produktu nie może być całkowicie kontrolowany przez odpowiedni dział projektowania. W niniejszej pracy zaproponowano rozwiązanie tego problemu wykorzystujące nową metodę alokacji obsługiwalności opartą na charakterystykach czasowych. W proponowanej metodzie bierze się pod uwagę związek między zawartością projektu a czasem naprawy, czas naprawy zaś dzieli się na wspólny i indywidualny. Wspólny czas naprawy, który zależy od ogólnej konstrukcji systemu, odejmuje się od całkowitego czasu naprawy. Indywidualny czas naprawy alokuje się do konkretnej jednostki za pomocą odpowiedniej tradycyjnej metody alokacji. W pracy przeprowadzono studium przypadku, którego wyniki pokazują, że nowa metoda jest bardziej odpowiednia i skuteczna jeśli chodzi o alokację obsługiwalności niż metodystosowane pierwotnie.

Słowa kluczowe: obsługiwalność, eksploatacja, metoda alokacji, średni czas do naprawy MTTR.

1. Introduction

Maintainability, defined as "the ability of an item under given conditions of use to be retained in or restored to a state in which it can perform a required function when maintenance is performed under given conditions and using stated procedures and resources," is an important product characteristic [15]. Complex equipment with very complicated structures and a largenumber of entities can be promptly restored from a failure state through maintenance activities [19]. Mean time to repair (MTTR) is an important metric of system maintainability [11, 16].

Maintainability allocation is the process whereinthe target or indicator of maintainability for a system is allocated to the target or indicator for subsystems or components; this processis an important task in the product design stage [3, 14].The objectives of maintainability allocation are

a) identify the target or indicator of maintainability for subsystems or components to guarantee the maintainability requirements of the system or product;

b) clarify the maintainability target of the product to the supply side so that management becomeseasy and reasonable.

Maintainability allocation is an essential and very cost-effective taskin product design because all designs begin with clear targets or indicators; maintainability as an intrinsic characteristic of products

is determined in the design stage [9]. A rational allocation scheme allows equipment to be maintainedwith less time, at the lowest cost, with minimum impact on the environment, and with minimum expenditure of resources [4, 5].

A number of methods, such as equivalent allocation method, failure rate-based allocation method, trade-off of failure rate and design feature-based allocation method, and similar product maintainability data-based allocation method, are available for maintainability allocation [17]. Coulibaly proposed an approach for product maintainability prediction based on behavioral performance assessment [6]. Gero *et al*. presented a generic product model based on function,behavior, and structure concept to build a global and multi-view model throughproduct data and other process information [13]. Barabadi*et al*.conducted a research on maintainability analysis and considered severalenvironmental and operational conditions to compute repair time data and describe maintainability with a statistics-based indicator [1]. Song *et al*. proposed an allocation method based on the analytic hierarchy process to overcome the limitation of common methods when the design character is feckly; the researchersapplied the method toan underwater vehicle [20]. Zhao *et al.* proposed a fuzzy maintainability allocation method and utilizedinterval analysis, fuzzy comprehensive evaluation, and the analytic hierarchy process to quantitatively analyzeseveralconsidered influence factors in the process of maintainability allocation fornumerical control machine tools [21]. Celestine *et*

al. proposed a new and computationally efficient heuristic algorithm for reliability and maintainability allocation in complex hierarchical systems [7]. Several researchers also utilized virtual reality systems and collaborative design environments to verify product functionalities and analyze maintainability after a product is designed [12, 22, 24]. However, when the aforementioned methods are employed in actual practice, design factors such as the maintenance access channel are not considered by the specific unit design department; the MTTR index allocated to each unit cannot be totally controlled by the corresponding design department, which is contrary to the purpose of allocation [8].

The purpose of this paper is to overcome the limitation of traditional allocation methods and improve the accuracy and effectiveness of the allocated MTTR index. A maintainability allocation model based on time characteristics is built to improve the applicability and operability of the allocation process in complex equipment and overcome the limitations of traditional methods.

This paper is organized as follows. Section 2 presents the commonly utilized maintainability allocation methods. The proposed maintainability allocation method based on time characteristics is described in Section 3. The results of the conducted case study, which show the efficiency and effectiveness of the proposed method, are discussed in Section 4. Section 5 provides the conclusions of this paper.

2. Commonly Utilized Maintainability Allocation Methods

Assuming that a system is composed of n units, the MTTR of the units and the MTTR of the system during the life cycle must fulfill the equation [2]

$$\bar{M}_{CT} = \frac{\sum_{i=1}^{n} \lambda_i \bar{M}_{CT_i}}{\sum_{i=1}^{n} \lambda_i} \qquad (1)$$

where n is the total number of units, λ_i is the failure rate of unit i, and $\bar{M}_{CT_i}$ is the MTTR of unit i. When, $i=1,2,\ldots,n$ $\bar{M}_{CT}$ is the MTTR of the system.

The MTTR allocated to each unit must satisfy Equation (1). However, many solutions can satisfy the equation; thus, the appropriate solution must be determined based on the criteria of maintainability allocation.

2.1. Failure rate-based allocation method

The principle of this allocation method is that "the repair time allocated to the unit with high failure rate is short and vice versa." The premise of this method is that the allocated or predicted values of the reliability metrics already exist. The MTTR distributed to each unit is calculated as

$$\bar{M}_{CT_i} = \frac{\bar{M}_{CT} \sum_i \lambda_i}{n \lambda_i} \qquad (2)$$

where $\bar{M}_{CT_i}$ is the MTTR distributed to unit i, $\bar{M}_{CT}$ is the MTTR of the system, λ_i is the failure rate of unit i, and n is the total number of unit types.

Not all units in an upgraded system need to be redesigned because some of the units of the original system are adopted. Assuming that an upgraded system is composed of n subsystems among which L sub-

systems are employed from the original system, the maintainability allocation result of the new system follows the equation

$$\bar{M}_{CT_j} = \frac{\bar{M}_{CT} \sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{L} \lambda_i \bar{M}_{CT_i}}{(n-L)\lambda_j}, \quad j=L+1,\ldots,n \qquad (3)$$

where $\bar{M}_{CT_j}$ is the MTTR for newly designed subsystem j, $\bar{M}_{CT}$ is the MTTR of the upgraded system, $\bar{M}_{CT_i}$ is the MTTR of original subsystem i, and λ_i and λ_j are the failure rates of subsystems i and j, respectively.

The maintainability indicators $\{ \bar{M}_{CT_i} \}$ allocated based on the failure rates are reasonable but may not be feasible. For example, one or a few indicators could be extremely small that they may be technically impossible to achieve. Indicators must be adjusted if they are technically difficult to realize or require high costs (including economic, time, and manpower cost). Based on the preliminary structure scheme, the various maintainability qualitative characteristics (e.g., complexity, accessibility, scalability, ease of replacement, testability) that influence repair time must be considered, and a trade-off must be made to determine the allocation results [10, 18, 23].

2.2. Trade-off of failure rate and design feature-based allocation method

Relevant factors such as complexity, accessibility, and testability are transformed into weight coefficients when the allocation method based on the trade-off of failure rate and the design features is utilized. The MTTR allocated to each unit is calculated as

$$\bar{M}_{CT_i} = \beta_i \bar{M}_{CT} \qquad (4)$$

where $\bar{M}_{CT_i}$ is the MTTR distributed to unit i, $\bar{M}_{CT}$ is the MTTR of the system, and $\beta_i = \frac{\bar{\lambda} k_i}{\lambda_i \bar{k}}$ is the weight coefficient of the repair time for the unit. $\bar{\lambda} = \frac{\sum_{i=1}^{n} \lambda_i}{n}$ is the average failure rate of each unit, $\bar{k} = \frac{\sum_{i=1}^{n} k_i}{n}$ is the average of each unit weight coefficient, and $k_i = \sum_{j}^{m} k_{ij}$ is the weight coefficient of factor j in unit i.

For an upgraded system, the maintainability allocation result of the newly designed subsystem follows the equation

$$\bar{M}_{CT_j} = \frac{M_{CT} \sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{L} \lambda_i \bar{M}_{CT_i}}{\lambda_j \sum_{j=L+1}^{n} k_j} k_j, \quad j=L+1,\ldots,n. \qquad (5)$$

The designed maintainability characteristics should be clear when this method is utilized. The weight coefficients in this method are the indexes of the influence of factors on the maintainability indicators of each unit.

3. Time characteristics-based maintainability allocation model forcomplex equipment

3.1. Classification of repair time

Repair time is classified in this study given the fact that the different elements of repair time are controlled by different design departments in reality. Repair time is classified in two categories: common repair time and individual repair time.

1) Common repair time

The repair time determined by the overall system design or the upper design department, such as preparation time and approaching time determined by the overall layout, is defined as the common repair time in this level for product units in a certain level of the equipment. This type of time is determined by the overall design or upper level department and is not directly affected and controlled by product design in this level.

2) Individual repair time

The repair time determined by product design, such as assembly, changing, and adjustment time, is defined as the individual repair time in this level for product units in a certain level of the equipment. This type of time is determined by the department that designs the unit.

Considering that the formation mechanism of the different types of maintenance time is different, the types of maintenance time are influenced and controlled by different product design departments. The allocation method differs according to the categories of repair time as shownin Fig. 1.
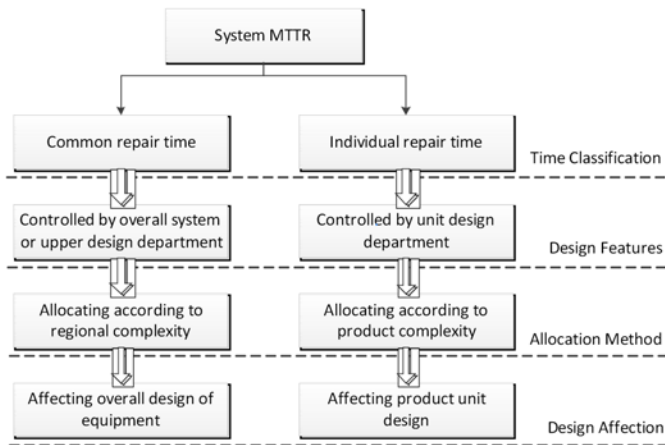

Fig. 1. Influence of the different types of time

3.2. Time of maintenance activities

Common repair time is related to the structure and layout of the system, maintenance access design, and product unit design features. The system theory, layout, function hierarchy, and main replaceable units should be mastered to identify common repair time. The identification of common repair time relies on information and data derived from equipment design, including the historical data of similar equipment, existing failure rate data of developing equipment, and data on the order ofmaintenance activities and factors influencing repair time.

Through the analysis of system maintenance activities, system repair time can be divided into the following: preparation, localization and diagnosis, approaching, correction, reassembly, adjustment, and checkout time.

Common repair time generally includes preparation, approaching, and reassembly time. However, accessing and reassembly time belong to individual repair time in some cases. Thecorresponding repair process when failure is isolated to a single replaceable unit (RU)is

shown in Fig. 2. The accessing channel to the fault belongs to the single RU, and accessing and reassembly time are the individual repair time of RU.

Fig. 2. Process of repairing a single RU

The single RU must be replaced to determine the fault when failure is isolated to an RU group of two or more RUs. The worst case is that the entire RU group is replaced; the accessing channel is shared by all RUs, and accessing and reassembly time are determined by the upper level design and belong to common repair time. The repair process in this case is shown in Fig.3.
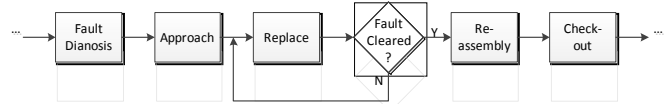

Fig. 3. Process of repairing an RU group

Common repair time can be determined through experience or composition of the time of basic maintenance activities. Individual repair time is calculated with a mathematical allocation model.

3.3. Theory of the method

The method of allocating repair time according to the different characteristics of the time of each maintenance activity is utilized based on the classification scheme of maintenance time. Common repair time is deducted from MTTR, and individual repair time is allocated further down to the level of subsystems and/or components through a suitable traditional allocation method. Each product design department obtains a maintenance time indicator that can be completely controlled. The use of this method can guarantee that the maintainability indicators of each product level are clear and the distribution process is reasonable, accurate, and feasible.

3.4. Allocation model

The repair time of an equipment system is classified, and the influencing factors are considered. Given that product information and the classification of repair time are different for the high-level and low-level product units, different allocation models are built for different product levels.

3.4.1. Allocation model for high-level products

For high-level products, we assume that the system consists of n subsystems (subsystem 1, subsystem 2,…, subsystem n) and that the corresponding failure rates are $\lambda_1, \lambda_2, …, \lambda_n$. The repair time of the high-level products is analyzed.The framework of allocating repair time for high-level products is shown in Fig. 4.

According to the definition of common repair time and the above-mentioned classification method, common repair time includes preparation time T_P, approaching time T_A, and reassembly time T_R. Individual repair time is calculated by eliminating common repair time from the system MTTR.

1) Common repair time

The composition of preparation time is relatively simple; it is generally determined by a number of relatively fixed basic operational components, controlled by the overall sector of the equipment, and mainly influenced by the basic operations types. The method of confirming preparation time is similar products ratio method.
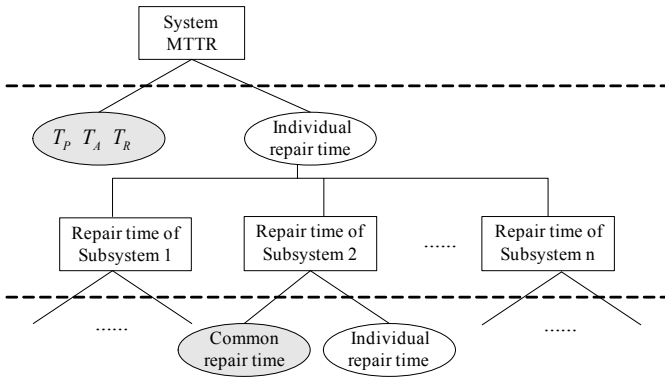
Fig. 4. Allocation model for high-level products

If the MTTR of the designing product is $\bar{M}_{CT}$ and that of the similar product is $\bar{M}'_{CT}$ and the preparation time for the similar products is , the preparation time forthe designing product is

$$T_P = \frac{\bar{M}_{CT}}{\bar{M}'_{CT}} T'_P. \tag{6}$$

Approaching time refers to the time spent opening the flap, moving through the maintenance access channel, removing the obstacles in the channel, and externalblocking of the replaceable unit by maintenance staff. The main factors that generally affect approaching time include access channel size, failure rate of the product units and components in the maintenance access channel area, flap type and opening time, fastener type, and others. Thus, common repair time is divided into three parts: time spent opening the flap of the access channel (T_{A1}), time spent moving and accessing the cabin that requires repair (T_{A2}), and time spent opening the fasteners and removing the obstacles near the replacement unit (T_{A3}). Approaching time T_A is

$$T_A = T_{A1} + T_{A2} + T_{A3}. \tag{7}$$

Approaching time is not equal to zero when the system shares the maintenance access channel;however, when each RU has its own maintenance access channel, approaching time belonging to common repair time is zero.

Reassembly involves the assembly of removed units in the channel and is regarded as the opposite of approaching process. Similar to approaching time, reassembly time is controlled by the overall sector or the upper level design department and is affected by the same factors that affectapproaching time. Thus, T_R is

$$T_R = T_A \tag{8}$$

Common repair time T_{cmn} is calculated as

$$T_{cmn} = T_P + T_A + T_R \tag{9}$$

2) Individual repair time

After determining common repair time and eliminating common repair time from the system MTTR, individual repair time T_{idv} is obtained.

$$T_{idv} = \bar{M}_{CT} - T_{cmn} \tag{10}$$

Failure rate-based allocation method is utilized to allocate individual repair time to the lower level of the equipment.

$$\bar{M}_{CT_i} = \frac{\bar{\lambda}}{\lambda_i} T_{idv} \tag{11}$$

where $\bar{M}_{CT_i}$ is the repair time allocated to subsystem i, λ_i is the failure rate of subsystem i, and $\bar{\lambda} = \frac{\sum_{i=1}^{n}\lambda_i}{n}$ is the average failure rate of all subsystems.

For the upgraded product, assuming that the system consists of n subsystems and that subsystems $1\sim L(L<n)$ are existing products, the maintainability indicators of the newly designed subsystems are allocated as

$$\bar{M}_{CT_j} = \frac{T_{idv}\sum_{i=1}^{n}\lambda_i - \sum_{i=1}^{L}\lambda_i\bar{M}_{CT_i}}{(n-L)\lambda_j}, j=L+1,\ldots,n \tag{12}$$

3.4.2. Allocation model for low-level products

The maintenance process for the low-level product unit mainly includes isolation, disassembly, and replacement, which are all determined by the design features of each unit. Thus, the time spent on the abovementioned activities belongs to individual repair time. The total individual repair time for all low-level units is

$$T_{RUidv} = \bar{M}_{CT_i} - T_{RUcmn} \tag{13}$$

where T_{RUidv} is the individual repair time allocated tothesingle RU, $\bar{M}_{CT_i}$ is the time indicator allocated to subsystem i from system level using the high-level product allocation model, and T_{RUcmn} is the common repair time in this level.

The equipment replacement scheme should be considered in the late development stage to improve the precision of allocation. When failure is isolated to a single RU, the RU can be replaced individually to correct the fault. If failure is isolated to an RU group and the RUs in the group are irrelevant, the RU group can be regarded as a single RU. The group in which the RUs are replaced alternately is denoted as RU_{GE}. The group in which the RUs are all replaced is denoted as RU_{GA}. Maintainability allocation then involves the allocation of the system MTTR to $R_{U1},\ldots,R_{Uj},RU_{GE1}\ldots,RU_{GEk},RU_{GA1},\ldots,RU_{GAl}$ according to the failure and design features of each RU or RU group. The framework of allocation of low-level repair time is shown in Fig. 5.
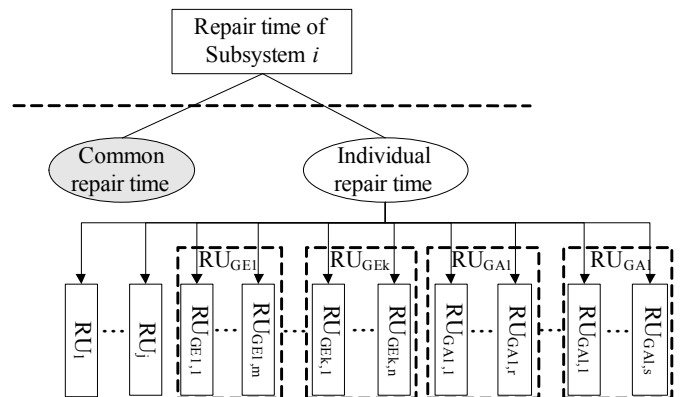

Fig. 5. Allocation model for low-level products

The average number of alternate replacements denoted as S_i needs to be calculated for the alternately replaced RU group RU_{GE1}. If the average of S_i is required to remedy the fault, the time spent replacing the RU group is S_i times the time for a single RU. In some cases, approaching and reassembly time also turn into S_i time. If the replaced RU group consists of r RUs, the corresponding time turns into r time.

The average number of replacements in the alternately replaced RU group consisting of m single RUs is

$$S_i = \left[\frac{m+1}{2}\right] \qquad (14)$$

where [x] is a maximum integer not larger than x.

Trade-off of failure rate and design feature-based allocation method is utilizedin low-level product allocation. Six kinds of maintainability design features, namely, fault detection and isolation, maintenance channel, fasteners, internal assembly, replacement, and scalability, are considered. These features may be different for different products owing to specific circumstances.

Repair time differs because different maintenance schemes are employed. Repair time when the failure is isolated to an RU group differs from repair time when failure is isolated to a single RU. Isolating failure to an RU group causes all RUs to be replaced because of the failure of one RU. Thus, this scheme is more complex than the scheme that involves the isolation of failure to a single RU. Coefficient α_i is introduced to the model to correct the weight coefficient and to make the allocation reasonable and accurate.

If the failure is isolated to a single RU, the correct coefficient is

$$\alpha_i = 1.$$

If the failure is isolated to an RU group consisting of n RUs and the RUs are replaced alternately, the correct coefficient is

$$\alpha_i = S_i = \left[\frac{m+1}{2}\right]. \qquad (15)$$

If the failure is isolated to an RU group consisting of r RUs and all the RUs are replaced, the correct coefficient is

$$\alpha_i = r.$$

The repair time allocated to each RU is calculated as

$$\bar{M}_{cti} = \frac{k_i' \sum_{i=1}^{j+k+l} \lambda_i}{\lambda_i \sum_{i=1}^{j+k+l} k_i'} T_{RUidv}, i=1,\dots,j,j+1,\dots,j+k,j+k+1,\dots j+k+l \quad (16)$$

where $k_i' = \alpha_i k_i$ and $k_i = \sum_{j=1}^{m} k_{ij}$, m is the number of weight coefficients, k_{ij} is the weight coefficient of factor j in unit i.

For the upgraded product mentioned above, the maintainability indicators of the newly designed subsystems are allocated as

$$\bar{M}_{ctj} = \frac{T_{RUidv} \sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{L} \lambda_i \bar{M}_{CT_i}}{\lambda_j \sum_{j=L+1}^{n} k_j'} k_j', j=L+1,\dots,n. \quad (17)$$

4. Case study

4.1. Analysis of system structure

The main functions of the Z-system of a certain aircraft are flight control, display management, and task data loading and recording. The system includes three subsystems: flight control, display management consisting of 10 LRUs, and mission computer subsystems (Fig.7). The system MTTR target, which is 30 min, and the failure rate and design features of the three subsystems and 10 LRUs are provided.The goal is to determine the allocated maintainability index of each LRU in the display management subsystem.
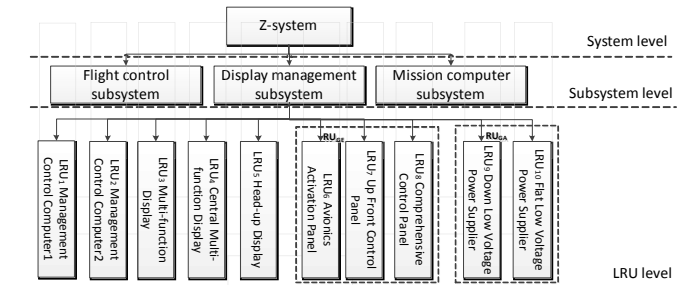

Fig. 6. Structure of the Z-system

Maintainability is fully considered in the design of the Zsystem. The design features include the following:

1. the installation position of each subsystem is concentrated in the equipment cabin, and the maintenance access channel is sufficient for observation and manual operation;
2. obstacles are removed when a maintenance personnel approaches each subsystem;
3. LRU is interchangeable, and no adjustment and calibration is required; thus, adjustment and checkout time are negligible;
4. In the diagnosis of failure, some failures can be isolated to a single LRU, some can be isolated to an alternately replaced LRU group, and others can be isolated to anentirely replaced LRU group.

The failure rate of each subsystem is shownin Table 1. Information on the LRUs is shown in Table 2.

Table 1. Failure rates of subsystems (/year)

Subsystem	Failure rate
Flight control	$\lambda_{FC}=0.0036$
Display management	$\lambda_{DM}=0.0049$
Mission computer	$\lambda_{MC}=0.0029$

4.2. Repair time allocation model

The system is divided into three levels, namely, system, subsystem, and LRU. The high-level product allocation model is utilized when the system level indicator is allocated to the subsystem level. The low-level product allocation model is utilized when the subsystem level indicator is allocated to the LRU level.

4.2.1. Allocation from system level to subsystem level

The high-level product allocation model is employed in this allocation process. Preparation, approaching, and reassembly time are determined by the overall system for the three subsystems. Preparation time T_P, approaching time T_A, and reassembly time T_R are therefore common repair time in the subsystem level. Based on experience, we obtain

$$T_P = 5 \ min, \ T_A = 6 \ min, \ T_R = 6 \ min.$$

Thus, the common repair time of this level is

$$T_{cmn} = T_P + T_A + T_R = 17 \ min.$$

The individual repair time that must be allocated to each subsystem is

$$T_{idv} = MTTR - T_{cmn} = 13 \ min$$

According to failure rate-based allocation method and Equation (2), the MTTR of the display management subsystem is

$$\bar{M}_{CT_{DM}} = \frac{\lambda_{FC} + \lambda_{DM} + \lambda_{MC}}{3 * \lambda_{DM}} = 10.0816 min.$$

4.2.2. Allocation from subsystem level to LRU level

The main maintenance activities For RU_1, RU_2,…, RU_5, RU_{GE1}, and RU_{GE2} are isolation, replacement, and reassembly. These activitiesare relevant to the diagnosis process and installation of each RU or RU group. The common repair time for the activities is zero. The use oftrade-off of failure rate and design feature-based allocation method allows the determination of the time index for each RU or RU group.

For $LRU_1, LRU_2,…,LRU_5$, the failure is isolated to a single RU; thus, $\alpha_i = 1$.

For LRU_6, LRU_7, LRU_8, the failure is isolated to an alternately replaced RU group RU_{GE1}; thus, $\alpha_i = 2$.

For LRU_9 and LRU_{10}, the failure is isolated to an alternately replaced RU group RU_{GE2}; thus, $\alpha_i = 2$.

According to Equation (16), the maintenance time allocated to each RU/RU group is

$$\bar{M}_{ct1} = 7.0175 \ min \qquad \bar{M}_{ct2} = 7.0175 \ min$$
$$\bar{M}_{ct3} = 7.2302 \ min \qquad \bar{M}_{ct4} = 10.8454 \ min$$
$$\bar{M}_{ct5} = 3.5612 \ min \qquad \bar{M}_{ctGE1} = 32.9101 \ min$$
$$\bar{M}_{ctGE2} = 11.0462 \ min$$

Considering the structure characteristics of RU_{GE1}, the time spent removing the obstacles near the three line replaceable units belongs to the common repair time of the three RUs.The approaching and reassembly time for both is 4 min, which is determined based on experience. The common repair time of three LRUs is

$$T_{RUcmn} = 8 \ min$$

and

$$T_{RUidv} = \bar{M}_{ctGE1} - T_{RUcmn} = 24.9101 \ min.$$

When T_{RUidv} is allocated to LRU_6, LRU_7 and LRU_8 through trade-off of failure rate and design feature-based allocation method, we obtain

$$\bar{M}_{ct6} = 42.3 \ min$$
$$\bar{M}_{ct7} = 60 \ min$$
$$\bar{M}_{ct8} = 13 \ min$$

Similarly, we obtain the maintenance index of LRU_9 and LRU_{10}.

$$T_{RUcmn} = 4 \ min$$
$$\bar{M}_{ct9} = 8.8916 \ min$$
$$\bar{M}_{ct10} = 5.6583 \ min$$

The results of the proposed allocation method and traditional allocation method are shown in Table 3 and Fig. 7.

The following conclusions are derived from the comparison of the results of the new allocation method and traditional trade-off of failure rate and design feature-based allocation method.

a) Only a minimal amount of time is allocated to each LRU whenthe new method is utilized because common repair time is obtained from the indicator that will be allocated. Allocating a low MTTR to each LRU is appropriate because a low MTTR can influence the design process and improve the performance of equipment.

Table 2. Information on LRUs

RU/RU group	k_i of RU/RU group	α_i of RU/RU group	k_i' of RU/RU group	Failure rate of RU/RU group*	LRU name	LRU code	Obstacles in the channel to access LRU	Installation of LRU	Failure rate of LRU*	k_i of LRU**
RU_1	8	1	8	0.00034	Management control computer 1	LRU_1	No mechanical disassembly is required	Swing nut	0.00034	8
RU_2	8	1	8	0.00034	Management control computer 2	LRU_2	No mechanical disassembly is required	Swing nut	0.00034	8
RU_3	8	1	8	0.00033	Multi-function display	LRU_3	No mechanical disassembly is required	bolt	0.00033	8
RU_4	12	1	12	0.00033	Central multi-function display	LRU_4	No mechanical disassembly is required	bolt	0.00033	12
RU_5	8	1	8	0.00067	Head-up display	LRU_5	No mechanical disassembly is required	bolt	0.00067	8
RU_{GE1}	16	2	32	0.00029	Avionicsactivation panel	LRU_6	Extensive disassembly is required	screws	5.044E-05	14
					Up front control pane	LRU_7	Extensive disassembly is required	Insertion	4.322E-05	17
					Comprehensive control panel	LRU_8	Extensive disassembly is required	screws	0.0002	17
RU_{GE2}	10	2	20	0.00054	Downlow-voltage power supplier	LRU_9	Extensive disassembly is required	Insertion	0.00021	10
					Flat low-power supplier	LRU_{10}	Extensive disassembly is required	Insertion	0.00033	10

*The unit of failure rate is year-1.

** of each LRU can be obtained with PRC military standard GJB/Z57.

Table 3.   Results of the proposed method (min)

| Subsystem level T_{cmn}	RU/RU group	T_{RUcmn}	LRU code	Allocated time forLRU	Theoretical total time	Traditional method result	Actual maintenance time
17	RU_1	0	LRU_1	7.0175	24.0175	13.9005	27
	RU_2	0	LRU_2	7.0175	24.0175	13.9005	27
	RU_3	0	LRU_3	7.2302	24.2302	14.3218	29
	RU_4	0	LRU_4	10.8454	27.8454	21.4826	29
	RU_5	0	LRU_5	3.5612	20.5612	7.0540	21
	RU_{GE1}	8	LRU_6	42.3	67.3	163.97	70
			LRU_7	60	85	232.37	82
			LRU_8	13	38	50.2157	36
	RU_{GE2}	4	LRU_9	8.8916	29.8916	28.132	32
			LRU_{10}	5.6583	26.6583	17.902	25
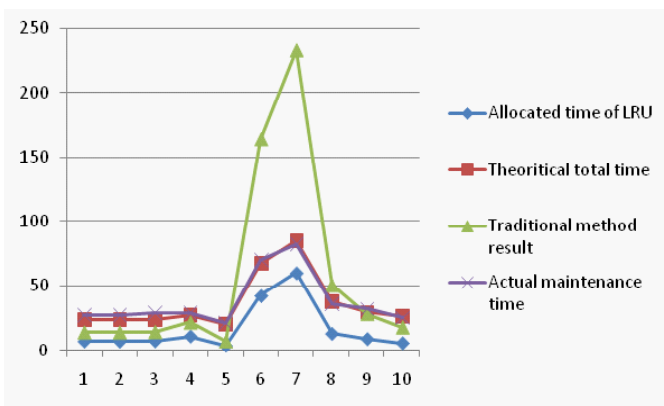
Fig. 7. Comparison of the results of the proposed and traditional method

b) Theoretical total repair time is almost similar to actual repair time when the new method is employed, indicating that the new method is more accurate than traditional allocation methods.

5. Conclusions

Commonly utilized maintainability allocation methods are limited because design factors such asthe maintenance access channel are not considered by the specific unit design department. The MTTR index allocated to each unit cannot be completely controlled by the corresponding design department, which is contrary to the purpose of allocation. A time characteristics-based maintainability allocation method is proposed in this study to address this problem. By considering the structure of the system and the determinants of repair time, repair time is classified into two categories: common repair time and individual repair time. High-level and low-level product unit allocation models are built based on the classification of repair time. The main difference between the new method and traditional methods is that common repair time is obtained and only individual repair time is allocated to low-level units. The case study shows that the new method is more accurate and much less complicated than the original methods, which is beneficial for equipment performance.

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