Available online at www.sciencedirect.com
ScienceDirect
IFAC-PapersOnLine 49-12 (2016) 197–202

# Integration of learning and forgetting processes with the SHERPA model.

**Valentina Di Pasquale*. Salvatore Miranda.* Raffaele Iannone.* Stefano Riemma.***

** Dept. of Industrial Engineering – University of Salerno,*
*Via Giovanni Paolo II, 132 - 84084 - Fisciano (SA), Italy*
*(Tel: +39 089 964106 e-mail: vdipasquale@unisa.it).*

**Abstract:** The present paper is targeted to address the impact of the learning and forgetting processes on the system performance during the working activities in combination with the human error quantification. The Learning and Forgetting Curves Model (LFCM) has been implemented as a new module in the SHERPA simulator, developed for the human error assessment. The LFCM module assumes, according to the literature, that human performance improves with the increase in cumulative production, leading to a progressive reduction of the processing times. On the contrary, the performance deteriorates when learning sessions are separated by rest breaks that cause knowledge depreciation or forgetting. The paper provides a different model to measure the system performance when the learning and forgetting processes are present, considering at the same time the productivity and the error probability. The model has been applied to a case study showing interesting results in terms of learning and forgetting processes effects on the system performance.



*Keywords:* Learning curves, Forgetting, Human Reliability, Human Error Probability, Simulation, Human behavior modeling.

## 1. INTRODUCTION

Many researchers have been tried to understand the learning and forgetting processes since the beginning of the twentieth century and several studies are still ongoing. The learning curves are based on the clear improvements that occur when the workers learn how to do a job through the production of more and more units, decreasing the production time per unit (Azizi, et al., 2010). This phenomenon is observed by the decrease in production time per unit as operators gain experience by producing additional units (Nembhard & Napassavong, 2001). The learning impact on the system performance changes when the operator does a break of sufficient length and the forgetting process starts to take place. In this case the production time of the first unit after the break tends to be longer than the production time of the last unit before the break (Nembhard & Napassavong, 2001).

The impact of these processes on the performance of repetitive tasks has been widely studied and applied in various sectors, like manufacturing, healthcare, energy, information technologies, education, design and banking (Jaber & Glock, 2013; Anzanello & Fogliatto, 2011; Grosse, et al., 2015). Knowing how humans learn in production systems and how learning and forgetting affect the performance of the production processes is important for several reasons (Anzanello & Fogliatto, 2011). Considering learning in production planning may contribute to a significant reduction in total costs or to an improvement in the productivity (Jaber & Glock, 2013). Furthermore it could have a positive effect on the human error rate. The experience gained in performing a repetitive task involves, in fact, a decrease in the production time which could improve the human reliability, considering for example the higher available time for the execution of the task.

Recently these processes have been used to develop models that estimate the human error probability during the working activity (Givi & Jaber, 2014; Givi, et al., 2015a). Givi et al. (2015a) have developed a mathematical model that estimates the human error rate while performing an assembly job under the influence of learning-forgetting and fatigue-recovery. These studies highlight the growing effort to combine the learning and forgetting theory with the Human Reliability Analysis (HRA), which examines the human factor through the prediction of when an operator is more likely to fail (Di Pasquale, et al., 2015a, b).

This paper investigates how the learning and forgetting processes and the human reliability affect the system performance thanks to a new version of the Simulator for Human Error Probability Analysis (SHERPA). This simulator is able to estimate the human reliability for different workplaces, to assess the impact of context via performance shaping factors (PSFs) and to simulate a large numbers of work-rest policies (Di Pasquale, et al., 2015a, b).

In this paper SHERPA has been enhanced thanks to the implementation of the Learning and Forgetting Curves Model (LFCM), according to what proposed by Jaber and Bonney in 1996. The LFCM module in SHERPA allows to evaluate how the human reliability and the learning and forgetting processes impact on the system performance. The human reliability assessment identifies the human error probability (HEP) and the rate of non-compliant performed task, while the LFCM algorithm allows the quantification of the decrease in the processing times, taking into account both the single


10.1016/j.ifacol.2016.07.595

shift and more consecutive working days. During a single shift the forgetting effect is caused by the rest breaks and it is less evident due to their short time, while between two consecutive working days the interruption is longer and it has a greater impact. The new SHERPA outcomes make the model closer to the reality.

This paper is organized as follows: section 3 presents the literature review of learning and forgetting curves with particular attention to the LFCM model. In Section 4 the LFCM is expressed in algorithmic form, while Section 5 presents the SHERPA model and the LFCM implementation in the simulator. Section 6 shows the performed case study and finally the last section summarises the main findings and the conclusions.

## 2. NOTATION

The following notations will be used in this paper:

*i*= working cycle index;

*q*= number of units worked in every cycle;

$T_1$= theoretical time to produce the first unit;

$\hat{T}_1$= the equivalent time for the first unit of the forgetting curve;

*LR*= learning rate;

*b*= learning slope;

*f*= forgetting slope;

*x*= the amount of output that would have been accumulated if interruption did not occur;

*B*= the minimum time for total forgetting;

$t_b$= break time.

## 3. LEARNING AND FORGETTING CURVES

Learning and forgetting curves received increasing attention by many researchers in the past several decades. A learning curve is a mathematical description of workers' performance in repetitive tasks; in fact in every repetition the workers tend to demand less time to perform tasks due to familiarity with the operation and tools (Anzanello & Folgiatto, 2011).

The Wright's learning curve (1936) is the earliest and the most popular model observed in an industrial setting that expresses an exponential relationship between direct man hour input and cumulative production in the form of:

$$T_q = T_1 \cdot q^{-b} \tag{1}$$

where $T_q$ is the time to produce the $q$th unit, $q$ is the production count, $T_1$ is the theoretical time required to produce the first unit, and $b$= -ln(*LR*)/ln(2) is the learning slope, where *LR* is the learning rate (Jaber & Bonney, 1996). Typical *LRs* according to Givi (2015, b) are shown in Table 1. Equation (1) shows that with growing production the unit time decreases by a constant percentage each time the quantity doubles.

Due to its flexibility, its simple mathematics and to its ability to fit a wide range of data fairly well the Wright's curve has been applied to estimate the time to task completion; to estimate a product's life cycle; to evaluate the effect of interruptions in the production rate and to study the prevalence of human learning in the order picking process (Anzanello & Fogliatto, 2011; Jaber & Bonney, 1996; Grosse & Glock, 2013). Alternative models were developed following the Wright model's principles, although relying on more elaborate mathematical structures to describe complex production scenarios (Anzanello & Fogliatto, 2011; Grosse, et al., 2015).

**Table 1: Learning rates for different tasks (Givi, et al., 2015b).**

| TYPE OF WORK | LR% | INDUSTRY | LR% |
|---|---|---|---|
| Assembly | 84-85 | Aerospace | 85 |
| Prototype assembly | 65 | Complex machines | 75-85 |
| Clerical ops | 75-85 | Construction | 70-90 |
| Inspection | 86 | Electonix mfg | 90-95 |
| Machining | 90 | Machine shop | 90-95 |
| Welding | 85-90 | Shipbuilding | 80-85 |

* Table 1 was adopted from Crawford (1944).

At first this phenomenon has been studied individually but it is strongly correlated with the forgetting process. In intermittent production runs, there is a break of sufficient length that some of the learning accumulated in producing $q$ units in the previous lots is not retained when a new run starts up (Jaber & Bonney, 1996). Hence the production rate at the recommencement would not be as high as when the production ceased. The increase in time to produce the first unit in the next production run depends on the length of the interruption and the time to produce the $q$th unit which is when the interruption occurred.

To take forgetting effects into consideration, a handful of theoretical, experimental and empirical mathematical forgetting models have been developed, with no unanimous agreement among researchers and practitioners on the form of the forgetting curve (Jaber & Sikstrom, 2004). Carlson and Rowel describe the forgetting by a negative decay function comparable to the decay observed in electrical losses in condensers. Their curve is one of the most widespread models and it is expressed in the form of (Jaber & Bonney, 1996):

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

where $\hat{T}_x$ is the time for the *x*th unit of lost experience of the forgetting curve, $x$ is the amount of output that would have been accumulated if interruption did not occur, $\hat{T}_1$ is the equivalent time for the first unit of the forgetting curve, and *f* is the forgetting slope (Jaber & Bonney, 1996).

### *3.1 The learn–forget curve model (LFCM)*

Starting from equations (1) and (2), Jaber and Bonney (1996) developed the learning and forgetting curves model (LFCM). The LFCM assumes that there is one learning curve and one forgetting curve, with the forgetting curve having its slope and intercept adjusted after each production break. The exponent of the power forgetting function depends on the total forgetting time, the learning slope and the amount of