Effects of Forgetting Phenomenon on Surveillance Test Interval

Ho-Joong Lee and Seung-Cheol Jang
Korea Atomic Energy Research Institute, P.O Box 105, Yuseong, Daejeon, 305-600, Korea
hjlee94@kaeri.re.kr, scjang@kaeri.re.kr

1. Introduction

Technical Specifications (TS) requirements for nuclear power plants (NPPs) define Surveillance Requirements (SRs) to assure safety during operation. SRs include surveillance test intervals (STIs) and the optimization of the STIs is one of the main issues in risk-informed applications. Surveillance tests are required in NPPs to detect failures in standby equipment to assure their availability in an accident. However, operating experience of the plants suggests that, in addition to the beneficial effects of detecting latent faults, the tests also may have adverse effects on plant operation or equipment; e.g., plant transient caused by the test and wear-out of safety system equipment due to repeated testing[1]. Recent studies have quantitatively evaluated both the beneficial and adverse effects of testing to decide on an acceptable test interval.

The purpose of this research is to investigate the effects of forgetting phenomenon on STI. It is a fundamental human characteristic that a person engaged in a repetitive task will improve his performance over time. The learning phenomenon is observed by the decrease in operation time per unit as operators gain experience by performing additional tasks. However, once there is a break of sufficient length, forgetting starts to take place. In surveillance tests, the most common factor to determine the amount of forgetting is the length of STI, where the longer the STI, the greater the amount of forgetting.

2. Methods and Results

This section describes the forgetting curve which uses the learning curve phenomenon reported by Wright[2]. The forgetting model is constructed based on the learn-forget curve (LFCM) model[3], and we illustrate numerically the effects of forgetting phenomenon on STI.

2.1 The Learning and Forgetting Curves

The learning curve phenomenon reported by Wright[2] shows that as the quantity of units produced doubles, the number of direct labor hours it takes to produce an individual unit decreases at a uniform rate (e.g., 90%, 80%, 70%, etc.). Learning curve expresses an exponential relationship between direct man-hour input and cumulative production as follows:

$$T_j = T_1 j^{-l} \tag{1}$$

where T_j = the time to produce the j th unit, j = the production count, T_1 = the theoretical time required to produce the first unit, and l = the learning slope.

The forgetting curve relation is assumed to be that of Carlson and Rowe[4]:

$$\hat{T}_x = \hat{T}_1 x^f \tag{2}$$

where $\hat{T}_x$ = the time for the x th unit of lost experience of the forgetting curve, x = the amount of output that would have been accumulated if interruption did not occur, $\hat{T}_1$ = the equivalent time for the first unit of the forgetting curve, and f = the forgetting slope.

2.2 The Forgetting Model

Jaber and Bonney[3] presented the LFCM model in which they assume that both learning and forgetting are functions of time. The theory assumes that the longer the period of production, the more the productivity increases, whereas the longer the stoppage, the greater the forgetting. In surveillance tests, the most common factor to determine the amount of forgetting is the length of STI, where the longer the STI, the greater the amount of forgetting. The amount of forgetting can be evaluated by the time required to test safety system equipment. In order to calculate the testing time varied according to the length of STI, we construct the forgetting model based on the LFCM model.

The forgetting rate in the proposed forgetting model is expressed as follows[3]:

$$f_i = \frac{l(1-l)\log q_i}{\log(C_i + 1)} \quad \text{where } i = 1,2,3,... \tag{3}$$

where f_i, which varies in every test, is the forgetting slope after the i th testing and $C_i = t_B / t(q_i)$ is the ratio of t_B, the minimum time for total forgetting, to $t(q_i)$, the amount of time required to test equipment q_i times. $t(q_i)$ is determined by integrating equation (1) over the proper limits as follows:

$$t(q_i) = \int_0^{q_i} T_1 j^{-l} dj = \frac{T_1 q_i^{1-l}}{(1-l)}$$

Therefore C_i is represented as follows:

$$C_i = t_B \left[\frac{T_1}{1-l} q_i^{1-l} \right]^{-1} \tag{4}$$

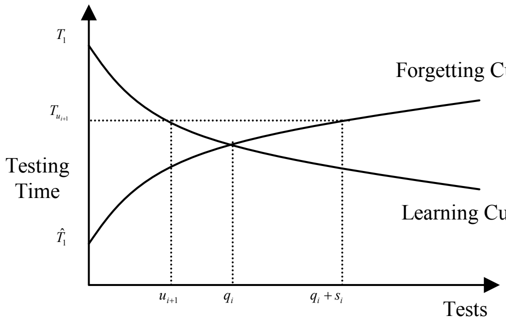

Figure 1. The forgetting curve relation

At the completion of the i th testing in Figure 1, equation (1) is set equal to equation (2); i.e., $T_{q_i} = \hat{T}_{q_i}$. Then the intercept of the forget curve is determined from equation (5) in order to adopt the changing value of the forgetting slope.

$$\hat{T}_i = T_1 q_i^{-(l+f_i)} \qquad (5)$$

The coordinates $(q_i + s_i, \hat{T}_{q_i+s_i})$ on the forgetting curve have equivalent coordinates on the learning curve $(u_{i+1}, T_{u_{i+1}})$, where u_{i+1} is equivalent testing times remembered at the beginning of the $i+1$ th testing and $T_{u_i+1} = \hat{T}_{q_i+s_i}$. Equating (1) to (2) after substituting $u_{i+1} = j$ in equation (1) and $q_i + s_i = x$ in equation (2) and then solving for u_{i+1} gives:

$$u_{i+1} = q_i^{(l+f_i)/l} (q_i + s_i)^{-f_i/l} \qquad (6)$$

Therefore, the time required to test equipment next time is

$$\tilde{T}_{i+1} = T_1 \left[q_i^{(l+f_i)/l} (q_i + s_i)^{-f_i/l} + 1 \right]^{-l} \qquad (7)$$

2.3 Numerical Example

In order to investigate the effects of forgetting phenomenon on STI, the amount of time spent on tests is calculated.

Assume that the time required for testing with no previous experience is 0.2 days, and if STI extend to 2 years, then total forgetting occurs. Also assume that the testing process has a 70% learning curve.

Table 1 shows the results obtained from repeating the same procedure for the proposed model. It illustrates the variation of testing time for STI= 3months.

Table 1. Results for the proposed model.

i	u_i	$\tilde{T}_i$	$\hat{T}_i$	f_i	q_i	C_i
0	0.0000	0.2000	0.2000	0.0000	1.0000	1770.2500
1	1.0000	0.2000	0.1376	0.0242	2.0000	1264.8384
2	1.2245	0.1802	0.1295	0.0282	2.2245	1201.2209
3	1.2653	0.1772	0.1282	0.0290	2.2653	1190.6835
4	1.2725	0.1767	0.1280	0.0290	2.2725	1188.8634
5	1.2737	0.1766	0.1279	0.0290	2.2737	1188.5467
6	1.2739	0.1766	0.1279	0.0290	2.2739	1188.4916
7	1.2740	0.1766	0.1279	0.0290	2.2740	1188.4820
8	1.2740	0.1766	0.1279	0.0290	2.2740	1188.4803
9	1.2740	0.1766	0.1279	0.0290	2.2740	1188.4800

Figure 2 shows the amount of time spent on tests as for different values of STI. The time required for testing converges to a value of 0.1614 days for STI=1month. Similarly, when STI is 3 months and 6 months, the time required for testing converges to a value of 0.1766 and 0.1850, respectively. If STI equals the minimum time for total forgetting, the time required for testing is 0.2 days constantly.

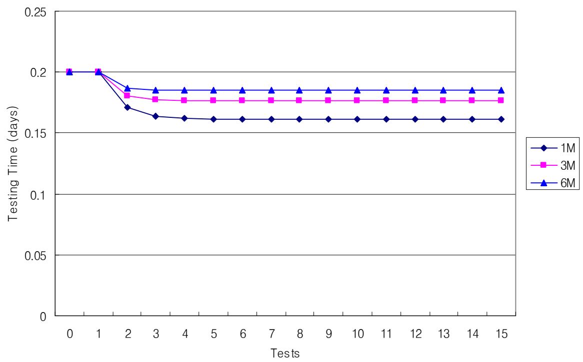

Figure 2. The behavior of the learn forget curve for different values of STI.

3. Conclusion

In this article, the effects of forgetting phenomenon on STI were investigated by the proposed model. Illustrative examples show that the longer the STI is, the greater the amount of forgetting is. The previously accumulated experience is lost due to the deterioration of human memory over STI. This deterioration in memory, known as the forgetting phenomenon, has an adverse effect on the availability of system. Therefore the forgetting phenomenon also can be considered together when STI is optimized.

A limitation to the work is that no field data was available to aid the authors in justifying the assumptions made to develop the proposed model. This model should be tested with field data. If this model proves to be unsatisfactory to represent reality, a new modified model should be developed to represent reality more faithfully.

REFERENCES

[1] P. K. Samanta, W. E. Vesely, Handbook of Methods for Risk-Based Analyses of Technical Specification, NUREG/CR-6141, USNRC, 1994.
[2] T. Wright, Factors Affecting the Cost of Airplanes, Journal of Aeronautical Science, Vol.3, p.122, 1936.
[3] M. Jaber, M. C. Bonney, Production Breaks and the Learning Curve: The Forgetting Phenomenon, Applied Mathematical Modelling, Vol.20, p.162, 1996.
[4] J. G. Carlson, R. G. Rowe, How Much Does Forgetting Cost?, Industrial Engineering, Vol.8, p.40, 1976.