A field data based RAM analysis and classification of intensive management items for the Korean Utility Helicopters

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This paper addresses a field data-based RAM analysis and classification of the intensive management items (IMIs) for the Surion helicopters. To achieve this, the field data such as operation, maintenance and failure are gathered from the defense logistics integrated information systems for army (DELIIS/A) and the operation/maintenance documentations in the field forces, subsequently basic performance and Reliability, Availability and Maintainability (RAM) analysis are conducted based on gathered field data. In addition, IMIs are classified by applying to cross efficiency weighted linear optimization (CE-WLO) method, which is one of the objective weight assignment methods for the multi-criteria decision making (MCDM) problem. The RAM analysis results can be utilized as the reference to set of RAM target values for developing the similar weapon systems, update RAM prediction values in the development phase and estimate items usage in developing next version of the helicopters. The classification of the IMIs results can be utilized as the reference information for inventory policy or logistics support establishment.

Ⅰ. INTRODUCTION

Surion, Korea utility helicopter (KUH), was designed and developed to meet the requirements of the South Korean army air force, and to replace the ageing Uh-1H attack helicopters and the 500DM light helicopters fleet of South Korea army. A total of 245 Surion helicopters were ordered by the Republic of Korea Army (ROKA). The delivery began in 2012 and will last for eight to ten years. The helicopter will be used in a variety of applications, including troop assault, search and rescue, tactical lift, liaison and medical evacuation. And helicopters are expected to improve the combat power of the South Korean army air force innovatively.

In accordance with the regulation of defense acquisition program (No.292) in South Korea, a follow-up logistics support task has to be performed within 3 years after deploying a newly developed weapon system. The follow-up logistics support task addresses the optimization of logistics supportability and technical support throughout the operational life cycle of the systems. In general, the impact of the optimization of integrated logistics support (ILS) is measured in terms of metrics such as reliability, availability and maintainability (RAM), and sometimes system safety (RAMS) or testability (RAMT). RAM analysis of weapon systems is helpful in carrying out design modification and quality verification, if any, required to achieve minimum failures or to increase mean time between failures (MTBF) and thus to plan maintainability requirements, optimize reliability and maximize equipment availability (Ref. 1). RAM analysis addresses both operation and safety issues and aims to identify areas within the system or process where improvement actions can be initiated. With RAM analysis of the system key performance metrics such as Mean Time to Failure (MTTF), Equipment down Time (EDT) and System availability values can be ascertained. The information obtained from analysis helps the management in assessment of the RAM needs of system. In order to conduct a more accurate RAM analysis for the operational life cycle of the systems, fact that how well obtains the correct field data from the field forces is important issue. The field data for RAM analysis includes operation, maintenance and failure data during the weapon systems' operation.

This paper addresses a field data-based RAM analysis and the classification of the intensive management items (IMIs) of the Surion helicopters. To achieve this, the field data such as operation, maintenance and failure are gathered from the defense logistics integrated information systems for army (DELIIS/A) and the operation/maintenance documentations in the field forces, subsequently basic performance and RAM analysis are conducted based on the gathered field data. In addition, the IMIs are classified by applying to cross efficiency weighted linear optimization (CE-WLO) method, which is one of the objective weight assignment methods for multi-criteria decision making (MCDM) problem. The RAM analysis results can be utilized as the reference to set RAM target values for developing the similar weapon systems, update RAM prediction values in the development phase and estimate items usage in developing next version of the helicopters. The classification of the IMIs results can be utilized as the reference information for the inventory policy or logistics support establishment.

The structure of this paper is organized as follows. Section 2 discusses the RAM analysis method for the Surion helicopters, and Section 3 presents the analysis results. Section 4 summarizes the results.

Ⅱ. RAM analysis method

RAM analysis can be categorized reliability, availability and maintainability analysis. Reliability is a measure of the probability for failure-free operation during a given interval, i.e. it is a measure of success for a failure-free operation. The reliability of a component is calculated as $R(t) = e^{-\lambda t}$, where λ is the constant failure rate of the component and t the operational time. The reliability can be categorized as mission reliability and logistics reliability based on the analysis standard, and the reliability rating scales are *MTBF* and *MTTF* (mean time to failure) according to the reparability of the components of system. The estimation method for MTTF according to the distributions can be illustrated as TABLE 1.

TABLE 1. MTTF estimation method according to the distributions

Distributions	***f(t)***	***MTTF***
Exponential	$e^{-\lambda t}$	$1/\lambda$
Weibull	$\frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{-\left(\frac{t}{\theta}\right)^{\beta}}$	$\theta\Gamma\left(1+\frac{1}{\beta}\right)$
Log normal	$\frac{1}{\sqrt{2\pi}\sigma t} e^{-\frac{(Int-\mu)^2}{2\sigma^2}}$	$e^{\mu+\frac{\sigma^2}{2}}$

Availability is the probability that a system or component is performing its required function at a given point in time or over a stated period of time when operated and maintained in prescribed manner. The availability rating scale is categorized as inherent availability (A_i) and operational availability (A_o), respectively. TABLE 2 shows the operation time classification. $A(t)$ called the point availability at time t. $A(t) = (1/T)\int_0^T A(t)dt$ called average availability over interval. It can be generalized into log run availability as $A_i = \underset{T\to\infty}{Lt}\ A(T) = \frac{MTBF}{MTBF+MTTR} = \frac{TOT}{TOT+TCM}$ and $A_o = \frac{TUT}{TUT+TDT}$, where *MTTR* means the mean time to repair, respectively.

TABLE 2. Operation time classification

Total Time (TT)					
Total Up Time (TUT)		**Total Down Time (TDT)**			
		Total Maintenance Time (TMT)		Total Administration/Logistics Delay Time (TALDT)	
Total Operating Time (TOT)	Total Standby Time (TST)	Total Corrective Time (TCT)	Total Preventive maintenance Time (TPM)	Total Administration Delay Time (TADT)	Total Logistics Delay Time (TADT)

Maintainability is the probability that a failed component or system will be restored or repaired to a specified condition within a period of time when maintenance is performed in accordance with prescribed procedures. A key maintainability figure of merit is *MTTR* and a limit for the maximum repair time. The maintainability rating scales are MTTR, mean time to preventive maintenance (MTPM), mean time between maintenance (MTBM), mean time between repair (MTBR), maintenance rate (MR), maximum time to repair (MAXTTR) and mean activity maintenance downtime (MAMDT). Under the assumption of exponential distribution, MTTR is expressed as $\frac{\sum M_{ct}}{N}$ where N is the number of failure maintenance and M_{ct} is the total failure maintenance time. Maintainability is expressed as $M(t) = 1 - \exp(-t / MTTR) = 1 - \exp(-\mu t)$, where μ is constant maintenance rate.

Ⅲ. Analysis result

Ⅲ.A. RAM analysis

We obtain the field data such as operation, maintenance and failure are gathered in DELIIS/A from 01/2013 to 06/2015. The number of the obtained field data is reported in Table 3. The number of operation, maintenance and failure are 3,777, 5,401 and 1,679, respectively. Note that the number of failure is extracted from the number of maintenance. As illustrated in TABLE 4, the total flight time is 8,992, and the number of taking off and landing is 28,054, respectively. The average operating time, which is divided by the number of helicopters, is 383, and a helicopter take off and land averagely 1,183 during the operating time. The maintenance time and status are shown in TABLE 5. The preventive maintenance time, corrective time and total maintenance time is 27,169, 1,296 and 28,466, respectively.

TABLE 3. The number of the obtained field data

Operation	Maintenance	Failure
3,733	5,401	1,679

TABLE 4. Operating time

Total operating time	Average operating time	Total number of taking off and landing	Average taking off and landing
8,992	383	28,054	1,183

TABLE 5. Maintenance time and status

Operating time	Preventive maintenance time	Corrective time	Total maintenance time
8,992	27,169	1,296	28,466
MAMDT	**MR**	**MTBM**	**MAXTTR (95%)**
2.71	3.17	1.71	10.5

The reliability is analyzed by assuming exponential distribution and PLP distribution. The MTBF under the assumption of exponential distribution and PLP distribution are 8,683 (hr) and 7.35 (hr), respectively. Table 6 shows the reliability growth analysis based on the PLP distribution. Since the test statics is -3.131, and β is closer to 1 as 0.983, it can be said that the distribution follows Non-Homogeneous Poison Process (NHPP). Figure 1 shows the accumulated failure number ($N(t)$) according to the estimated time by the reliability growth analysis.

TABLE 6. Result of the reliability growth analysis

Log-likelihood value	-2531.722	**Standard of analysis: Laplace** [Significance level(α): 5%, Test statics(Z): -3.131]
B value (estimated)	0.983	
λ value (estimated)	0.153	

MTTR for the maintenance is analyzed under the assumption of log normal distribution and exponential distribution as shown in TABLE 7. OT, ST, TUT, TCM and TDT are calculated as 8992, 391839, 400831, 1072, 1072, subsequently, the A_i and A_0 are calculated as 89% and 91%, respectively.

TABLE 7. MTTR result

Distribution	Likelihood function	MTTR	Parameter	Estimation value
Log normal	-743.763	1.490	μ	-0.653
			σ	1.452
Exponential	-1100.162	1.980	λ	0.504

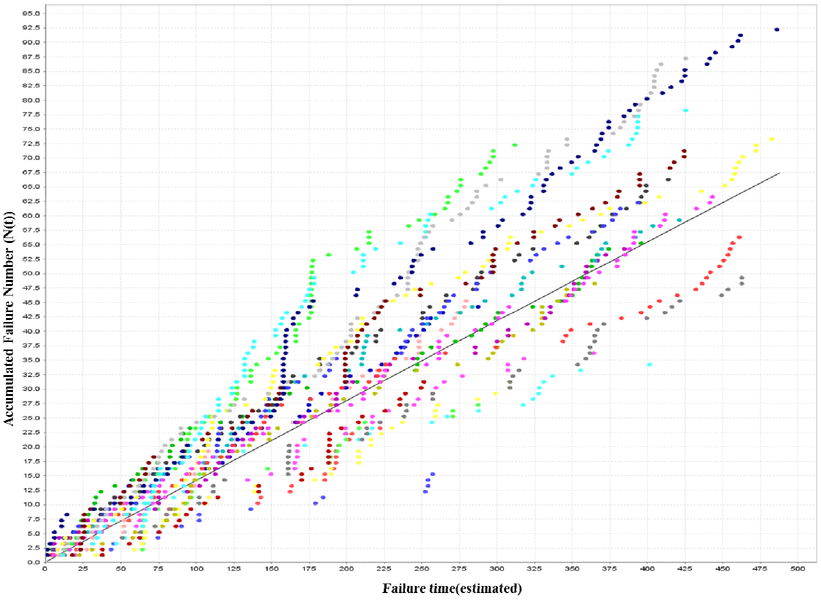

Figure 1. Accumulated failure number according to the failure time

Ⅲ.B. Classification of intensive management items

This paper considers the number of failure, maintenance time, number of used items, and high price items are utilized as the performance measures for the classification of intensive management items. Table 8 show the correlation analysis among the high ranked items according the performance measures, and we can find a fact that high ranked items are irrelevant each other.

TABLE 8. Correlation analysis among the performance measures

	Number of failure	Number of used items	Maintenance time	Unit price
Number of failure	1	0.48	0.21	0.15
Number of used items		1	0.35	0.09
Maintenance time			1	0.13
Unit price				1

Because four criteria are considered as a performance measures in classifying the intensive management items (IMIs), the approach of this paper is a multi-criteria decision-making (MCDM) problems. One key issue in MCDM is how to aggregate multiple performance measures into a single performance measure in a proper manner by choosing a set of reasonable weights on multiple measures. Data envelopment analysis (DEA) provides a way of systematic choice of weights on multiple measures where optimal weights are determined by solving mathematical (typically linear) programs. A DEA run determines a performance score for a decision making unit (DMU), and DEA can rank DMUs according to their performance scores. Basically, DMUs in DEA correspond to multiple alternatives in MCDM, input and output factors in DEA correspond to multiple performance measures in MCDM, and the notion of performance in DEA corresponds to that of convex performance of MCDM. When DEA is used as a MCDM technique, it can be called multi-factor performance measurement model (Ref. 2).

We utilize DEA for the IMI classification, and the model can be represented as model (1).

$$\begin{aligned} l_k &= Max \sum_{r=1}^{s} u_{rk} y_{rk} \\ &s.t.\ \sum_{r=1}^{s} u_{rk} y_{rj} \le 1, \quad j = 1,\dots,n \\ &u_{rk} \ge 0, \quad \forall r. \end{aligned} \tag{1}$$

where u_{rk} is the weight given to the r-th criterion of the k-th item (y_{rk}). The weighted additive function, l_k, aggregates the performance of an item in terms of the different criteria, and its optimal value is used as the importance of IMI for the k-th item. The function is maximized under the condition that the weighted sum of the performance levels for each item, computed using the same set of weights, should be less than or equal to 1. The dual version of the model (1) problem can be formulated as model (2). λ_j is the dual variable that is assigned to item j. The dual problem is computationally easier to solve than the primal one, considering the fact that the number of items is typically much greater than the number of criteria.

$$\begin{aligned} l_k &= Min \sum_{j=1}^{n} \lambda_j \\ &s.t.\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rk},\ r = 1,\dots,s, \\ &\lambda_j \ge 0, \quad j = 1,\dots,n \end{aligned} \tag{2}$$

For each item, model (2) is repeatedly solved by altering the competing item, resulting in n-1 optimal weights. Therefore, the optimal weights of an item under evaluation can vary according to the competing item being evaluated. In this way, an item under evaluation can involve multiple strategies (optimal weights) by which it emphasizes its strengths and a specific competing item's weaknesses. By changing the item under evaluation, the formulation is rerun n-1 times, where n is the number of items. The mean of these scores can be utilized as an index for ranking items and identifying more important ones. All of the n scores that an item obtains are averaged to yield its importance index. Specifically, I_p is the importance index of item p, and is computed, by the following model (3), as

$$I_p = \frac{\sum_{k=1}^{n} I_{pk}^{*}}{n}, \quad p = 1,\dots,n \tag{3}$$

Based on model (3), IMIs are classified as illustrated, and TABLE 9 shows the high ranked eight items.

TABLE 9. High ranked eight items

Rank	**NIIN**	**number of failure**	**number of used items**	**maintenance time**	**Unit price(₩1,000)**	**Score**
1	A81035***	18	57	55.4	7,000	1.00
2	375204***	4	4	0.84	67,503	1.00
3	011212***	12	36	76.4	258	0.81
4	375205***	7	10	24.62	68,258	0.69
5	375205***	5	5	0.59	86,370	0.67
6	015968***	5	5	6.15	60,791	0.55
7	375204***	6	6	7.33	41,830	0.51
8	375205***	4	4	36.9	45,000	0.50

Ⅳ. CONCLUSIONS

This paper addressed a field data-based RAM analysis and the classification of the intensive management items (IMIs) of the Surion helicopters. The field data such as operation, maintenance and failure were gathered from the defense logistics integrated information systems for army and the operation/maintenance documentations in the field forces, subsequently basic performance and RAM analysis was conducted based on the gathered field data. In addition, the IMIs were classified by applying to cross efficiency weighted linear optimization (CE-WLO) method, which is one of the objective weight assignment methods for multi-criteria decision making (MCDM) problem. The RAM analysis results can be utilized as the reference to set RAM target values for developing the similar weapon systems, update RAM prediction values in the development phase and estimate items usage in developing next version of the helicopters. The classification of the IMIs results can be utilized as the reference information for the inventory policy or logistics support establishment.

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