Learning and Forgetting Curves: A Practical Study

Andrew Thomassen

Department of Management Systems

University of Waikato

New Zealand

agt@mngt.waikato.ac.nz

Abstract

There exists a substantial body of literature on learning curves; however considerable less work has been done on the impact of forgetting. This paper, after surveying the literature on learning and forgetting, describes an experiment involving the processing of circulars (or "junk mail”) designed to satisfy three objectives. These are to compare learning curves between the production line assembly and the single person assembly, to evaluate the impact of forgetting on the length of break, and to develop an equation which measures the time lost due to forgetting. In reference to these three objectives, the study first shows that the learning ability of an individual appears greater than that of a production line, but slower. The production line assembly is therefore more efficient than the individual. In terms of the impact of the break length on forgetting, it was found that the same power model equation used to model forgetting in earlier studies best measured the forgetting phenomenon. The time lost equation parameters showed that the greatest amount of forgetting occurs only after a short break, which is consistent with other studies.

Introduction

For more than sixty years, the effect of task repetition on task performance has been studied. Wright [21] developed an analytical model in which task performance was represented as a power function of the cumulative number of repetitions, with the following form:

$$Y_x = Ax^{m} \qquad (1)$$

where:

- x = the cumulative number of repetitions
- Y_x = the performance time of the xth repetition
- A = the performance time of the first repetition
- m = log p/ log 2 where p = learning percentage

Hirschmann [8], Fusfeld [5], Preston and Keachie [15] all reveal how learning curves are exhibited in the production of goods in many industries. Stobaugh and Townsend

[19], and Lieberman [14] also reveal how learning curves occur in the cost of goods produced. This is attributed to the gaining of experience and is explained below.

Sources of Experience

Given that there is evidence to support the existence of learning curves as good descriptors of how learning occurs, the question arises as to why this effect appears. The answer appears to be that it has three major sources: learning, technological advances, and scale effects.

Learning

The efficiency of all aspects of labour input (production, maintenance, supervision etc.) increases as the people involved learn or gain experience in the activity in question. Learning also involves the discovery of better ways to organise work through improved methods and work specialisation or getting better performance from production equipment as personnel become better acquainted with it. Abell and Hammond [1], Joskow and Rozanski [12] and Rosenburg [16] all present how learning from the labour sector is a great factor.

Technological improvements

New production processes, especially in capital-intensive industries, often contribute substantial economies to the learning effect. Beevan [3] noted as an example, Golden Wonder's introduction of continuous-flow potato chip manufacture, compared with the traditional batch-frying mode. Changes in the resource mix, such as the replacement of labour by automation, also provide a technology-driven basis for the learning effect. Process and product changes that improve yield are yet another source. Product standardisation and redesign has contributed to changes in learning rates also.

Scale effects

Scale economies at the plant level result from savings on capital costs, an increased potential for division of labour, and better utilisation of resources.

Hollander [9], in a study of the sources of efficiency increases at DuPont rayon plants, concluded that only 10 to 15 percent of the efficiency gains were attributable to scale effects.

Forgetting

Just as learning increases with experience, forgetting appears to increase as a function of a break from task performance.

Steedman [18] suggested that the residual memory of the participants after a break, is a function of the length of the break and performance time immediately before the break took place. Carlson and Rowe [4] developed a learning-forgetting-learning model in which forgetting is modelled by a curve similar to the learning curve. According to their model, forgetting is a function of the break length and the performance time prior to the break. Their forgetting curve is also assumed to be of an exponential form. Sule [20] proposed a similar approach, assuming that the same learning curve may be used to model both learning and forgetting. However Bailey [2] articulates that a measure of the forgetting rate is uncorrelated to that of the learning rate. He challenges that forgetting is a “retrogression” along the original learning curve. Globerson and Levin [7] present a conceptual model hypothesising that the forgetting process is a function of several factors, including turnover, communication and documentation. Unlike learning models that are based on real data collected in industry, all relevant forgetting models are based either on conceptual theory or experimental data. This is because it is difficult to monitor and anal yse the impact of interruptions.

The issue of forgetting has attracted the attention of psychologists for sometime. Researchers in the area of memory decay for example Hulse et al., [10] Starbuck [17], differentiated between short-term and long-term memory decay. Short-term memory has a limited capacity. If the information stored is not retrieved within 30 seconds or so, it will be totally forgotten. Studies concerning forgetting and short-term memory involved experiments in which subjects were asked to memorise a list of nonsense syllables and to repeat them after a specified time intervals of no more than a few moments.

Long-term memory research is more applicable to forgetting in an organisational environment. Experiments in this area involve repetitions of a memorised list of words after a pre-specified break length, typically up to few days. Klatzky [13] reports the results of such a study showing that memory decay is a power function of the break length. For example, subjects forget 55 percent of the words within a six-hour break time and 80 percent within 72 hours. While such break lengths between consecutive sessions may be relevant to organisational environments, the nature of the task is not.

Although the results of the psychological studies are not relevant to most practical situations, the research methodology associated with these types of controlled experiments are advantageous for model development. Taking this approach, an experiment was designed to satisfy the following objectives.

1) Compare learning curves between the production line assembly and the single person assembly initially,
2) Evaluate the impact of forgetting on the length of break by using measures taken from Globberson and Levin [7].
3) To develop a lost time equation to be used in one of the measures

The following section describes the experiment. It is followed by an analysis and a discussion of the results.

Methodology

The process concerned was the putting together a number of circulars (otherwise known as junk mail) and packaging them into one parcel. Each time the experiment took place there were 10 circulars to package together. The time taken to process 50 packages was used as a repetition. Four subjects involved in the assembly line were between 10 and 14 years old.

In the forgetting experiment the time breaks between repetitions were 2,4, and 8 days. Single person assembly was used, as this would be easier to control.

Results and Analysis

The analysis is divided into two major parts. The first deals with the assembly line learning process versus the single person process. The second part analyses how forgetting is a function of break length. The power model described by equation (1) was used as the basic learning model. Its validation was checked against the chart that can be seen in Figure 1.

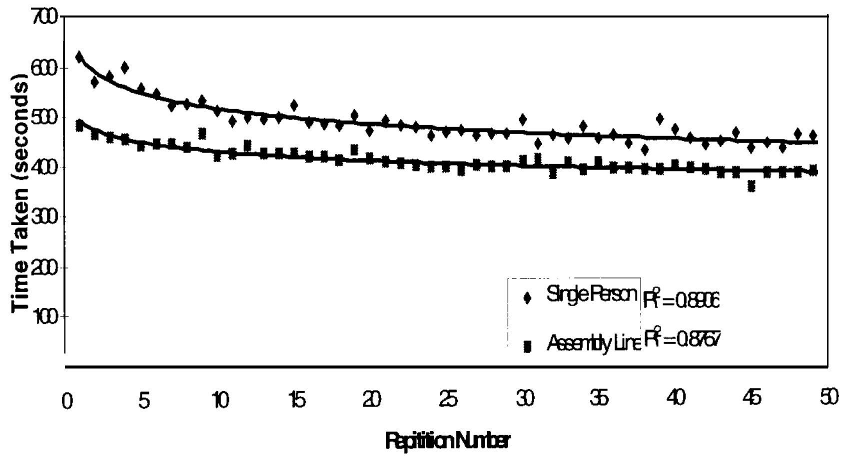

Figure 1. Learning Curves for Production Line and Single Person Assembly

The power model gives the two respective learning rates;

Single Person = 94%,

Assembly Line= 96%

These numbers were rounded to the nearest percentage. The percentage figures show that the single person assembly learns a little faster than the respective assembly line process. This would be expected as the single person has a larger ability to learn new techniques and change his or her process design. In this experiment the production line was in cramped conditions and therefore the ability to learn as a group was lowered, because not much experimentation occurred.

What must be noted, though, is that there seems to be a cyclic trend. This can be explained by the fact that the participants easily get bored. A quick encouragement seemed to get the participants motivated again. Looking at Figure 1 it can be seen that the power model closely relates to the actual data. This signifies that the power model is correct and can be used for the main part of the experiment. To try to forecast the time it will take to do the task after a break period of D.

The impact of forgetting may be evaluated on two levels: the initial level and the cumulative one. Evaluating forgetting on the initial level is an estimate of performance decline immediately after the break, while the cumulative level deals with a performance decline in a batch production environment.

The initial level may be measured by the ratio;

$$FI = \frac{B - Ab^{m}}{Ab^{m}} \qquad (2)$$

where:

A	=	The initial time taken for the predecessor period,
B	=	The initial time taken after the break
b	=	The upper boundary limit for the predecessor period

FI is defined as the proportion of additional time required to complete the first repetition after the break, as compared to the time that would have been taken without the break. The initial forgetting was found to be function of the break length as is shown in Figure 2.

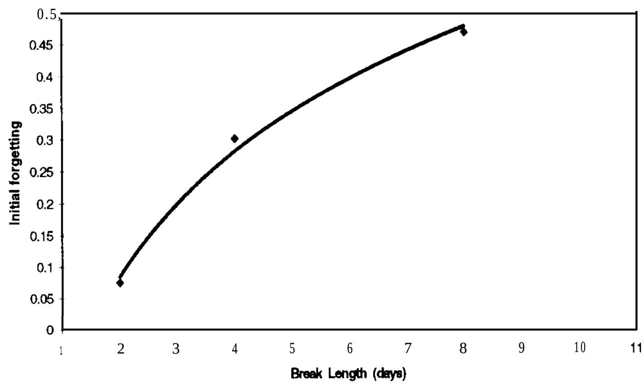

Figure 2. Initial Forgetting as a Function of Break Length

This shows that after eight days there is still a significant potential for forgetting. Recovery from forgetting is also important. The slower it is to recover, the more important it is to reduce the break length. Therefore, it is not sufficient just to identify the forgetting intensity; one should also relate to the cumulative time lost due to the break. This can be calculated by the following equation:

$$\text{The time lost} = \sum_{i=1}^{n} A x_i^{m} (a - b) + B x_i^{n} (b - a) \qquad (3)$$

Where a = The lower boundary limit, for the second process

m = log p_1/ log 2 for the initial learning curve,

n = log p_2/ log 2 for the learning curve after the break,

p_i = The learning percentage for the respective curve.

This equation is determined by the following;

The total time lost is the area between the new learning curve and the path that the original learning curve would have taken. This can be shown diagrammatically by the following graph

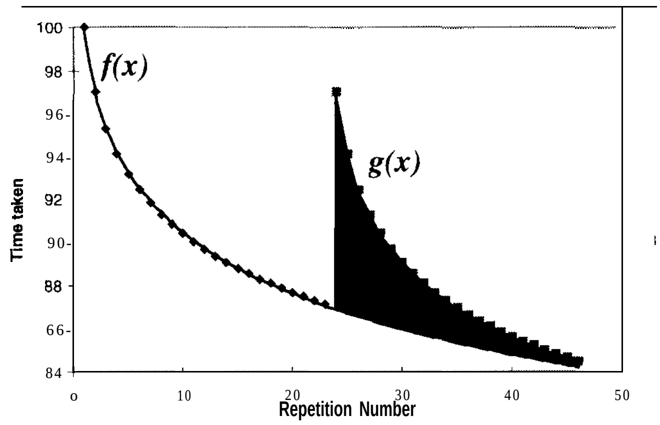

Figure 3: Hypothetical graph showing the shaded area equal to the time lost due to forgetting.

The shaded area in the graph can be calculated by the following integral.

$$\text{Shaded area} = \int_a^b g(x)dx - \int_c^d f(x)dx \qquad (4)$$

where *f(x)* = the original power model,

g(x) = the power model after the break.

d = the upper boundary limit of *g(x)*

c = the lower boundary limit of *g(x)*

What must be noted here, is that it is assumed that the original power model if there were no break, would continue along its initial learning curve. Also the boundary condition values for the respective graphs are different. What must be considered now is the transformation of g(x) to reference it with *f(x)*. This is shown to be what we shall term as the transformation factor of $-a+1$. So therefore d is equivalent to $b-a+1$, and $c = 1$ since it is the first repetition of g(x).

$$\text{Time Lost} = \int_1^{b-a+1} Bx^n - \int_a^b Ax^m \qquad (5)$$

Integrating the preceding equation we get can get the relative time lost for each respective repetition unit

$$\text{Time Lost for repetition } i \quad = Ax_i^{\,m}(a-b) + Bx_i^{\,n}(b\ b\text{-}a) \qquad (6)$$

Time lost can be used in another parameter. This parameter is defined by Globberson and Levin as follows;

$$\text{FP} = \frac{\text{Time Lost}}{\text{Time of the last repetition in the first set}}$$

FP is the forgetting parameter. This parameter denotes the time lost expressed by equivalent number of times of the last repetition performed. Since expressing the time lost by using the forgetting parameter is a relative rather than absolute measure, it may be used for evaluation purposes. The relationship between FP and the break length is shown below.

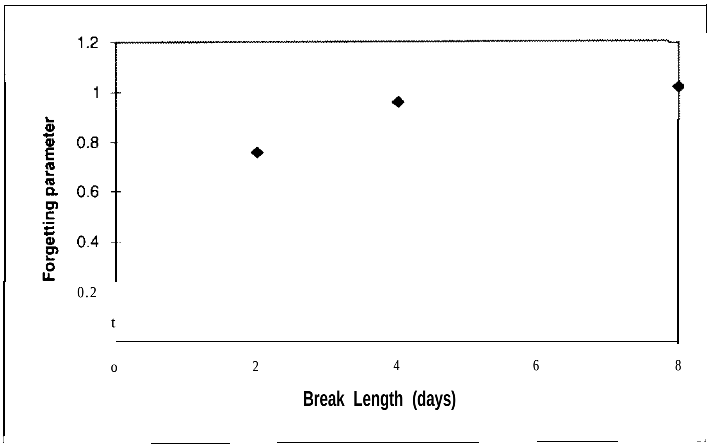

Figure 4: Forgetting Parameter measured against Break length

The nature of the relationship demonstrates the decreasing impact of the break length on the forgetting parameter. So the majority of the forgetting that occurs is performed after a short break length. What the consequence of this is, that for all processes to avoid delays then it is vital to avoid all unnecessary breaks.

Conclusion

This report has sought to compare production line and single person learning. Based on experimental, evidence the learning ability of an individual appears greater than of a production line but slower. Although this is the case, the production line assembly is more efficient in processing the circulars. Both learning curves fitted a power model.

Secondly, we asserted the impact of the break length on forgetting. The same power model was found to be the best one to depict the forgetting phenomenon. A time lost equation was also produced and used to produce another parameter, the forgetting parameter. This is a relative measure and shows that the greatest amount of forgetting occurs only after a short break, which confirms the study done by Globberson and Levin.

Further studies could be undertaken on the forgetting phenomenon, as this experiment only contains a small amount of data. Studies should concentrate on longer break periods as well as tasks of a different nature to find out whether forgetting is task dependent. Further studies undertaken (Hurley 1996), postulate that the model used in this paper is irrelevant to normal day practice. Subsequent investigation may wish to use more relevant models for their research.

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