Sensitivity Analysis of RAM Parameters

Yeong-Seok Kim[1*], Myeong-Seok Lee[2] and Jang-Wook Hur[3]

Abstract: The objective of RAM analysis in the weapon system is to improve combat readiness by satisfying RAM targets and reduce the life cycle cost. The sensitivities of the operational availability against the RAM analysis parameters were conducted by using Markov Process Simulation (MPS). The time required for the operational availability to reach the normal state was approximately between 15,000 and 30,000H (2-4 years). The sensitivities of operational availability parameters were in the order of ALDT ≫ MTBF > MTTR. Consequently, it is necessary to pay attention to ALDT, which was the most sensitive to the operational availability, and continuously improve the system in order to improve the combat readiness.

Keywords: Sensitivity, Analysis, Parameters

I. Introduction

RAM stands for reliability, availability, and maintainability. Moreover, it means an activity to minimize the failure of the weapon system or equipment and increase the availability of the equipment by shortening the maintenance time in case of failure. The setting the target value of RAM, which is done in the requirement institution of the weapon system or the equipment or a preliminary research stage, becomes the standard for allocation and prediction of reliability and maintainability in the system development. Consequently, it is considered as an important baseline.

Particularly, the operational availability is defined as the probability that a weapon system or equipment will operate under actual operating conditions. It is the availability including the standby time, administrative and logistics delay time, and maintenance time. It is not possible to exclude administrative processing time or parts procurement time in reality and these are essential factors, although delay time of them due to these factors somewhat varies. Therefore, the operational availability can be expressed as a possibility to run a system in the specified condition under a practical supporting circumstance.

The operational availability is closely related to the combat readiness. Therefore, major developed countries including the USA apply the Markov Process, which can confirm a result at a specific state at a specific time as well as a normal state.

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However, South Korea mainly uses a mathematical method, which only considers a normal state. Moreover, even the M&S method, which is used from time to time, only reflects a normal state.

This study developed Markov Process Simulation (MPS), which can reflect both normal state and a specific state. This study analyzed the sensitivity of RAM analysis parameters (i.e., MTBF, MTTR, and ALDT) and tried to contribute to the improvement of combat readiness by enhancing the system related to the sensitive parameters.

II. Development Of Markov Process Simulator

An independent random process satisfies the Markov process if one can predict the future of the state solely based on its present state and the prediction is independent to the past. It is also called a Memoryless Process in the aspect that it does not remember the past state. For the arbitrary time , $t_1 < t_2 < \dots < t_k < t_{k+1}$, if *X(t)* is a discrete value, it can be expressed as Eq. (1).

$$P[X(t_{k+1}) = x_{k+1} | X(t_k) = x_k, \cdots, X(t_1) = x_1] = P[X(t_{k+1}) = x_{k+1} | X(t_k) = x_k] \quad (1)$$

If X(t) is a continuous value, the Markov property is described as Eq. (2).

$$P[a < X(t_{k+1}) \le b | X(t_k) = x_k, \cdots, X(t_1) = x_1] = P[a < X(t_{k+1}) \le b | X(t_k) = x_k] \quad (2)$$

In these equations, t_k, t_{k+1}, and $t_1, \cdots, t_{k-1}$ stand for the present, the future, and the past, respectively. At time *t*, the value of *X(t)* is defined as a 'state'. When the value of the Markov process is an integer, it is called Markov Chain. The Markov chain can be divided into a discrete-time Markov process and a continuous-time Markov process depending on the property of t; discrete *t* and continuous *t*, respectively. When X(t) satisfies the Markov chain, the joint probability at an arbitrary time can be expressed as Eq. (3) by using a conditional probability and the Markov property.

$$\begin{aligned} &P[X(t_3) = x_3, X(t_2) = x_2, X(t_1) = x_1] \\ &= P[X(t_3) = x_3 | X(t_2) = x_2, X(t_1) = x_1] P[X(t_2) = x_2, X(t_1) = x_1] \\ &= P[X(t_3) = x_3 | X(t_2) = x_2] P[X(t_2) = x_2, X(t_1) = x_1] \\ &= P[X(t_3) = x_3 | X(t_2) = x_2] P[X(t_2) = x_2 | X(t_1) = x_1] P[X(t_1) = x_1] \end{aligned} \quad (3)$$

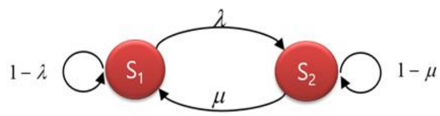
It can be expanded to Eq. (4).

$$P[X(t_{k+1}) = x_{k+1}, X(t_k) = x_k, \cdots, X(t_1) = x_1]$$
$$= P[X(t_{k+1}) = x_{k+1} | X(t_k) = x_k]\, P[X(t_k) = x_k | X(t_{k-1}) = x_{k-1}] \times \cdots \times$$
$$P[X(t_2) = x_2 | X(t_1) = x_1]\, P[X(t_1) = x_1] \quad (4)$$

A general probability problem does not consider the temporal concept, but many phenomena appearing over time often have stochastic properties. The group of stochastic variables considering time is called a stochastic process. The stochastic theory considering time is deemed dynamic. The Markov process technique is used as a reliability analysis with considering the time of a system based on these properties. All stochastic processes of the Markov process shall satisfy the condition of Eq. (5) for all $x(u), 0 \le u \le s$.

$$P[X(t+s) = j | X(s) = i, X(u) = k, 0 \le u < s]$$
$$= P[X(t+s) = j | X(s) = i] \quad (5)$$

The Markov process can be simply described as Fig. 1. The probability value of a continuous-time Markov process can be estimated by using the differential of the discrete Markov process and the transition matrix.



$$T = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} 1-\lambda & \lambda \\ \mu & 1-\mu \end{bmatrix}$$

Fig. 1: Basic Markov Analysis Model

The analysis procedure of the Markov process based simulation is shown in Fig. 2. The system state is defined by using the probabilities of transition to different states. Afterward, the time from one state to the next state is entered into the transition matrix. The input matrix value calculates probabilities by using the differential equation and Laplace transformation. The results were analyzed subsequently.

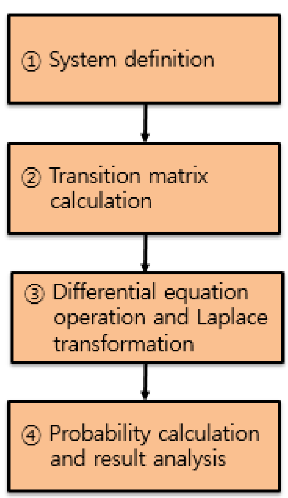


Fig. 2: Markov Process Steps

Markov Process Simulation (MPS) was developed and the main screen of it is as shown in Fig. 3. Each state was defined on the main screen and the event to occur was set. Afterward, the simulation duration, number of simulation reiteration, operation time, alert time, standby time, maintenance time, administrative and logistics delay time, and preventative maintenance time were entered and a simulation was conducted.

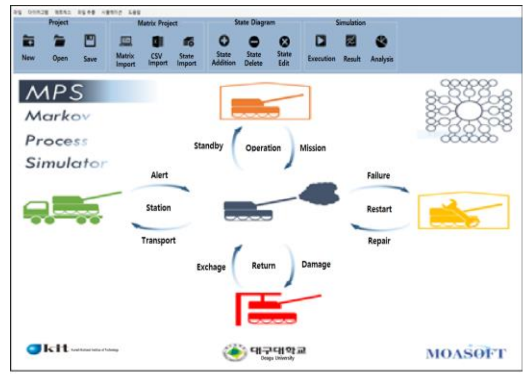


Fig. 3: Main Screen of Markov Process Simulation

III. MPS State Modeling and Sensitivity Analysis Method

The tracked vehicle was selected as the target for conducting a sensitivity analysis of MPS, developed for the RAM analysis. The system configuration of the tracked vehicle is shown in Fig. 4. The modeling results with using it are shown in Fig. 5. In the figure, the components of the tracked vehicle were divided into the operational states and non-operational state. Parts indicated as operating, standby, and alert are in the operational states and those marked as a failure, ALDT, and maintenance are in the non-operational states. The total time was set to 5 years (44,000H) in order to calculate the operational availability of the tracked vehicle. MTBF, MTTR, and ALDT were set as 31.2, 2.1, and 56.7H, respectively, according to the RAM analysis result report. The state transition parameter flow for each component is classified by the maintenance step and the parameters related to them followed the failure rate prediction and the technical manual.

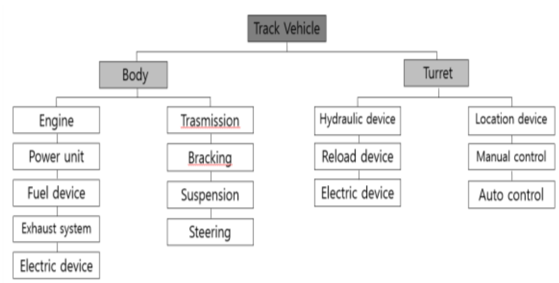


Fig. 4: System Configuration of Tracked Vehicle

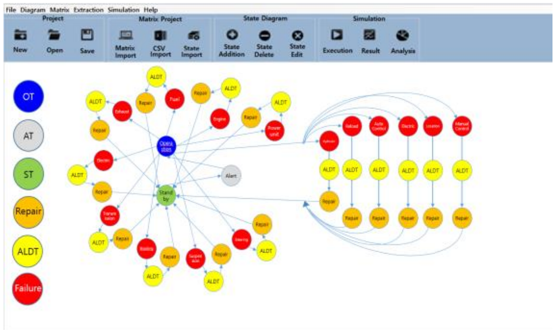


Fig. 5: Results of MPS Modeling

The factors affecting the performance of weapon systems and equipment can be broadly divided into external and internal factors. External factors generally result from surrounding environment so they are treated as constraints. Internal factors are related to the system design and parameters to be determined by the designer's judgment are defined as design variables. The effect of each design variable on the performance of weapon systems and equipment varies. Therefore, the effect of the unit change of each design variable on the performance of weapon systems and equipment is defined as sensitivity and the sensitivity analysis is a task to quantitatively calculate the sensitivity.

A sensitivity analysis was conducted by using the selection technique, which extracts samples by changing one variable at a time and compare the results. This method does not consider the interactions among input variables and requires a large sample size for an interpretation, which are shortfalls. However, it has the advantage of finding a factor that has a major influence on the response of the target model. Moreover, the trend line of a regression analysis was applied to reduce the excessive deviation of simulation results. Through the analysis, a trend line had a regression coefficient (R^2) closest to 1 was examined and it was determined that the logarithm function was the most appropriate for the trend format. The log trend line is the most appropriate curve when the fluctuation rate rapidly increase or decrease at the beginning and approaches to asymptote. Where a regression coefficient indicates how well a regression equation explains the actual data and it is calculated by using Eq. (6).

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{6}$$

SSR: Sum of Square Regression
SST: Total Sum of Squares
SSE: Sum of Squared Errors

The normal state was assumed as the state when the operational state showed a steady-state. When the difference between the current operational availability and the past operational availability was within 1%, it was defined as a normal state. The time until reaching the normal state was evaluated by changing the scale of each parameter.

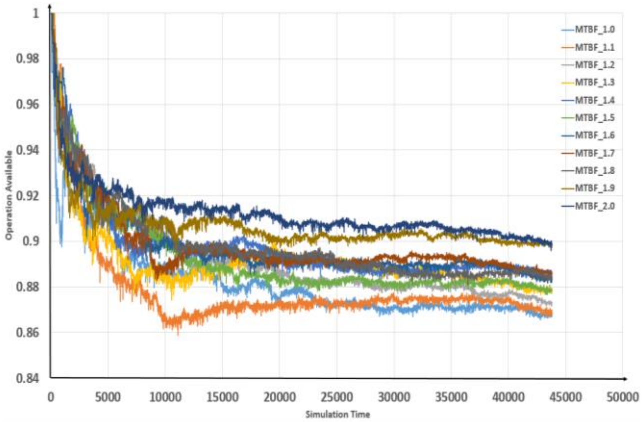
IV. Simulation Results and Discussion

Figure 6, Figure 7, and Figure 8 show the changes in the operational availability and trend lines over time with varying the operational availability parameters (i.e., MTBF, MTTR, and ALDT) by 10% with using MPS, respectively. In each figure, the operational availability at the normal state and the time until reaching the normal state were examined and shown in Table 1. The operational availability at the normal state increased at a fixed rate with the increase of MTBF, the decrease of MTTR, and the decrease of ALDT. The time until reaching the normal state did not show a constant change to the changes of parameter scale. However, it could be estimated that the time until reaching the normal state would be approximately between 15,000 and 30,000H, approximately 2-4 years.

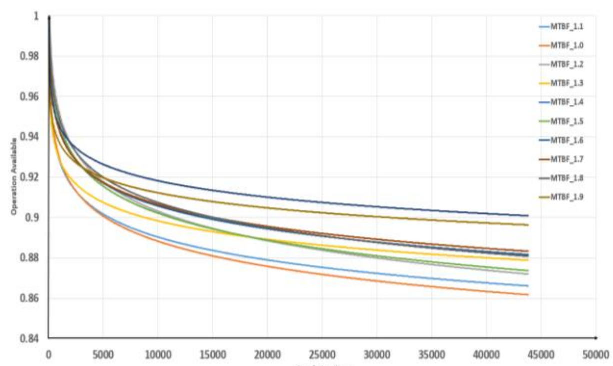
TABLE I:
SIMULATION ACCORDING TO RAM PARAMETER SCALE RATES

Classification		**Time until reaching the normal state (H)**	**Operational Availability at Normal State (%)**
Default	1.0	25,000	86.75
MTBF	10%↑	20,000	86.90
	20%↑	25,000	87.31
	30%↑	20,000	87.85
	40%↑	20,000	88.64
	50%↑	20,000	87.84
	60%↑	20,000	88.31
	70%↑	20,000	88.60
	80%↑	20,000	88.41
	90%↑	20,000	89.84
	100%↑	20,000	89.90
MTTR	10%↓	25,000	86.12
	20%↓	20,000	86.13
	30%↓	25,000	86.14
	40%↓	25,000	86.31
	50%↓	30,000	86.32
	60%↓	20,000	86.43
	70%↓	30,000	86.44
	80%↓	25,000	86.54
	90%↓	25,000	86.55
ALDT	10%↓	15,000	87.03
	20%↓	20,000	89.28
	30%↓	20,000	89.56
	40%↓	25,000	91.84
	50%↓	20,000	92.96
	60%↓	15,000	94.04
	70%↓	30,000	95.51
	80%↓	20,000	96.84
	90%↓	20,000	98.29

Figure 9 shows the operational applicability at the normal state according to the changes in the parameter scale. The operational applicability of ALDT showed the greatest change (slope=1.133) due to the changes in scale. It was because TDT greatly affected the operational applicability and TDT accounted for a large portion of ALDT. MTBF showed the second highest sensitivity (slope=1.036) because MTBF accounted for the second largest portion of TDT. MTTR means the pure maintenance time and it had limited effects on the operational availability. Consequently, MTTR was relatively less sensitive (slope=1.001). The results

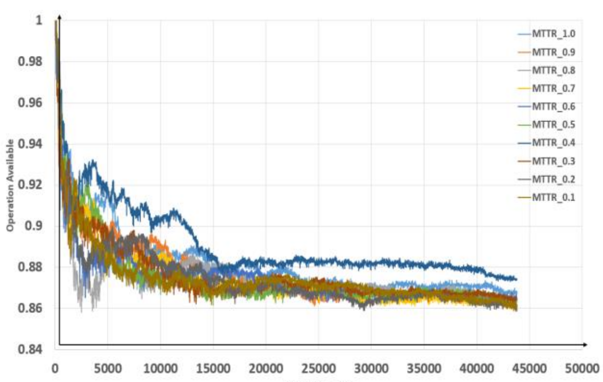


(a) Simulation Result

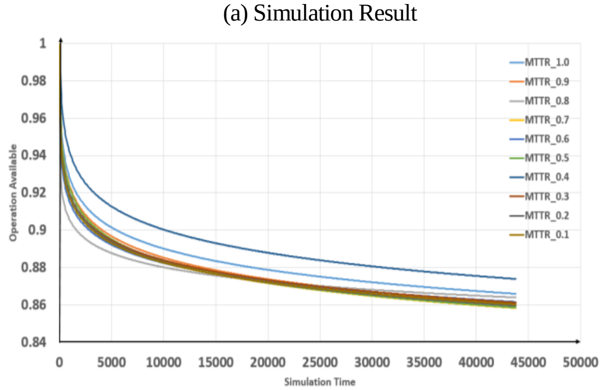


(b) Trend Analysis Result

Fig. 6 Ao trend according to the changes of MTBF



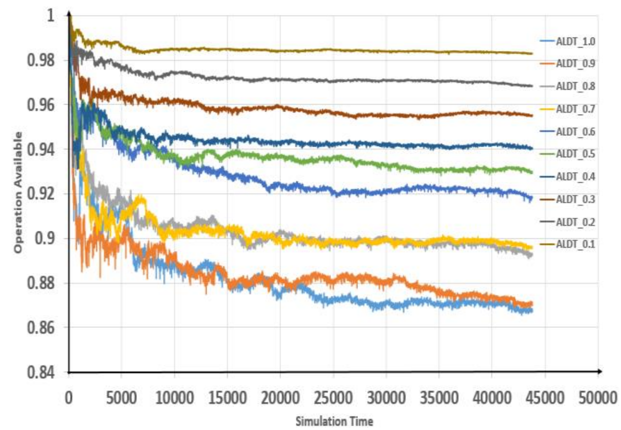
(a) Simulation Result



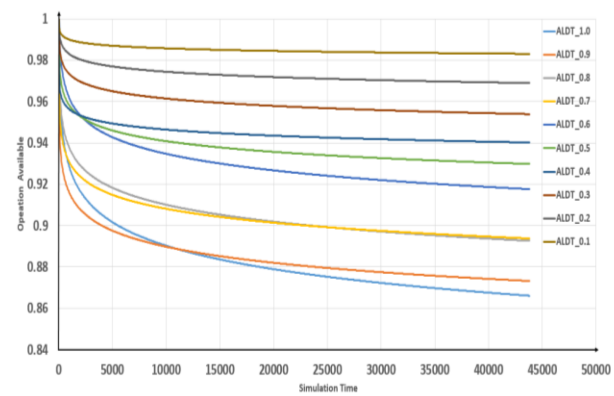
(b) Trend Analysis Result

of this study suggested that it would be important to pay attention to ALDT, which was the most sensitive to the operational availability, and continuously improve the system.

Fig. 7 Ao according to the changes of MTTR



(a) Simulation Result



(b) Trend Analysis Result

Fig. 8 Ao according to the changes of ALDT

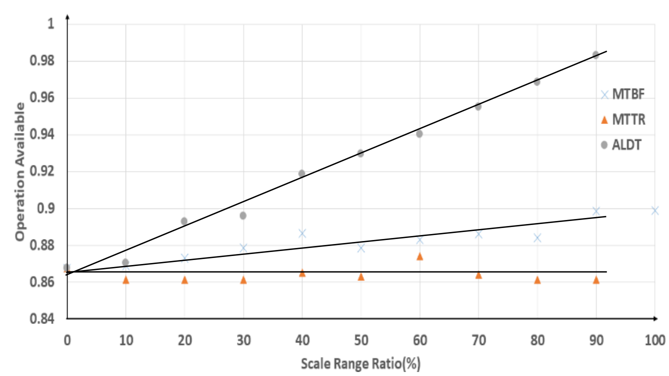


Fig. 9 Changes in the Ao according to the scale

V. CONCLUSIONS

The sensitivities of parameters (i.e., MTBF, MTTR, and ALDT) affecting the operational availability were analyzed by using MPS.

(1) the time required for the operational availability to reach the normal state was approximately between 15,000 and 30,000H (2-4 years).

(2) the sensitivities of operational availability parameters were in the order of ALDT $\gg$ MTBF > MTTR.

(3) in order to improve the combat readiness, it is necessary to pay attention to ALDT, which was the most sensitive to the operational availability, and continuously improve the system

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