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# TREBALL DE FI DE CARRERA

**TÍTOL DEL TFC: An experiment of planning manual work taking into account learning and forgetting**

**TITULACIÓ: Enginyeria Tècnica de Telecomunicació, especialitat Sistemes de Telecomunicació i Telemàtica**

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**DATA: 29 de juny de 2007**

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**Resum**

Avui en dia, les indústries es troben exposades freqüentment a canvis en el volum de producció, en els productes que es fabriquen i a canvis de tecnologies als processos que desenvolupen, per tal de millorar la productivitat. Aquest factor provoca que els treballadors hagin d'estar constantment en un procés d'aprenentatge de tasques, fent oscil·lar el seu rendiment. Per aquest motiu, en els últims anys, la planificació de tasques està adquirint cada vegada més importància dins l'àmbit industrial.

El rendiment en una tasca de tipus manual no només es veu afectat per l'experiència en ella, sinó també per quant recent es aquesta i la quantitat d'experiència prèvia que es té en tasques similars.

En aquest projecte, dotze voluntaris muntaran repetidament tres tipus de circuits electrònics amb l'objectiu d'obtenir les corbes d'aprenentatge i els paràmetres generals que caracteritzin els diferents muntatges. Per portar-ho a terme, es farà servir el model matemàtic d'aprenentatge i oblit de Nembhard i Uzumeri, així com una modificació d'aquest per tal de que el model s'ajusti millor al nostre estudi.

A continuació, i per primera vegada, es definirà un nou model de planificació de tasques proposat per Albert Coromines i es provarà d'aplicar per a casos reals. Seguint en aquesta línia es crearà un programa per tal de poder plantejar ràpidament les equacions d'aquest model.

Els resultats finals mostraran com el voluntaris han estat afectats per el fet de tenir experiència en muntatges previs i en quin grau. A més, s'implementarà i s'analitzarà el funcionament del nou model de planificació de tasques.

Finalment, cal mencionar que aquest projecte no ha finalitzat encara. Es el punt de partida cap a futures investigacions sobre planificació de tasques més complexes.

**Title:** An experiment of planning manual work taking into account learning and forgetting

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**Date:** June, 18th 2006

**Overview**

Nowadays, industries are frequently exposed to changes in the quantity of production, the produced items or even in technology. These changes improve the productivity but on the other hand, it promotes learning processes in workers. This situation decreases the output. For this reason and other ones, planning is becoming essential in the industrial world.

Performance in a task is influenced not only by the experience in it, but by how recent this is and the amount of previous experience acquired in similar tasks. Competence-performance-Approach is used as theoretical framework.

In this project, 12 volunteers are going to carry on experiments about assembling electronic circuits. The goal of them is to obtain general learning and forgetting curves and parameters using mathematical models. We are going to apply Nemhard and Uzumeri's model and a variation of it that we have designed to fit it better with our experience.

Afterwards, a new planning model suggested by Albert Coromines is going to be applied in unreal cases. This model has never been applied before. Consequently, we are going to create a program in C language in order to set out quickly the problem of planning.

Final results will show how the volunteers have been affected by the experience in previous assemblies. Moreover, we are going to implement and analyse the work of the new planning model.

Finally, we want to mention that this project is not still finished because there is further work to do in order to apply all the data obtained from the experiments in planning.

# ÍNDEX

# INTRODUCTION

In production processes of today the use of knowledge is increasingly present in all positions. The concept of knowledge worker [1] can be extended to almost all jobs. Learning, and particularly learning at work, becomes essential. Needs for current work and needs for learning can be contradictory. Performance will be higher when a worker is assigned to a task in which he has experience, while learning procedures need that he assumes new tasks. To manage this problem we have to be able to forecast performance for each level of experience.

This project deals with two topics: one is related to learning and forgetting in manual work and the other is focused on the planning task taking into account the learning and forgetting factors.

The first goal of the project is going to be to define a series of tasks' standards. After that, a group of twelve volunteers are going to assembly a sequence of tasks following the defined steps. With this information we are going to evaluate the relation between tasks.

Second goal is to analyse Nembhard's model [2] in order to evaluate if it fits with our data. For adapting the model to take into account the relation between tasks we are going to modify the original formula of Nembhard.

Concerning the planning task, the first goal is to define a new model proposed by Albert Coromines and corroborate its good working. The second one is to create the software for writing the equations of the model considering the data, which is introduced by the user. Finally, and due to the limited time available to do the project, we can not include the planning task using our data of learning and forgetting. Nevertheless, nowadays there are studies that apply learning and forgetting models to solve work organisation problems [3] as well as planning [4]. This goal will be developed in the future.

This project is organised as follows. First's chapters correspond to theoretical concepts whereas last ones show the experiment and it results.

Chapter 1 introduces the basic knowledge of learning and forgetting curves and its parameters, defining them. It is done in order to enumerate the most common calculation's models and become introduced into the world of tasks for understanding the next contents

Chapter 2 enumerates the existing models of learning and forgetting and it defines the most famous: Nembhard [5] and Wright [6]. It also adds an illustrated example of each one, pointing out its characteristics.

Chapter 3 shows a summary of planning models' history and some of the different objectives of them. But mainly, it defines the new planning model of tasks for the first time.

Chapter 4 describes an example of planning's resolution using the new model and the software designed in order to set out its equations for any planning problem with fixed performance.

Chapter 5 starts with the general bases of the experiment. It describes the skills of volunteers that are going to do the assemblies. Also it describes the assemblies and the sequences that are going to be used.

Chapter 6 applies the models of learning and forgetting explained in theory. In other words, it contains the models followed and the results of the regressions done of Nembhard model, and its analysis.

Chapter 7 is about the future of this project. It shows all the information that authors have consider important in order to continue developing the planning tasks and improving the project.

# CHAPTER 1. LEARNING AND FORGETTING

Learning is defined as the process of acquiring knowledge, abilities or values through the study or experience. On the other hand, forgetting represents the intensity of the memory.

Daily, people are exposed to learning and forgetting procedures. There are tasks, such as play video games or program a video, which become easier when you repeat it. After a period of time without doing the activity, the difficulty increases again. This is due to the fact that, if an activity is performed repeatedly the personal ability increases. On the other hand, if the person spends too long not performing it, his/her level of skill dismisses.

This chapter defines two kinds of learning curves, its calculation's model, the forgetting curve and the theory of continuous improvement.

## 1.1. Definition of learning curves

A learning curve shows the relation between the elapsed time doing the task and the number of repetitions of it. In short, as the company becomes more experienced, it is able to develop products more efficiently at reduced cost. The premise is: "Organisations, as persons, do better their work as they do it again and again."

The theory of learning's curve is based on three suppositions. The first one is that the necessary time to complete a task decreases every time the action is repeated. The second says that the reduction of time follows a foreseeable standard. The last one lists that the rate of decreased time per unit is smaller every time. To sum up, according to learning curve theory, increases in cumulative output are accompanied by reducing the elapsed time per unit [7].

The most important form of learning curves is S. The first organisation who uses this curve was Wright Corporation in 1939. Nowadays, since 1970, the application of this concept is used as part of Boston Consulting Group. It represents the fact that, the majority of times, learning is slow during the initial phase as long as you are not used to do the task. On the other hand, it is faster when people know the conditions of the work. Finally, there is a period of stabilisation in the productivity when workers are used to the task. In this moment they are able to minimise their number of mistakes. Thanks to this curve it may be possible to expect the internal labour, schedule the production, evaluate the efficiency of the company, etcetera.

## 1.2. Learning models of calculation

The aim of these models is to establish a mathematical relation in order to match the elapsed time doing an specific task against the number of tasks done before and the time used doing it.

### 1.2.1. Arithmetic Model

This model is based on the fact that each time that the production is duplicated, the labour per unit decreases in a constant factor. This factor is known as learning rate. This model shows the value of some points of the curve but it doesn't establish the middles values that are undefined. These points are only available by extrapolation. For this reason, it is imprecise. Furthermore, the level of indeterminacy in the values increases as the number of repetitions rises.

The model is represented by this formula:

$$T_{2^n} = T_1 \cdot L^n \qquad \textbf{(1.1)}$$

Where n is the number of times that the task is done, L represents the learning rate (curve's gradient), $T_{2^n}$ is the time to process the $2^N$th unit while $T_1$ is the time to process the first one.

An example of it is detailed below:

A worker takes an hour to do the task the first time ($T_1$). Her/his learning rate is about 0.8. If the number of units done is duplicated, the results will be the ones shown in Table 1.1. Representation of values appears in Fig. 1.1.

**Table 1.1** Results of applying arithmetic model

| Unit N | Hours per unit N |
|---|---|
| 1 | 1,00 |
| 2 | 0.80=0,8 $^1$ x 1,00 |
| 4 | 0,64=0,80 $^2$ x 1,00 |
| 8 | 0,512=0,80 $^3$ x 1,00 |
| 16 | 0,41=0,80 $^4$ x 1,00 |

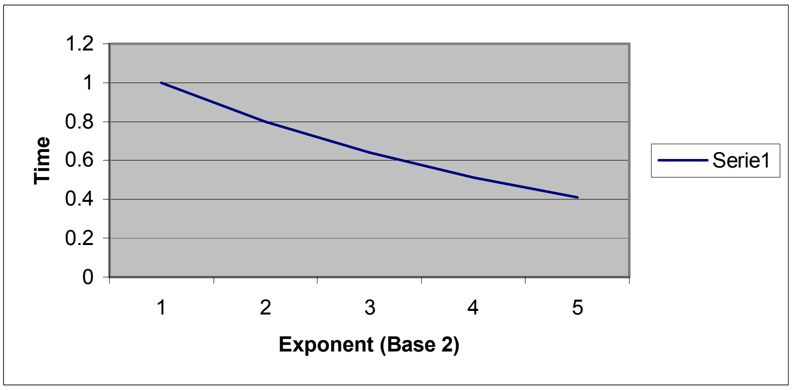



**Fig. 1.1** Representation of the example

### 1.2.2. Logarithmic Model

Logarithmic model [6] is another option to represent the curve of learning. It allows to determinate the work unit by unit, therefore it gives more precision than arithmetic model. For this reason it is the most useful.

Its formula (1.2) has different parameters. *N* represents the number of unit, $T_n$ is the time to process the nth unit, *b* is the logarithm of learning rate (*r*) in base two and finally $T_1$ is the elapsed time making the first unit.

$$\begin{aligned} T_n &= T_1 \cdot N^b \\ b &= \log_2 r \end{aligned} \tag{1.2}$$

An example of it is shown below:

Remaining the values of the arithmetic models, the learning rate (*r*) is 0.8, the elapsed time of the first unit is one hour. The times for each unit are the ones which appear in Table 1.2.

**Table 1.2** Estimated time of logarithmic example

| Unit | Temps |
|---|---|
| 1 | $1$ |
| 2 | $1 \cdot 2^{\log_2 0.8}$ = 0.8 |
| 3 | $1 \cdot 3^{\log_2 0.8}$ = 0.7021 |
| 4 | $1 \cdot 4^{\log_2 0.8}$ = 0.64 |
| 5 | $1 \cdot 5^{\log_2 0.8}$ = 0.5956 |

| | |
|---|---|
| 6 | $1 \cdot 6^{\log_2 0.8}$ = 0.5617 |
| 7 | $1 \cdot 7^{\log_2 0.8}$ = 0.5345 |
| 8 | $1 \cdot 8^{\log_2 0.8}$ = 0.512 |
| 9 | $1 \cdot 9^{\log_2 0.8}$ = 0.492 |
| 10 | $1 \cdot 10^{\log_2 0.8}$ = 0.476 |

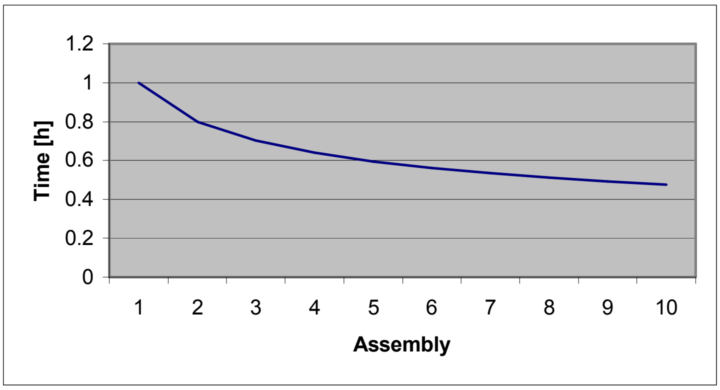



**Fig. 1.2** Representation of logarithmic example

## 1.3. Definition of forgetting curves

In general, forgetting curve illustrates the loss of memory with the passing. Intensity of record indicates how much time is kept content in mind. The more intensive the record is, the more time it reminds inside the brain. The curve of forgetting also depends on the quantity of things learned and the interruptions between them. Regardless of the shape of the curve, there is a proportion of forgetting which starts when workers stop doing the task learned before. Furthermore, the speed with which something is forgotten depends on different factors like the difficulty of the subject, its representation or physiological factors.

Carlson and Rowe [8] think that a S learning's curve is affected in the following two ways. Firstly, the output is quickly reduced, but it is gradually stabilised. Lastly, the speed and proportion of forgetting decreases if the task finishes before an interruption.

### 1.3.1. Interruptions

Interruptions are the period of time when the worker doesn't do the task because of the change of job, holidays or another situation.

There are two kinds of interruptions, the short period and long period ones. Short-period interruptions happen in different situations. For instance, when tasks are divided between the components of the team or when an urgent activity interrupts the one which is being done. Long term type involves that the knowledge has to be learned again just like the skills, rhythm... This situation happens when the worker suffers a change of job.

## 1.4. Forgetting model of calculation

A typical graphic of forgetting curve (Fig. 1.3) shows that normally, in a short period of time (days or weeks), more than a half of the knowledge is forgotten.

There is a mathematical approximation of memory's curve (1.3) where *R* is the memory, *S* the relative intensity of record and *T* is the time.

$$R = e^{-t/s} \qquad \textbf{(1.3)}$$

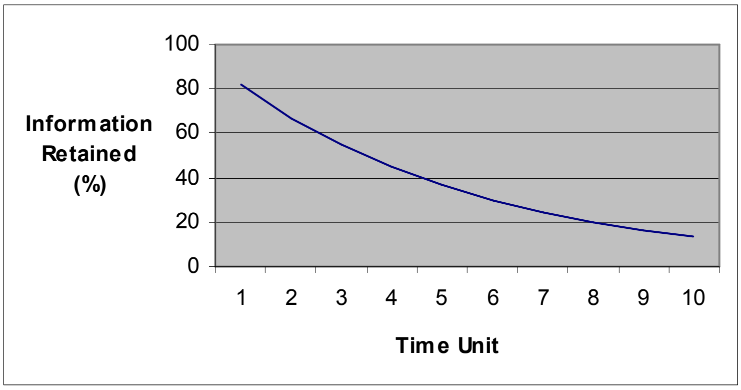



**Fig. 1.3** Representation of forgetting's curve

In formula (1.3) we can observe that memory (*r*) depends on the intensity of record (*s*) and the time (*t*) that has gone by since the last task's repetition. The greater the time is, the higher is the exponent *(–t/s)* and the lower is the record. The opposite effect matters with the intensity record.

## 1.5. Continuous Improvement

To finish this section, we consider important to expose the basic idea of continuous improvement, although it is not going to be studied in this project.

Inside the business world, continuous improvement is necessary in order to maximise the worker's level of competitiveness in every situation. For this reason, the definition of strategies and also an optimisation method are needed.

There is a famous method known as Kaizen. Kaizen is a Japanese word synonymous of continuous improvement. It involves research towards high speed of cycles, productivity, multi-skilling of workers and so on. Kaizen's aim is to improve the things at the beginning better than in the result.

# CHAPTER 2. MODELS OF LEARNING AND FORGETTING

The aim of the models, that we are going to explain in this chapter, is to define curves of learning and forgetting. They estimate parameters and apply formulas as well.

Different models have also been developed with the purpose of adapting different scenarios and data. They are used depending on what topic the expert wants to investigate. There are topics such as the effect of working pool (number of workers available), the selection of the workers taking into account their learning ratio or other skills.

Firstly, regardless of the model used, it is essential to establish the relation between the worker and the task. A worker can not do a task if it does not correspond to her/his capacity. It is important to observe and analyse the situation in with the worker always can do the task if she/he has received previous information. Finally there are workers who do quickly a task because he had previously done it.

In this section we are going to evaluate two models. These models will be applied in our experiment (chapter 6) because they fit with the requirements of the experiment. For this reason, it is important to know their shape and features. The names of the models chosen are Nembhard and Wright.

## 2.1. Software to estimate parameters: SPSS

SPSS (*Statistical Product and Service Solutions*), as its abbreviation shows, is an useful statistical software owing to its big databases. SPSS provides modules for analysing tables of data. It has multiple functions but the ones used in this project are the functions related with models of regression.

The 14th version gives the chance of using scripts in order to make easier the work.

In annex 4 there is basic information about this software. It will help to continue the development of this project.

## 2.2. Model of Wright

The name of this model comes from the Curtiss-Wright Corporation. It was, on the past century, a leading aircraft manufacturer of the United States. It has become a component manufacturer, specialising in actuators, controls, valves, and metal treatment.

This is the most used model due to its simplicity. It follows the logarithmic function (Fig. 1.2) without adding modifications.

To illustrate step by step the model we did an example of application.

A student played video-games, specifically a racing game. This person had never played this game. The mode of competition was against the clock in order to avoid fortuitous factors such as a crash with another car.
While he/she was playing another person was making note of the times per lap. Table 2.1 shows those times.

**Table 2.1** First part of player's time per lap in SPSS

| | Vegades | Temps |
|---|---|---|
| 1 | 1 | 124 |
| 2 | 2 | 127 |
| 3 | 3 | 108 |
| 4 | 4 | 110 |
| 5 | 5 | 101 |
| 6 | 6 | 91 |
| 7 | 7 | 92 |
| 8 | 8 | 103 |
| 9 | 9 | 82 |
| 10 | 10 | 84 |
| 11 | 11 | 85 |
| 12 | 12 | 76 |

Then, a non-linear regression was applied in order to estimate the parameters *r* and $T_1$ (the ones unknown). We used SPSS software. Firstly, we create the variables. Secondly, the expression of the model had to be written (Fig 2.1). After that, we had to define the restrictions. In this case they consisted in initialising the value $T_1$ to 124 s. Finally, the results of Wright's regression appeared (Table 2.2).


**Fig. 2.1** introduction of a model to estimate parameters by using non-linear regression

**Table 2.2** Estimated Values

| Parameter | Estimation | Typical error | Confidence Interval 95% | |
|---|---|---|---|---|
| | | | Low Limit | High Limit |
| R | 0.840 | 0.008 | 0.823 | 0.856 |
| T1 | 141.829 | 4.518 | 132.603 | 151.055 |

Next step was to write all the values in an excel sheet and find the estimated results of $T_n$ replacing the variables with the estimated values. Below (Table 2.3) you can see the comparison between real and estimated times and their representation (Fig. 2.2). This will be the behaviour of the racing player as the repetitions increase.

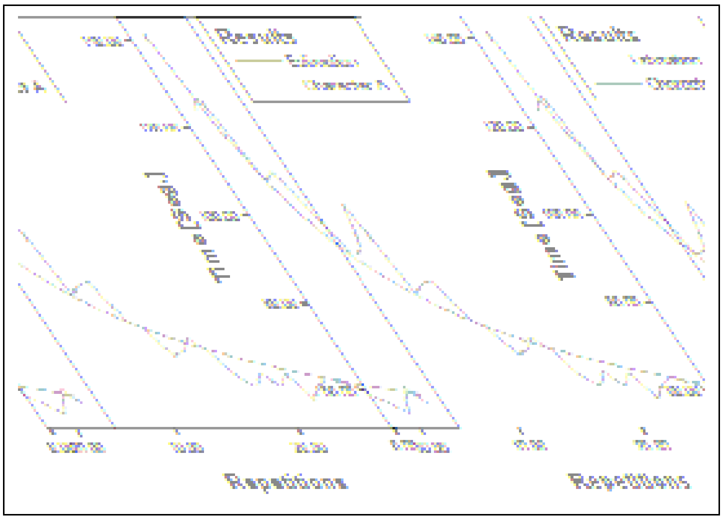



**Fig. 2.2** Representation of the results

**Table 2.3** Comparison between real and estimated results

| Circuit lap | Time [Sec.] | Estimated time [Sec.] |
|---|---|---|
| 1 | 124 | 141.829 |
| 2 | 127 | 119.080 |
| 3 | 108 | 107.504 |
| 4 | 110 | 99.980 |
| 5 | 101 | 94.508 |
| 6 | 91 | 90.261 |
| 7 | 92 | 86.819 |
| 8 | 103 | 83.943 |
| 9 | 82 | 81.486 |
| 10 | 84 | 79.349 |
| 11 | 85 | 77.464 |
| 12 | 76 | 75.783 |
| 13 | 74 | 74.268 |
| 14 | 68 | 72.893 |
| 15 | 69 | 71.636 |
| 16 | 72 | 70.479 |
| 17 | 69 | 69.409 |
| 18 | 63 | 68.416 |
| 19 | 61 | 67.489 |
| 20 | 64 | 66.622 |
| 21 | 61 | 65.807 |
| 22 | 64 | 65.039 |
| 23 | 58 | 64.314 |
| 24 | 61 | 63.628 |
| 25 | 63 | 62.976 |
| 26 | 62 | 62.356 |
| 27 | 61 | 61.765 |
| 28 | 59 | 61.201 |
| 29 | 57 | 60.662 |
| 30 | 55 | 60.145 |
| 31 | 61 | 59.650 |
| 32 | 57 | 59.174 |

## 2.3. Model of Nembhard

Dr. David Nembhard, Associate Professor and Harold and Engineer Marcus Career Professorship, bases his article "*The effect of worker learning, forgetting and heterogeneity on assembly line productivity*" [23] on the necessity of worker's flexibility in innovative sectors. The problem is the lack of workers time in order to achieve a high level of effectiveness and achieve the flexibility.

Nembhard's research investigates how the number of workers and the size of the task have an impact on worker's forgetting.

In order to determinate the learning curve, he uses a three parameters hyperbolic model.

$$
\begin{aligned}
& y_x = k\left(\frac{x+p}{x+p+r}\right) \\
& y, k, p, x \geq 0 \\
& p + r \,\phi\, 0
\end{aligned}
\qquad \textbf{(2.1)}
$$

Where $y_x$ is a measure of the productivity rate corresponding to $x$ units of cumulative (or total) work, $p$ represents the previous expertise, $k$ is the asymptotic productivity rate expected once all learning has been completed. Finally $r$ is the cumulative production and previous experience required in order to reach $y_x$ equals to $k/2$.

For this model we have to use a non linear regression. The data, as in Wright model, is the time (*Temps*) and the number of repetition (*Vegada*). The table is shown in Fig. 2.1.

Then, a non-linear regression was applied in order to estimate the parameters *p, r* and *k* (the ones unknown). We used SPSS software. Firstly, we created the variables. Secondly, the expression of the model has to be written (Fig 2.3). After that, we had to define the restrictions in order to follow the model's specifications. Finally the results of the Nembhard's regression appeared (Table 2.4).

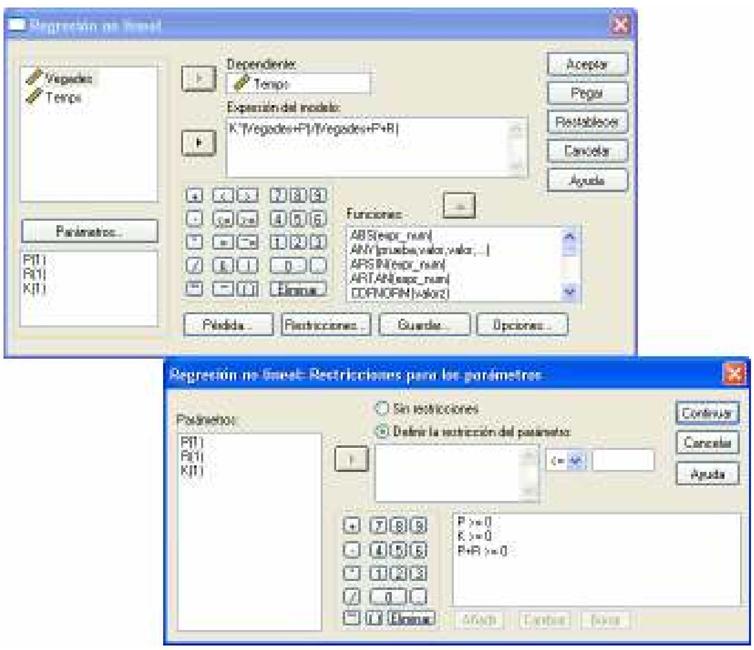



**Fig. 2.3** Configuration of the non-linear regression

**Table 2.4** Estimated Values

| Parameter | Estimation | Typical Error | Confidence Interval of 95% | |
|---|---|---|---|---|
| | | | Low Limit | High Limit |
| p | 56.514 | 32.837 | -11.586 | 124.614 |
| k | -46.123 | 30.040 | -108.424 | 16.178 |
| r | 25.815 | 9.126 | 6.887 | 44.743 |

With all these values and data, SPSS shows the behaviour of the worker (learning curve). For this process we used an excel sheet in order to substitute the estimated values and data in the formula of Nembhard.

Table 2.5 shows the comparison between real and estimated time while Fig. 2.4 represents the same but with a graphic.

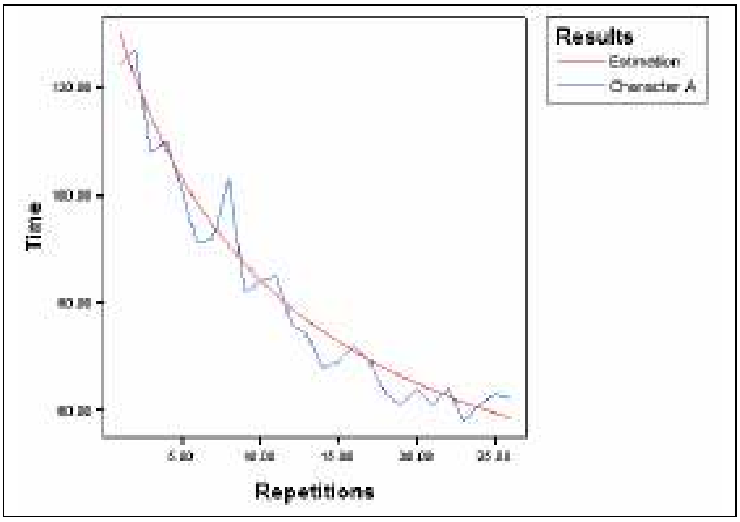



**Fig. 2.4** Representation of the results

**Table 2.5** Comparison between real and estimated time.

| Circuit lap | Time [Sec.] | Estimated time [Sec.] |
|---|---|---|
| 1 | 124 | 130.342 |
| 2 | 127 | 121.907 |
| 3 | 108 | 114.731 |
| 4 | 110 | 108.553 |
| 5 | 101 | 103.177 |
| 6 | 91 | 98.457 |
| 7 | 92 | 94.280 |
| 8 | 103 | 90.557 |
| 9 | 82 | 87.219 |
| 10 | 84 | 84.207 |
| 11 | 85 | 81.478 |

| | | |
|---|---|---|
| 12 | 76 | 78.992 |
| 13 | 74 | 76.718 |
| 14 | 68 | 74.631 |
| 15 | 69 | 72.709 |
| 16 | 72 | 70.932 |
| 17 | 69 | 69.285 |
| 18 | 63 | 67.754 |
| 19 | 61 | 66.327 |
| 20 | 64 | 64.994 |
| 21 | 61 | 63.746 |
| 22 | 64 | 62.575 |
| 23 | 58 | 61.474 |
| 24 | 61 | 60.437 |
| 25 | 63 | 59.459 |
| 26 | 62 | 58.534 |

In addition, in all processes there are periods of time when the task is not done. For this reason it is important to extend the model with the forgetting factor [9]. The obtained learning and forgetting model has been proved to be efficient. It appears in the value $R_x$.

$$R_x = \frac{\sum_{i=1}^{x} (t_i - t_0)}{x \cdot (t_x - t_0)} \qquad \textbf{(2.2)}$$

Where x is the cumulative production, $R_x$ is the average of time from the last produced unit, the elapsed time per unit is $(t_x - t_o)$ which is the difference between the time when the worker starts the present unit and the time when he/she did it the first time. The value of $R_x$ fluctuates from 0 to 1. A zero value shows that the experience was obtained a lot of time before. A one value indicates that the experience was currently obtained. The value tends to be 0.5. Finally, it is important to consider the effect of the memory in each worker. For this reason, a new parameter (*α*) is added. It can be considered as the record. If α is small, the record of the task will be high. This situation occurs because the value of $R_x$ must be below or equal to 1. On the other side, if *α* is high, forgetting will increase.

The complete equation is the one that appears below.

$$\begin{aligned} & y_x = k\left(\frac{xR_x^{\alpha} + p}{xR_x^{\alpha} + p + r}\right) + \varepsilon_r \\ & y, k, p, x, \alpha \geq 0 \\ & p + r \phi 0 \end{aligned} \qquad \textbf{(2.3)}$$

In future sections these models will be applied to real tasks. Moreover they will add extra parameters in order to fit better in the experiment. The SPSS will be used in the same way, as well.

# CHAPTER 3. PLANNING MODEL

Planning is one of the key topics inside the industrial sector. Due to the frenetic rhythm of work and the diversity of tasks it is important to be efficient (when we plan the work).

There are different models of planning tasks. Each model can provide a solution for more than one goal. The most pursued goals are: reduce the number of workers, extra hours, the elapsed time doing a task and so on.

When a model of planning is created it is important to take into account different parameters in order to make it applicable and to simulate the reality. The ideal model doesn't exists and it is also not going to exits, because the fact that the environment is unforeseeable. Before starting the planning we have to know the data of the worker, how is her/his performance, the task they are going to do..

In this chapter we only put forward a model of planning in order to validate that works properly.

## 3.1. Planning Models

There are many studies about this planning. The researches used to explain their model and give a brief example. Below you can read a summary about planning history.

One of the most well-known models of planning is created by Nembhard [2]. He did a heuristic planning. It mentions that the period while you do a task is shorter and this situation causes the fastest learning of the workers.

Years before, Ecstein, Roholeder [10] proved a simulation taking into account the learning of the workers.

Slomp, Bokhorst, Molleman [11] based their planning on the performance which depends on the individual learning by task. This case takes into account the cost due to incorporate a worker to a task.

With the model of Wu, Sun [12] was searched the optimum solution considering the learning of the tasks. That was the first time that appears an equation that includes the workers' accumulated experience.

Finally, Olivella [13] developed a planning model taking into account the performance depending on the learning of the overall tasks. This means that the efficiency depends on the previous experience and not in the own task or another tasks.

Our project details a similar model to the last one. It is based on assignation of tasks taking into account the performance and depending on the learning of the

overall task. It does not still have name because it has been recently created for this reason we name it, new planning model. We thought that it would be interesting to apply a model that no one had applied before in order to evaluate its functionality.
Below we are going to define the variables and equations of the model.

## 3.2. Definition of the model

In order to solve the planning it is important to have a detailed definition of the problem. It is carried out thanks to different variables. The definition of them is needed to find a valid solution.

The first parameter is the horizon (*T*) of the task. It is the maximum number of periods (*t*) for finishing the task. In other words, it is the available time in order to complete all the tasks. A single period (*t*) represents the interval of time between two timestamps. The selection of the period size is a subjective decision. The smaller the period, the more accurate the problem is and the more number of variables. It results in the increase of the difficulty. Different periods oscillate between 1 and the horizon (*T*).

Another requirement is to define the number of tasks (*N*). All tasks are differentiated thanks to the subscript *i*. Furthermore, it is necessary to group them together by type (*K*). Each task (*i*) has to belong to a type of task (*K*). All the tasks match with the same type as long as they have some learning's relation among them.

Every task (*i*) has a number of needed periods in order to carry it out (*W*). It corresponds to the inverse of the productivity, at the same time, the productivity is the inverse of the time.

All tasks have an individual variable $r_i$. This is the ready time of the task and since this period the task can start.

Finally, it is necessary to take into account the number of workers (*P*). Each worker has a subscript j so as to be identified.

When data is defined, it is necessary to create the variables of the model. In other words, they are the values that the program which solves the model estimates.

The set of variables are:

| | |
|---|---|
| $t_i \quad i = 1,...,T$ | Period when the task *i* is finished. It is always between 1 and the horizon. |
| $j = 1 \ldots P$ | Subscript number (between 1 and the maximum number of workers) in order to identify a worker. |

| | |
|---|---|
| $i = 1 \ldots N$ | Number of tasks. There are no new ones during the execution of the task. |
| $1 \le k \le N$ | Number of types of task. |
| $X_{jit} \in \{0,1\}$ | Binary variable. Shows whether, or not, a worker is doing a task in a period of time. If the value is 1 it means that the worker *j* is in the period *t* doing the task *i*. Otherwise the value is 0. |
| $S_{jkt}$ | Cumulative experience of a worker *j* that had done a task *k* at the beginning of the period *t*. |
| $\rho_{jkt} = \varphi_k(S_{jkt})$ | Performance achieved by a worker *j* that does a task *k* in a period *t*. Between 0 (not do the task in the studied period) and $\rho_{jkt}$. |
| $W_{it}$ | Amount of work done corresponding to the task *i* until the period *t*. Lower than 1 when the task is being carried out and 1 when it is finished. |
| $\alpha_{k,k'}$ | Relation between the *k* task and the *k'* tasks. |
| $Y_{it} \in \{0, 1\}$ | Auxiliary variable. |

## 3.3. New model

In this section we are going to define different equations and restrictions for previous variables. It is done in order to simulate the reality.

New model can be applied to achieve different goals. Next we detail the common restrictions regardless of their purpose.

Concerning the restrictions, Equation 3.1 represents that all workers have to be doing a task every time.

$$\sum_{j=1}^{P} X_{jit} = 1 \quad \forall i \le N,\ \forall t \le T \tag{3.1}$$

Equation 3.2 means that any worker can not do simultaneously more than a task during a period *t*.

$$\sum_{j}^{P} X_{jit} \leq 1 \quad \forall i \leq N,\ \forall t \leq T \tag{3.2}$$

Equation 3.3 shows the experience of a worker who does a task *k* at the beginning of the period t. It is the previous experience $S_{jk0}$ plus all the acquired experience during the preceding periods until the current one. The product $\alpha_{k,k_i} \cdot X_{jit}$ indicates whether the worker *j* has done any of the experience and the influence of it.

$$S_{jkt} = S_{jk0} + \sum_{kj1}^{t} \sum_{i=1}^{N} \alpha_{k,k_i} \cdot X_{jit} \quad \forall i \leq N,\ \forall t \leq T \tag{3.3}$$

The real performance of a worker *j* who does the task *i* in the period *t* is always the same or less than $X_{jit}$. If he/she has done the task *i* in the period *t*, $X_{jit} = 1$, $\hat{\rho}_{jit}$ takes its corresponding value (3.4). If $\hat{\rho}_{jit}$ value is 1, it means that the worker has initiated and finished the task in the same period. Normally this situation doesn't happen. In case that the worker had not done the task *j* in the period *t* ( $X_{jit} = 0$ ) its value will be 0.

$$\hat{\rho}_{jit} \leq \rho_{jit} \quad \forall j \leq N, \forall i \leq N, \forall t \leq T \tag{3.4}$$

The real output of any worker who does his/her task in any period is always the same or less than the theoretic output in the task *i* in the same period *t*. This restriction complement the preceding because if it is not 0 ( $X_{jit} = 0$ ) the result will be $\rho_{jit}$ . (3.5)

$$\hat{\rho}_{jit} \leq X_{jit} \quad \forall j, \forall i, \forall t \tag{3.5}$$

The totality of finished work is the same as the addition of all workers' real output during the whole periods (before the period studied).

$$w_{it} = \sum_{t=ri+1}^{t} \sum_{j} \hat{\rho}_{jik} \tag{3.6}$$

It shows that in period t the experience has not ended.

$$w_{it}\ \pi\ 1 \quad \rightarrow \quad T\ \phi\ t \tag{3.7}$$

Another way of solve the planning is defining the next objective equation. It is used in order to minimise the time elapsed.

$$C_{\max} \geq \sum_{t=1}^{T} t \cdot \sum_{j=1}^{P} \sum_{i=1}^{N} X_{ijt} \tag{3.8}$$

# CHAPTER 4. SOFTWARE TO SOLVE THE PLANNING MODEL

We are going to create a practise example in order to clarify the model and test their applicability. Software to obtain the results is developed.

## 4.1. Software to solve integer and mixed linear programs

There is several software libraries to solve integer and mixer linear problems. We will use lp_solve [14], an open code program.

Next, we are going to detail the format of the data for each program. This type of file, with the respective data, is used to define the equations needed for finding the results of the model. Mainly, there are two formats to make the linear problems readable by the libraries: LP and MPS.

The first one, LP's (Linear Programming) has an easy syntax and is very visual because the equations are written as mathematically. The file is composed of one or more goal functions, restrictions and variables' declarations following this order.

The second, MPS, differs from LP in the way how the information is given. The data is directed to columns and rows. Writing the instructions in this way is more difficult than LP.

In order to do the call and get the results the steps are the following. First of all you have to open the command window with the command "cmd" and after that execute the name of the program with the name of the file created (LP file). If the file that you want to solve is in MPS format, it can be converted easily to lp thanks to the program mps2lp [16]. It is important to take into account the position of the executable and the file. They have to be in the same directory. For instance, Fig 4.1 shows the syntax in order to solve the model who has been written in LP format.

```
C:\Documents and Settings\My Documents\EPSC\3B\TFC\Tasques_Software>lp_solve "LP_JON+ACS.lp"
```

**Fig. 4.1** Command in order to solve a planning task with lp_solve

For more information consult annex 6.

## 4.2. Generation of linear program format of the problems

### 4.2.1. First example

Our objective was to solve an easy problem of planning using the new model.

We supposed scenery where there were two tasks for doing. Those two tasks were different but they had a relation between them. This means that if you did one of them, you will do better the second one because you have a degree of experience. Temporarily, the tasks were independents, that is, a task can start although the other hasn't still finished. There were two workers who did the task with the same speed. They had the same ability to learn as well.

The maximum amount of time for finishing both tasks was 32 hours (3 days) because the workers worked 8 hours each day.

The planning's objective was to minimise the elapsed time doing overall work. We want finish both task as quickly as possible.

To sump up, the defined variables are the following:

- The horizon (*T*) was 3. There were at the most 3 periods in order to end all the tasks
- There were two workers (*P=2*)
- The number of tasks were two (*N=2*)
- There were two types of tasks (*k*)
- The value of ready time $r_i$ for both tasks was 1, because from the period 1 the two tasks could be done

### 4.2.2. Writing the example in linear program problems' format

As we previously said, the goal was to minimise the elapsed time doing all the tasks. We wrote the necessary code in lp file in order to find a numeric solution (Fig. 4.2).

This example can be done manually because of the reduced number of variables. For higher models it is needed an specific program that automatically writes the equations.

The format of following file is LP. We show it here because we think it is useful in order to understand the restrictions and functions defined in the previous chapter. Furthermore, it is finished off with the needed comments.

```
/*PROGRAM'S DATA
------------------------------------------------------------

 Xjit: (Binary variable) Shows whether or not the worker is doing a task.

 Sjit: (Real Variable) Experience of the worker j when he/she does the task i at
the beginning of the period t.

 Rajit: (Real Variable) Output of the worker j if he/she does the task i in the
perido t.

 Rbjit: (Real Variable) Output of the worker j if he/she does the task i in the
period t (Values between 0 and Ra).

 T : Period where all the task is finished.

*/

/*OBJECTIVE FUNCTION
------------------------------------------------------------*/

min: CMax;

/*RESTRICTIONS
------------------------------------------------------------*/

/*Restriction 1:

The workers can't stop working and they can do only one task simultanetly.

eq1: X111 + X121 < 1;
eq2: X112 + X122 < 1;
eq3: X113 + X123 < 1;
eq4: X211 + X221 < 1;
eq5: X212 + X222 < 1;
eq6: X213 + X223 < 1;

/* variables maximum 1 */
X111 < 1;
X121 < 1;
X112 < 1;
X122 < 1;
X113 < 1;
X123 < 1;
X211 < 1;
X221 < 1;
X212 < 1;
X222 < 1;
X213 < 1;
X223 < 1;

/*Restriction 2:

Learning of the task due to the previous experience */

/* At the beginning of the period 1 */

S111 = 0;
S121 = 0;
S211 = 0;
S221 = 0;

/* At the beginning of the period 2 */

S112 = S111 + 1   X111 + 0.1 X121;
S122 = S121 + 0.1 X111 + 1   X121;
S212 = S211 + 1   X211 + 0.1 X221;
S222 = S221 + 0.1 X211 + 1   X221;
```

```
/* At the beginning of the period 3 */

S113 = S112 + 1   X112 + 0.1 X122;
S123 = S122 + 0.1 X112 + 1   X122;
S213 = S212 + 1   X212 + 0.1 X222;
S223 = S222 + 0.1 X212 + 1   X222;

/* potential output */

/* Final period 1 */
Ra111 = 0.45 + 0.1 * S111;
Ra121 = 0.45 + 0.1 * S121;
Ra211 = 0.45 + 0.1 * S211;
Ra221 = 0.45 + 0.1 * S221;

/* Final period 2 */
Ra112 = 0.45 + 0.1 * S112;
Ra122 = 0.45 + 0.1 * S122;
Ra212 = 0.45 + 0.1 * S212;
Ra222 = 0.45 + 0.1 * S222;

/* Final period 3 */
Ra113 = 0.45 + 0.1 * S113;
Ra123 = 0.45 + 0.1 * S123;
Ra213 = 0.45 + 0.1 * S213;
Ra223 = 0.45 + 0.1 * S223;

/* Real output */

/* Potential output is higher than real output */

Rb111   <       Ra111   ;
Rb121   <       Ra121   ;
Rb211   <       Ra211   ;
Rb221   <       Ra221   ;
Rb112   <       Ra112   ;
Rb122   <       Ra122   ;
Rb212   <       Ra212   ;
Rb222   <       Ra222   ;
Rb113   <       Ra113   ;
Rb123   <       Ra123   ;
Rb213   <       Ra213   ;
Rb223   <       Ra223   ;

/* Potential output fluctuates between 0 (don't do anything) and 1 (finish all
the work in one period)*/

Rb111   <       X111    ;
Rb121   <       X121    ;
Rb211   <       X211    ;
Rb221   <       X221    ;
Rb112   <       X112    ;
Rb122   <       X122    ;
Rb212   <       X212    ;
Rb222   <       X222    ;
Rb113   <       X113    ;
Rb123   <       X123    ;
Rb213   <       X213    ;
Rb223   <       X223    ;

/* FINAL CONDITION:

The work has to be finished */

Rb111 + Rb211 + Rb112 + Rb212 + Rb113 + Rb213 > 1;
Rb121 + Rb221 + Rb122 + Rb222 + Rb123 + Rb223 > 1;

/* OBJECTIVE FUNCTION:
It is important to minimise the used periods */

CMax =    X111 +   X121 +   X211 +   X221 +
        2*X112 + 2*X122 + 2*X212 + 2*X222 +
        3*X113 + 3*X123 + 3*X213 + 3*X223;

/*DECLARATIONS
-----------------------------------------------------------*/
```

```
int X111,X121,X112,X122,X113,X123,X211,X221,X212,X222,X213,X223;

int CMax;
```

**Fig. 4.2** The LP code

In order to solve the previous equations we use lp_solve. If you want convert it in mps format you have to turn the .lp file into .mps file with lp2mps.

Independently of the chosen method, the value of all the variables and the result of the planning's goal will be displayed on screen. Fig. 4.3 shows the solution of the example.

```
Value of objective function: 6

Actual values of the variables:
Ra111                   0.45
Ra112                   0.46
Ra113                   0.47
Ra121                   0.45
Ra122                   0.55
Ra123                   0.65
Ra211                   0.45
Ra212                   0.55
Ra213                   0.65
Ra221                   0.45
Ra222                   0.46
Ra223                   0.47
S111                    0
S112                    0.1
S113                    0.2
S121                    0
S122                    1
S123                    2
S211                    0
S212                    1
S213                    2
S221                    0
S222                    0.1
S223                    0.2
X111                    0
X112                    0
X113                    0
X121                    1
X122                    1
X123                    0
Cmax                    6
X211                    1
X212                    1
X213                    0
X221                    0
X222                    0
X223                    0
Rb111                   0
Rb112                   0
Rb113                   0
Rb121                   0.45
Rb122                   0.55
Rb123                   0
Rb211                   0.45
Rb212                   0.55
Rb213                   0
Rb221                   0
Rb222                   0
Rb223                   0
```

**Fig. 4.3** Result of the planning using the new model

Previous image shows that both workers had only worked for the two initial periods. The former worker did the task 2 and the second did the task 1. These results are represented with the variables *X*. They allude to the binary variable $X_{jit}$ of the new model where *j* is the worker, *i* the task and t the period. Only $X_{121}, X_{122}, X_{211}, X_{212}$ are equal to 1 (workers were doing the task in the appropriate period), the others are 0 (workers were not doing the task).

The associated learning is represented with the variable $S_{jkt}$, where k is the type of task. In the example, $k = i$ because there were as tasks as types of tasks.

The possible output also appears. The theoretic performance is $Ra_{jkt}$ and the real is $Rb_{jkt}$. In Fig. 4.3 you can see how the best are $Ra_{121}$, $Ra_{122}$, $Ra_{211}$ and $Ra_{212}$.

Thanks to $R_a$ it is possible to end both tasks in a total of two periods. The next conditions (4.1) have been carried out.

$$\begin{aligned} \mathrm{Rb}_{211} + \mathrm{Rb}_{212} \geq 1 \\ \mathrm{Rb}_{121} + \mathrm{Rb}_{122} \geq 1 \end{aligned} \tag{4.1}$$

The result of the objective function is 6. This result is due to the following sentences:

```
min: CMax;

CMax =    X111 +   X121 +   X211 +   X221 +
2*X112 + 2*X122 + 2*X212 + 2*X222 +
3*X113 + 3*X123 + 3*X213 + 3*X223;
```

**Fig 4.4** The objective function

As we can see in the first lines, this result tries to find the minimum elapsed time. For this reason, each extra period penalises the result with the next values: assemblies in period 1 are multiplied by one, the ones of the second period by two and finally, the assemblies of the third period by three.

In this way we encourage the program in order to calculate the tasks in the minimum time.

The results agree with the previous hypothesis. The solution of the problem, where we can reduce the number of hours of works, consists in giving a task of each type to each worker.

### 4.2.3. Automatic generation of lp and mps format problems

Solving planning problems with the new model is not an easy task. There are lots of aspects to consider. This model leads to a high number of variables and functions, as we can see in the example. Doing it by hand involves a lot of work and a high risk of being wrong. For this reason, the program for set out this new model has been created.

The aim of this program is to read the data related to the problem of planning tasks and then to create a file with .lp and/or .mps extension. Later by means of the program lp_solve we can find a numeric solution.

The data of the planning problem will be introduced in an easy way by the user. He/she has only to type the data following a series of instruction.

The current version of the program is number 4. The previous ones do not fit with all the needed specifications. The programming language is C and all the code can be found in annex 7. This application is only compatible with Windows's operative system but can be modified in order to work with Linux, as well.

As you can see in Fig. 4.5 the program is executed from the windows console. The image shows the main menu.

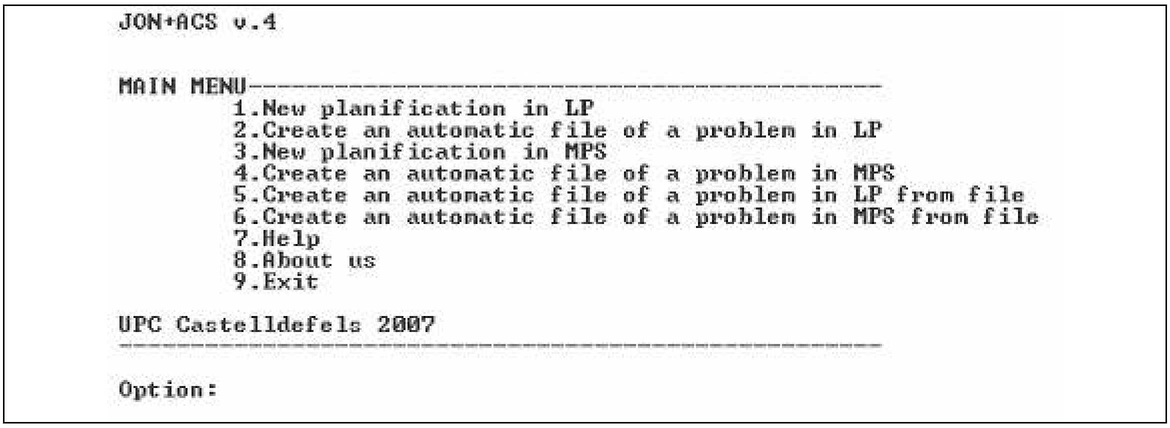



**Fig. 4.5** Multiple choice menu of the created program.

The program has different functions. Its operation is extremely simple, you have to follow the indications shown in each section.

Striking the key "1" and after answering a series of questions about the data of the problem, the file needed will appear in the screen (in lp format) in order to solve our planning task. Key "3" does the same but in mps format. Fig. 4.6 shows the set of questions for answering. They appear in a sequential order.

If you want to automatically create a file without visualising its content, you will choose options 2 and 4 (depending on the format you want). After that the same questions as before will appear on the screen. The only difference is that the result is not displayed on the screen. It is saved in the memory of the PC.

Fig. 4.6 shows an example introduced by the user. The number of workers is 5, the output between the current task and the previous one is 0.1. Moreover there are 3 different tasks (*n*), but they can be classified in two types (*k*).

First task corresponds to type 1 and at the beginning of it any worker is only able to do the 45% of the total task in first period. Second task corresponds to type 1 and at the beginning of it any worker is only able to do the 47% of the total task of the period. Third task corresponds to type 2 and at the beginning of it any worker is only able to do the 40% of the total task without previous experience. Relations between the types of tasks are 1 (if they do another task of the same type) or 0.1 if the types of tasks are different.

One complementary aim is to force that all workers get, at least, the capacity to do the 50% of each task by period in the final of this planning. The horizon, or total number of periods, is 9.

```
Number of workers: 5
Value of learning of all the workers: 0.1
Number of tasks: 3
How many types of tasks: 2

The type task 1 is: 1
Enter the amount of task done in one period (w) of the task 1: 0.45

The type task 2 is: 1
Enter the amount of task done in one period (w) of the task 2: 0.47

The type task 3 is: 2
Enter the amount of task done in one period (w) of the task 3: 0.40

Relation of learning beetwen type task 1 and type task 1 is: 1
Relation of learning beetwen type task 1 and type task 2 is: 0.1
Relation of learning beetwen type task 2 and type task 1 is: 0.1
Relation of learning beetwen type task 2 and type task 2 is: 1

Enter the final mininum experience in task 1 of workers: 0.5
Enter the final mininum experience in task 2 of workers: 0.5
Enter the final mininum experience in task 3 of workers: 0.5

Number the horitzon (in number of periods): 9
```

**Fig. 4.6** Example of introduced data in the program

In order to make easier the entrance of data, option 5 and 6 allow read all the data from a file. It has to be written in the same order than in the preceding example (Fig. 4.6). The example about how to introduce the values of the case we are dealing with is the following:

```
5
0.1
3
2
1
0.45
1
0.47
2
0.4
1
0.1
0.1
1
0.5
0.5
0.5
9
```

**Fig. 4.7** The input file

It is important to mention that all the lines have to be separated with a line break. If you see the data introduced and the created file, you will see quickly the relation.

Finally, the folder where this program is executed has to be in a known place because the executable lp2mps.exe has to be added to the same folder. If not there are options which don’t work.

# CHAPTER 5. EXPERIMENT 1$^{st}$ PHASE

In order to apply all the theoretical information and models explained in preceding chapters, we created an experiment about it. There are different important topics to deal with. Some of them, such as the workplace, the profile of the volunteers and the definition of the tasks are going to be detailed below.

This information is the base of the study, the introduction about what we did and how we did it.

## 5.1. Workplace

First of all, it is important to mention that this project belongs to the field of university research. In this case, the designers' and director's office is sited in the University Campus of UPC in Castelldefels (EPSC).

This school gives two kinds of different technical engineering: Telecommunications (speciality in Systems of Telecommunications and in Telematics) and Aeronautics (speciality in Aeronavigation).

The University has different laboratories and all the necessary equipment in order to allow the students to do their practice lessons. One of these labs was required in our experiment. For this reason, that was the most suitable place to do our experiment.

## 5.2. Volunteers' Profile

Engineers of telecommunications are people used to learning to learn. They have to improve as the same rhythm as innovation makes progress. Furthermore we needed volunteer people with availability in order to do the experiments. For both reasons, we thought that they would be the best candidates because we would be able to see how they adapt new learning and how the forgetting affects in this process.

To do the experiment, these volunteers were chosen without distinction between those who study the speciality of systems or those who study telematics. Researching into the profile of these people it has been found the percentage of hours corresponding to each department of the university (Fig 5.1 and Fig 5.2). This factor shows the previous formation of each volunteer depending on the subjects done during the degree.

It is important to mention that our experiment corresponds to the EEL department.

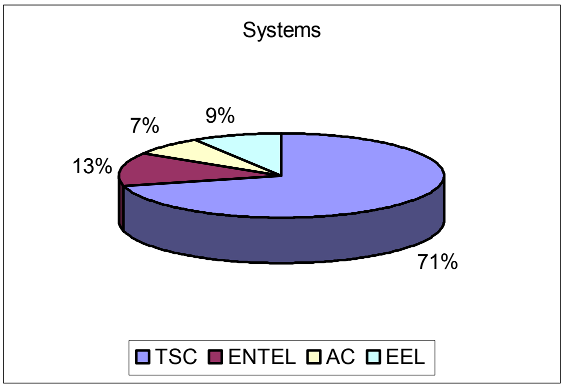



**Fig. 5.1** Distribution of subjects in departments (Systems)

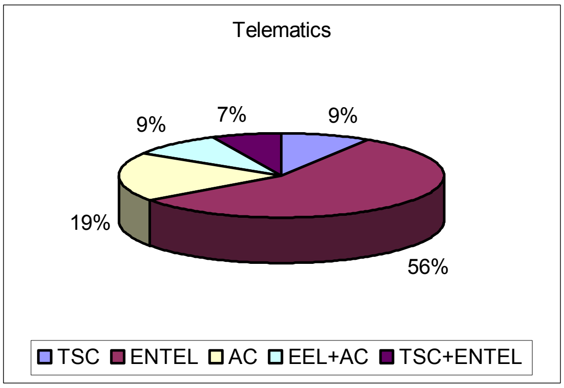



**Fig. 5.2** Distribution of subjects in departments (Telematics)

The first year students of both specialities study the same subjects in order to assimilate basic knowledge needed for developing the degree. In the second year, the number of hours related with EEL department is the same but they do different activities. Systems' speciality is more similar to the experiments than the Telematics one. This situation can provoke that students who curse Systems take less time doing the trials than students who curse Telematics.

The average age of the students, who were volunteers, was 21 years old and they were mainly men. (66.67 per cent)

## 5.3. Test of Personality

All the students who took part in the experiment previously realised a CPS (Questionnaire about Situational Personality) test. It includes not only a simple evaluation about their personality, but also their occasional behaviour.
For summarize, it is a questionnaire that shows an evaluation about the behaviour of the volunteers, taking into account the characteristics of them and how the external situation affects in the way they are behaving or acting.

In this project was interesting to evaluate the features of the students. The aim was to analyse whether there was a relation between the times used in realize the task and the individual ability or level of learning.

### 5.3.1. Variables

There are lists of 233 elements, or sentences, which evaluate fifteen different variables. Annex 2 shows the 233 questions and the ranges of the parameters used to interpret them.

The first variable is Emotional Stability and it represents the adjustment of emotions and affects. Anxiety is the category that evaluates the reaction in front of different situations. Self- Judgement is defined as the self-personal valuation. Effectiveness weighs up the security for facing up problems and situations. In order to quantify the security in front of problems we use the Confidence. We can find the Independency as well where you can evaluate the tendency of the person to act without taking into consideration others' interests. Domination shows the tendency to run other people and to organize activities. Cognitive Control evaluates the control's abilities of the student. The facility to public relations is represented by the Sociability, whilst the Social Adjustment shows the social behaviour and the degree of adaptation to familiar and scholar environment. Other considered values are Agressivity, Tolerance, Social Intelligence, Integrity and Honesty, Leadership, Sincerity, Social Desirability and Answers' Control. This last one shows if the answers are coherent between them and not contradictory.

### 5.3.2. Results

When the students had answered all the questions the next step was to analyze the results by the TeaPlan software. This program gives a numeric value for each variable taking into account the volunteers' answers.

The second step was to verify the results with different tables provided by the book in order to obtain the punctuation of the student in each variable (in %).

It's important to mention the fact that the results were calculated taking into account that volunteers had been completely sincere in their answers. Moreover, they knew that those answers don't have influence on their activity because that was not a selection process.

From that consideration and through a series of calculation the results of the Table 5.1 have been obtained. It shows approximately the profile of the students who took part in the study. Annex 2 shows each person's profiles, the tables mentioned before and the process taken.

According to the average of all the individual values, the profile of the student who took part in the experiment was the next one:

**Table 5.1** Results of the students on average

| Parameter | Average Value (%) | Explanation |
|---|---|---|
| Stability | 74,833 | Peaceful, stables and balanced |
| Anxiety | 33,667 | Patients |
| Self-Judgement | 78,333 | High self-esteem |
| Effectiveness | 73,917 | Competent and with initiative |
| Confidence | 77,833 | Self-confident |
| Independence | 51,5 | A bit dependents |
| Domination | 41,667 | Not domineering |
| Cognitive Control | 82,75 | Organized and methodical |
| Social-Adjustment | 73,833 | Sociable and reliable |
| Agresivity | 33,5 | Peaceful |
| Tolerance | 65,833 | Understanding and permissive |
| Social intelligence | 77,667 | Good adaptation to situations |
| Honesty | 60,75 | Responsible |
| Leadership | 55,417 | Low initiative |
| Sincerity | 26,333 | Liars answering this test |
| Social Desirability | 91,5 | ---- |
| Control | 36,25 | Natural and spontaneous |
| Adjustment in general | 57,375 | ---- |
| Leadership in general | 37,783 | Permissive |
| Independence in general | 21,767 | Low independency |
| Consensus | 29,858 | Unconfident |
| Extroversion | 23,475 | Withdrawn |

In conclusion, this data shows that volunteers who did the test did not have initiative, but this was not a problem because the experiment followed a standard. Their efficiency's level and security was high enough to develop the task.

## 5.4. Types of Experiments

As we mention before, the experiments are related to any of the degree's subjects. In general, the trials consist of a series of assemblies and measures with electronic circuits composed basically of amplifiers, resistors and transistors.

There are seven assemblies prepared in order to choose the most suitable three. All of them are about the same topics. The only difference among them is the level of difficulty and the similarities that they have. For instance, there are two assemblies with the same level of easiness and very similar set up in order to evaluate specific parameters.

The three assemblies chosen are detailed below.

In short, experiment A consists of an assembling, an inverse amplifier. Trial B is very similar to A but it included additional difficulties. Finally, C represents an intermediate accumulator composed of a transistor.

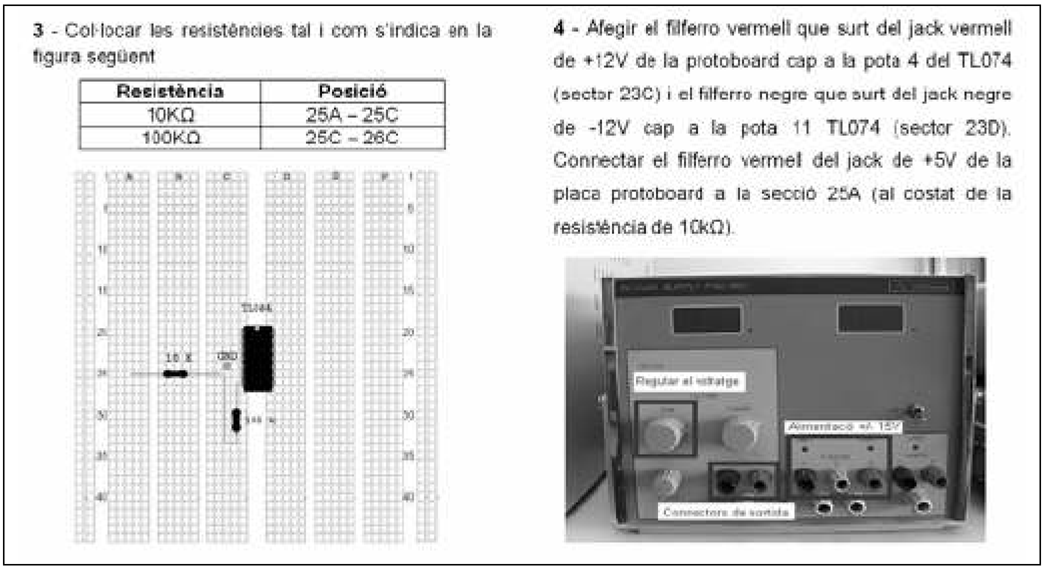
The students who collaborated gained access to the laboratory. In the first session they were informed about the main goals of the experiment. They also received all the necessary material with the standard about what they had to do. Moreover, a questionnaire about their situational personality was given. Finally, they also received a previous training.

### 5.4.1. Standards of assembly

The students must follow the same steps and operations to achieve an homogeneity in the task. For this reason, it was important to create an standard with all the needed material and steps.

The standard contains all the needed material and detailed information about the correct emplacement of each component. Furthermore, in it appears the configuration of the appliance and all the steps to do the assembly in a satisfactory way. On the other hand, it includes a wide range of photographs about the material and the position of the electronic components (Fig 5.3) Annex 1 shows all the detailed standards task by task.

This fact causes the independence of the results regarding personal methods of assembly or volunteer's individual ideas. To sum up, everybody did the same task in the same way.



3 - Col·locar les resistències tal i com s'indica en la figura següent

| Resistència | Posició |
|---|---|
| 10KΩ | 25A – 25C |
| 100KΩ | 25C – 26C |

4 - Afegir el filferro vermell que surt del jack vermell de +12V de la protoboard cap a la pota 4 del TL074 (sector 23C) i el filferro negre que surt del jack negre de -12V cap a la pota 11 TL074 (sector 23D). Connectar el filferro vermel del jack de +5V de la placa protoboard a la secció 25A (al costat de la resistència de 10kΩ).

**Fig. 5.3** Example of task standard

## 5.4.2. Description of the three standards chosen

The selection of only three assemblies was due to the fact that it was more important to see how repetitions affect in the evolution of learning and forgetting behaviour than did a lot of experiments. It would be a lost of time evaluating learning and forgetting factors in order to arrive at the optimum production, because that is reached when someone can not reduce their time any more.

The former task, A, consists in assembling an inverse amplifier (Fig 5.4). The material needed is an electrical supplier, functions generator and a set of electronic components such as resistors, amplifiers, wires, etceteras. The aim of this one was to see whether the student was able to assembly and observe how the $V_{out}$ was amplified and it appeared in an inverse way through the oscilloscope.

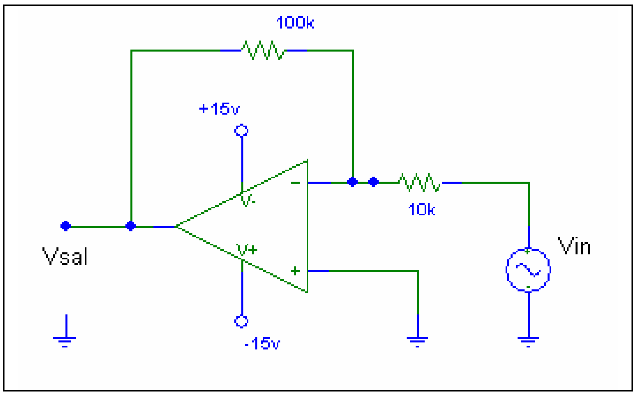



**Fig. 5.4** Inverse Amplifier's Schema

Secondly, task B is an amplifier circuit with more complexity than the preceding one (Fig 5.5). The volunteer used the same material and he/she had to observe the $V_{out}$ of this assembly through the oscilloscope.

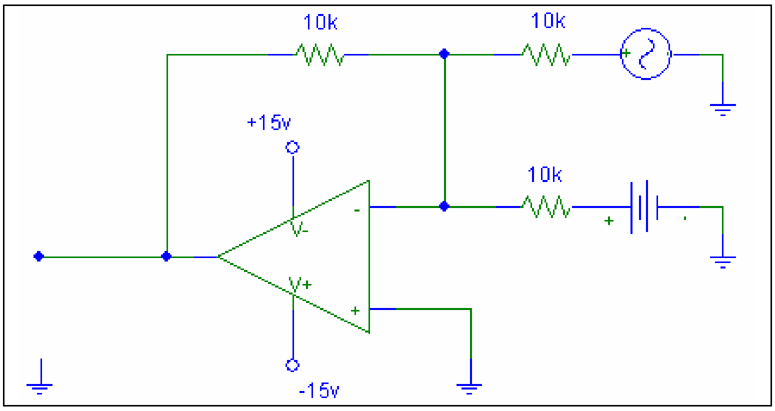



**Fig. 5.5** Modified amplifier's schema

Finally, task C is based on an intermediate accumulator (Fig 5.6). The material used was the same as in last experiments plus a transistor instead of an amplifier. The goal was to see how the incorporation of that new component affected the circuit.

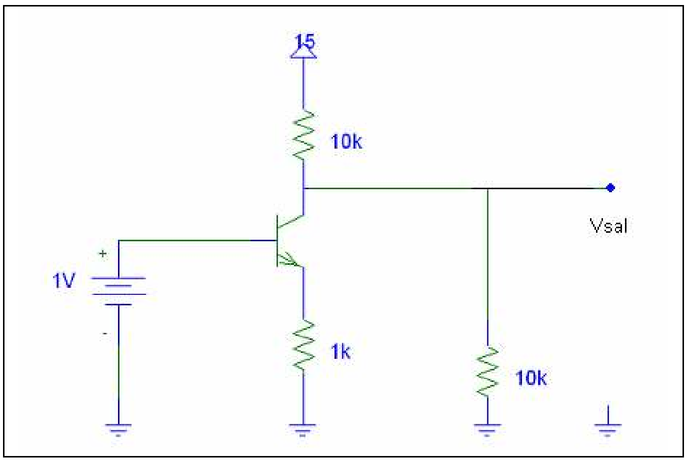



**Fig. 5.6** Intermediate accumulator's schema

### 5.4.3. Previous Training

When the volunteers arrived at the laboratory, they received a previous formation in order to introduce them. It is important to mention that laboratory equipment is expensive, for this reason, it is necessary to know its function in order to not damage it. The training was individually given for each person.

That formation consisted of a power point for each task. The slides show technical information, mainly about the laboratory's material (electric supplier, oscilloscope, function generator...) and the features of the components used in the experiments (amplifiers, transistors...). On the other hand, they included basic notions about the law of Ohm or virtual short-circuits.


**Fig. 5.7.** A volunteer doing an experiment inside the laboratory

Annex 1 shows the whole slides.

### 5.4.4. Sequences Chosen

The volunteers followed a sequence in order to establish which assembly they did firstly and afterwards. They did a rotation. Rotation provides workers with a general vision and makes standard more straightforward. Moreover, it implies the need to learn how to do various tasks. This factor has a great influence on work planning [13].

In order to define the sequences we took into account different premises or conditions that can affect learning and forgetting results. The first one was that the three tasks had to be repeated the same number of times. The second condition was that we need some sequences to measure the maximum productivity while the others had to show the relation between tasks. Finally the third consisted in having the same number of sequences of each type (measuring maximum productivity and relation).

Furthermore, because of the necessity of volunteers' help, the investigation was limited in a considerable way. There were not a lot of people with free time for taking part in the experiment. Every volunteer did one sequence.

There were six kinds of sequences. Each of them was carried out by two students who did their assembly in an independent way. The set of they were the following:

- Ten repetitions of experiment A, ten of experiment B and ten of C.
- Ten repetitions of experiment B, ten of experiment C and ten of A.
- Ten repetitions of experiment C, ten of experiment A and ten of B.
- Three repetitions of experiment A, three of experiment B and like that five times.
- Three repetitions of experiment C, three of experiment A and like that five times.
- Three repetitions of experiment B, three of experiment C and like that five times.

To sum up, Table 5.2 shows all sequences:

**Table 5.2** Sequences

| | |
|---|---|
| Sequence 1a | AAAAAAAAAA/BBBBBBBBBB/CCCCCCCCCC |
| Sequence 1b | BBBBBBBBBB/CCCCCCCCC/AAAAAAAAAAA |
| Sequence 1c | CCCCCCCCC/AAAAAAAAAA/BBBBBBBBBBB |
| Sequence 2a | AAA/BBB/AAA/BBB/AAA/BBB/AAA/BBB/AAA/BBB |
| Sequence 2b | CCC/AAA/CCC/AAA/CCC/AAA/CCC/AAA/CCC/AAA |
| Sequence 2c | BBB/CCC/BBB/CCC/BBB/CCC/BBB/CCC/BBB/CCC |

As we can see in the previous table sequences 1a, 1b, 1c mainly corresponds to the type that studies the productivity. Yet, they also help to determinate the relation between tasks. On the other hand, sequences 2a, 2b, 2c mainly represents the relation between tasks.

### 5.4.5. Initial Hypothesis and Goals

In advanced, it was difficult to secure the result of the experiments but different hypothesis could be formulated. On the other hand, the goals of the experiment were clear.

In general, in the first phase of the experiment, we wanted to show how would be the behaviour of someone who would assembly this kind of tasks in the future and how could influence in that the similarities and differences between tasks. Furthermore, we modified the used model in order to take into account the relation between tasks and its influence.

Besides that, a possible hypothesis would be that if someone does repeatedly a task since one point, he/she doesn't reduce the elapsed time doing it anymore.
Another one was that if someone had previously done a similar task to the one he is going to do, he would have achieved the maximum productivity faster than another person who had done before a task completely different. The last one was that tasks A and B had to have more similarities than A with C or B with C due to the components used in them.

# CHAPTER 6. APPLICATION OF LEARNING AND FORGETTING MODELS

Learning and forgetting models are applied to the results the experiment exposed. By working in different tasks experience is acquired. As competencies are acquired, performance in the task will increase. When a new task has only a limited number of new competencies, the learning process is expected to be faster [17]. Then, time of learning is the time required to acquire competence and performance in the transition to a new level of knowledge. It depended on the sequence of tasks followed.

This section shows the applications of two learning and forgetting models, in order to determinate which one would fit better in this experiment. The model has to be able to predict the performance of someone who will do the experiment in the future and the behaviour of the same worker in other similar tasks.

To obtain the approximations and estimates for the parameters of the model and tasks studied, it was used the software called SPSS (*Statistical Product and Service Solutions*) that provides the tools needed for analysing both models, Wright and Nembhard's ones.

The use of SPSS is detailed in annex 4.

## 6.1. Model of Wright

The former model (6.1), as it is said in the theoretical section, is frequently used due to its simplicity.

$$\mathrm{T_n} = T_1 \cdot n^{\log_2 r} \qquad \textbf{(6.1)}$$

This formula does not take into account forgetting factor and for this reason it is not the most suitable for our experiment. Owing to the limited availability of the volunteers who did the assemblies, they couldn't do all the activity in a whole day. They needed almost two days in order to end it properly. This situation makes necessary the forgetting factor.

Section 1.1 shows an example of this model.

## 6.2. Model of Nembhard

Nembhard model is hyperbolic with three parameters that minimise the mean square error and the quadratic deviation of it. Furthermore, it considers two scenarios depending on whether the forgetting factor appears. Now all the equations are shown containing the results of the experiment.

It is important to stress that this model can be affected by factors such external as the absenteeism at work or the holidays, therefore, the atmosphere has to be analysed too. This is not our case.

The formula of Nembhard without forgetting (6.2) is not used in this experiment because of the necessity of this factor. For this reason, we do not pay attention to its values. The explanation of this formula appears in chapter 2.

$$
\begin{aligned}
& y_x = k \cdot \left( \frac{x+p}{x+p+r} \right) \\
& y, p, k, x \geq 0 \\
& p + r \, \phi \, 0
\end{aligned}
\qquad \textbf{(6.2)}
$$

Considering forgetting effect in the students, due to the intervals of time between different assemblies, the formula is the next one:

$$
\begin{aligned}
& y_x = k \cdot \left( \frac{xR_x^{\alpha} + p}{xR_x^{\alpha} + p + r} \right) + \varepsilon_x \\
& \alpha, y, p, k, x \geq 0 \\
& p + r \, \phi \, 0
\end{aligned}
\qquad \textbf{(6.3)}
$$

$$
R_x = \frac{\sum_{i=0}^{x} (t_i - t_o)}{x(t_x - t_o)} \qquad \textbf{(6.4)}
$$

Where *x* is the number of times that a task has been done, *k* represents the productivity that can reach the student. *P* and *r* can be interpreted as the previous experience and the one required in order achieving half of the productivity respectively. $\alpha$ represents the degree to which the individual forgets the task, $R_x$ the forgetting factor and finally, $(t_x - t_o)$ is the difference between the timestamp of the current unit and the first unit.

It was necessary to estimate various parameters to adapt the model to different students. The first one was $\alpha$ which is unknown and differs among the people. P is also an estimating factor like *r* and *k*. The rest of variables ($R_x$ and *x*) were previously defined. *X* was the number of tasks taken by the student and $R_x$ was obtained thanks to the formula 6.4.

$R_x$ is bounded below by 0 and above by 1. Values approaching 1 indicate that the experience was obtained just before the present unit. Values approaching 0 indicate that the experience was obtained in the past. $R_x$ tends to be 0.5 showing a constant productivity rate.

### 6.2.1. Individual Results

This sub-section gives an example of the model. There is a volunteer who followed the sequence 1B where he put up 10 times task B, 10 times task C and finally another 10 task A. This information is related to her/his assemblies of task A.

Fig 6.1 shows the interesting values in order to do the calculations needed to do the estimation. The column *Vegada* represents the number of units produced by the student. The second, *Serie*, shows what serie of experiments had been realized.*Temps_min_seg* and *Segons* are the elapsed time assembling the present unit. Finally, column *Dia* expresses when he did the assembly. The notation used indicates that reference 0 corresponds to the first day, when he/she had done the first *A* assembly, and another number was the amount of days since this first assembly.

In the example, number 9 in the column *Dia* indicates that the student continued with the set of assemblies nine days later than the beginning day.

| | Vegada | Serie | Temps_min_seg | Segons | Dia | Rx |
|---|---|---|---|---|---|---|
| 1 | 1 | 1B | 0:09:50 | 590.0000 | 0 | 1.000000 |
| 2 | 2 | 1B | 0:08:09 | 489.0000 | 0 | 1.000000 |
| 3 | 3 | 1B | 0:04:20 | 260.0000 | 0 | 1.000000 |
| 4 | 4 | 1B | 0:03:50 | 230.0000 | 0 | 1.000000 |
| 5 | 5 | 1B | 0:04:05 | 245.0000 | 0 | 1.000000 |
| 6 | 6 | 1B | 0:06:17 | 377.0000 | 0 | 1.000000 |
| 7 | 7 | 1B | 0:07:09 | 429.0000 | 9 | .1428571 |
| 8 | 8 | 1B | 0:04:47 | 287.0000 | 9 | .2500000 |
| 9 | 9 | 1B | 0:04:17 | 257.0000 | 9 | .3333333 |
| 10 | 10 | 1B | 0:03:50 | 230.0000 | 9 | .4000000 |

**Fig. 6.1** The necessary data of the student in order to do the non-linear regression.

The variables were defined from the panel *Vista de Variables,* accessible from the inferior thumb. All the data is needed to apply the forgetting formula and subsequently the non-linear regression of Nembhard's model in order to see whether the time value obtained is similar to the student's time.

Next screenshot (Fig. 6.2) shows the regression model applied with the necessary parameters and restrictions.

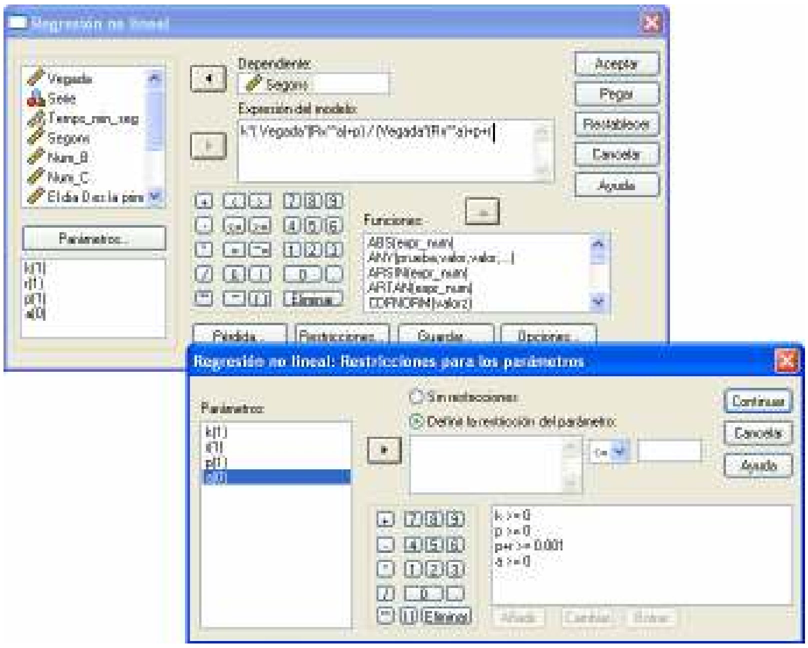



**Fig. 6.2** How to introduce Nembhard's model in SPSS and its restrictions

The following table (Table 6.1) shows the value of the parameters estimated by SPSS:

**Table 6.1** Estimation's Results

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low Limit | High Limit |
| k | 155.391 | 127.749 | -157.198 | 467.981 |
| p | 3.967 | 9.027 | -18.121 | 26.055 |
| r | -3.692 | 7.699 | -22.530 | 15.146 |
| a | .638 | .207 | .131 | 1.145 |

Lastly, all values (estimated or not) were substituted in the spreadsheet of Excel. Applying the model of Nembhard it is created one time for each assembly *x*. The time obtained for estimation was highly similar to the student's real time.

**Table 6.2** Comparison between real time and estimated time.

| Est. Time [Sec.] | Real Time [Sec.] |
|---|---|
| 605.143 | 590 |
| 407.493 | 489 |
| 330.527 | 260 |
| 289.565 | 230 |
| 264.131 | 245 |
| 246.803 | 377 |
| 404.895 | 429 |
| 315.622 | 287 |
| 276.366 | 257 |
| 253.450 | 230 |

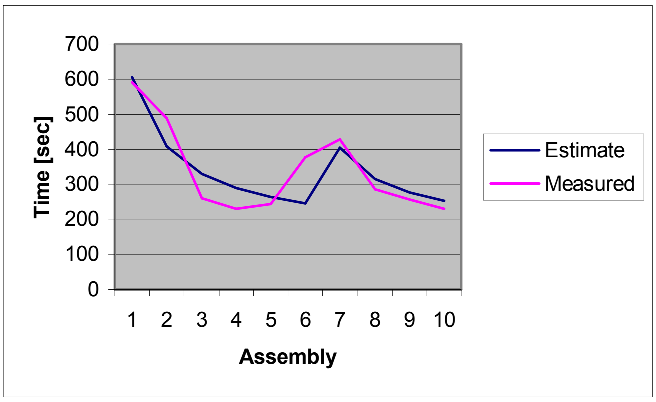



**Fig. 6.3** Curve of estimated and real values.

This process was independently repeated for each student. The results appear in the annex 3.

SPSS allows the use of scripts. It makes easier the task because it automatically creates the SPSS regressions. Furthermore, their generation is simple you only have to introduce the model and its restrictions as can be seen in Fig 6.2. After this press the button *Pegar.* The complete set of scripts used is in annex 5.

### 6.2.2. Results: Task A

In this subsection we estimated the approximate learning curve of someone who will do the assembly A in the future, thanks to the data of all the volunteers who did this assembly.
We followed the same steps as before. The only difference was the use of scripts. We used the script created for this assembly. In order to launch it, the steps are the following. Firstly, you have to open the file .sav where there were

the values (times and parameters as $R_x$). When you have opened it, you have to click on the file .spss and automatically the results of the regression will be shown on the screen.

Table 6.3 shows this values with a confidence interval of 95% where the typical error is quite limited although the higher and lower limits are a bit turned off.

**Table 6.3** Estimated parameters of task A

| Parameter | Estimation | Typical Error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| k | 129.754 | 28.540 | 73.227 | 186.282 |
| p | 4.846 | 2.528 | -.161 | 9.852 |
| r | -4.845 | 2.299 | -9.399 | -.291 |
| a | .501 | .087 | .329 | .674 |

After seeing the results we can assume that the time (*k*) was 129.754 sec. This is the expected time reached for a student when he/she has finished his/her learning process. The student tends to take this time after repeating the assembly more than 10 times. In this point volunteers could not reduce the time anymore because they were currently stabilised. Remember that *k* in our study tallies with the time that volunteer wasted assembling the task A. However, in the original Nembhard's model he uses the productivity, which is the inverse of the elapsed time making an assembly.

On the other hand, parameter *a*, which is the factor that shows how quickly the student forgets the task, was 0.501. This value means that, the task was easy to do but not remember how to do it with the passage of the time. Fig. 6.4 shows the previous explanation, it corresponds to the estimated behaviour of a student who will do the task A at least than 10 times. In order to get the image we substituted all the variables of the formula of Nembhard for their estimated value or the experiments data using an excel sheet. The image only represents the 10 first repetitions but as it has been said before the time tends to be stable (*k*).

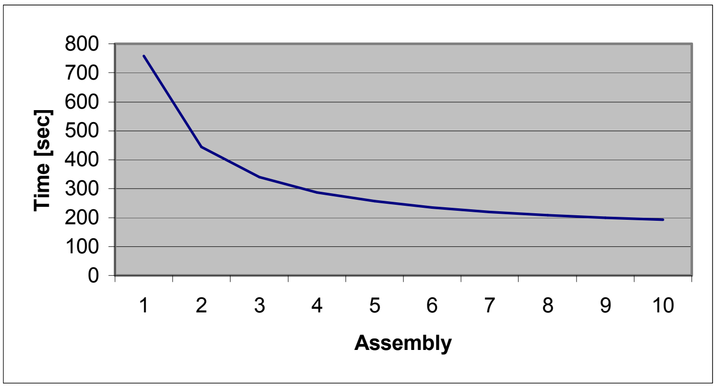



**Fig. 6.4** Approximate learning and forgetting curve of somebody who will do task A

### 6.2.3. Results: Task B

The method for estimating the parameters of task B was identical to A, including the script launched.

The elapsed time when the learning has finished was 197.853 sec. The factor that shows how quickly the student forgets a task (*a*) was very small 0.086. The complete values appear in Table 6.4.

Furthermore a graph showing the values estimated by the formula was done as in the previous subsection (Fig 6.5).

**Table 6.4** Estimated parameters of task B

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| K | 197.853 | 30.747 | 136.954 | 258.751 |
| P | 2.719 | 1.626 | -.501 | 5.940 |
| R | -2.718 | 1.321 | -5.335 | -.102 |
| A | .086 | .184 | -.277 | .450 |

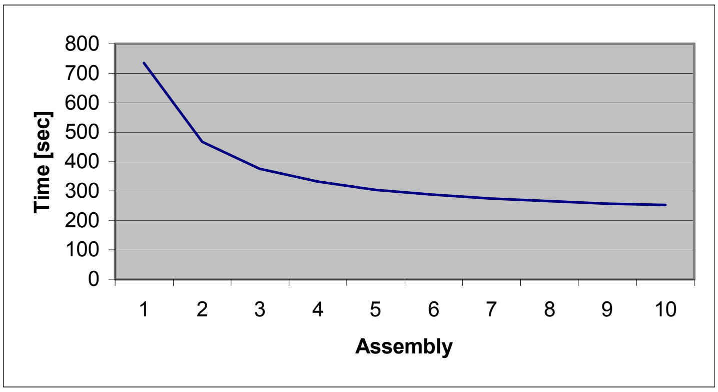



**Fig. 6.5** Approximate learning and forgetting curve of somebody who will do task B

### 6.2.4. Results: Task C

The calculation was like in previous sub-sections for this reason we only mention the results. The script used is the same too.

The elapsed time assembling task C, when you have reached the complete knowledge was 110.209 sec. When it had been done two or three time the task was easy and fast. The forgetting grade was about 0.582. For more details Table 6.5 contains all the results.

In the tenth repetition of the tasks, the stable level of productivity has not been achieved yet as we can see in Fig. 6.6.

**Table 6.5** Estimated parameters of task C

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| k | 110.209 | 42.912 | 25.217 | 195.201 |
| p | 6.039 | 4.860 | -3.588 | 15.666 |
| r | -6.038 | 4.537 | -15.023 | 2.947 |
| a | .582 | .113 | .359 | .805 |

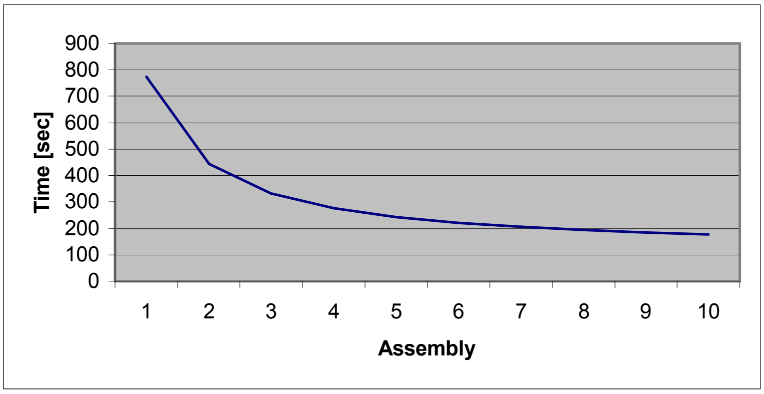



**Fig. 6.6** Approximate learning and forgetting curve of somebody who will do task C

### 6.2.5. Comparison between the results

Firstly, we should start showing all the results. In Table 6.6 there are the results of the estimated parameters.

**Table 6.6** Estimated values of all the tasks.

| Parameter | A | B | C |
|---|---|---|---|
| k | 129.754 | 197.853 | 110.209 |
| p | 4.846 | 2.719 | 6.039 |
| r | -4.845 | -2.718 | -6.038 |
| a | .501 | .086 | .582 |

With parameter k we can observe that the quickest task was C with an average of time 110.209 s. On the other hand, B corresponds to the longer assembly with 197.853 s. This is due to the fact that this experiment adds a high variety of material.

Concerning a, both A and C are easy to forget, probably because in them the volunteers had to remember the positioning of an specific electronic component. Otherwise, the most difficult assembly, letter B, is the easiest to remember once they had done it a series of times.

As Nembhard and Osothsilp discusses on an article [5] the effect of tasks with varying complexity over learning and forgetting. Firstly, they mention that tasks that require more attention, or that have more complications, are not easily forgettable. Moreover, they add that while complexity is low, productivity is high. If tasks complexity is high, the previous experience does not affect as if it was easy. Finally, they point out that complex tasks cause slow learning.

With the obtained results (Table 6.6) we have validated all these hypotheses. Remember that *a* ($\alpha$) represents the degree to which the individual forgets the task, *p* shows the previous experience, and productivity is the inverse of *k*.

## 6.3. New model: A variation of Nembhard's model

While doing the experiments we could see how the elapsed time of the students in order to do a task was motivated by the type of tasks that the volunteer had previously done, in case that he/she had any kind of experience.

To quantify and relate the previous experience and the kind of assembly done before the present one, we might modify Nembhard's model.

Our model only modifies the parameter p for $p_j$ that matches the student's previous experience for each of the three types of tasks: A, B and C.
$p_j$ represents the previous knowledge of each volunteer before doing the task $j$ in a concrete moment.

Therefore,

$$P = Num\_A \cdot a + Num\_B \cdot b + Num\_C \cdot c + e \qquad \textbf{(6.5)}$$

$$p_j = q_{j,0} + \sum_{j' \in K, j' \neq j} q_{j,j'} \cdot x_{j'} \qquad \textbf{(6.6)}$$

In the formula 6.5, *Num_X* is the number of times that the assembly X had been done (before the beginning of the present unit). A, b and c represents the influence of each kind of task in the current assembly. Finally, the *e* parameter shows the possible error due to the replacement of *p*, for external factors that are not considered in this project. It is highly important to take into account the sequence of the volunteer. In the case of someone who did the unit of type *N*, the value of *Num_N* and *N* has to be zero. If not, the influence of the previous assemblies would be considered twice.

Formula 6.6 represents the same. The variable $q_{j,0}$ is the value of the previous experience that the volunteers had due to factors not related with the tasks. On the other hand, $q_{j,j'}$ matches with the relation between the current task ($j$) and other which is associated to the preceding for a moment ($j'$). The number of $j'$'s assemblies is determined for $x_{j'}$.

Finally, taking into account preceding interpretations the modified formula is the following:

$$y_{x,j} = k\left(\frac{x_j + q_{j,0} + \sum_{j' \in K, j' \neq j} q_{j,j'} \cdot x_{j'}}{x_j + r + q_{j,0} + \sum_{j' \in K, j' \neq j} q_{j,j'} \cdot x_{j'}}\right)$$

$$y, k, p, x_j, x_{j'} \geq 0 \qquad \textbf{(6.7)}$$

$$p + r \succ 0$$

If the students hadn't previously done any assembly, his/her p value would be 0 as well.

In next sub sections, following the same steps as before, the modified Nembhard's formula is applied for all the students according to the assembly that they did, as in the section before. Annex 2 shows the set of scripts used for these estimations. Now, there are three types of scripts depending on the assembly.

### 6.3.1. Results: Task A

In this case the parameters for estimating are the following six: *k, al, b, c, r* and *e*. *K* as in the original Nembhard's model is the time per unit awaited in the end of the learning and in this case it was 114.636 sec. *Al*, the degree of forgetting the task was the same as in the original model 0,548.

*B* and *c* shows the importance of having done the assemblies B or C respectively and its results are 0.110 and 0.010.

The value of *c* is lower than the value of *b*. This situation is due to the fact that task B is extremely similar to A but adding difficulties, for this reason, B affects more in the assembly of A. On the other hand, C only shares the similarity of laboratory instruments with A. Although the number of people studied is not very high, these hypotheses are being confirmed.

Table 6.7 shows all the values. After having estimated the parameter we have calculated all the values in an excel sheet using the modified formula, taking into account the data of the experiment and the estimated results. The representation is Fig 6.7.

**Table 6.7** Estimated parameters of task A adding new parameters

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| k | 114.636 | 24.604 | 65.896 | 163.376 |
| b | .110 | .034 | .042 | .177 |
| c | .010 | .011 | -.011 | .032 |
| e | 6.456 | 2.832 | .845 | 12.067 |
| r | -6.456 | 2.653 | -11.713 | -1.200 |
| al | .548 | .073 | .403 | .694 |

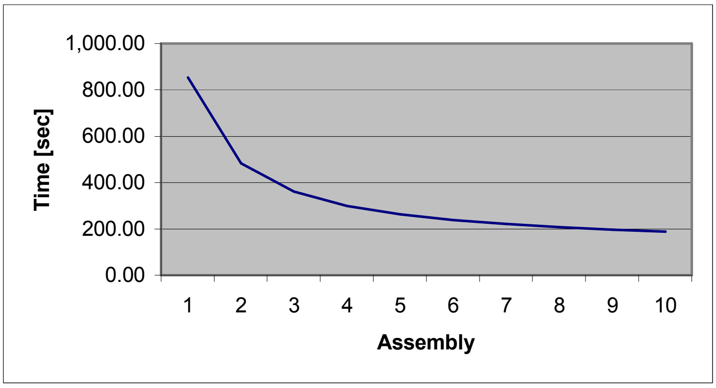



**Fig. 6.7** Approximate learning and forgetting curve of somebody who will do task A (with additional parameters)

### 6.3.2. Results: Task B

In order to do the corresponding calculations, the previous process has been repeated. This time we evaluate the influence of C and A in the assembly of B.

The minimum estimated time for doing a *k* unit is 167.014 seg. As you can see this is the highest value of the three tasks because the complexity of the task. It is higher than the difficulty in A or B.

Having done the regressions we have observed the parameter of forgetting which is 0.287. The repercussion of A is 0.241 because the grade of similarity between both assemblies is very high. However, the repercussion of C is 0 because this task does not affect in B. It is extremely different.

All the estimated results appear at Table 6.8. The graph (Fig. 6.8) shows the 10 first assemblies and we can observe how the curve comes close to the *k* value.

**Table 6.8** Estimated parameters of task B adding new parameters

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| k | 167.014 | 26.518 | 114.482 | 219.546 |
| a | .241 | .061 | .120 | .361 |
| c | .000 | .083 | -.164 | .164 |
| e | 4.949 | 2.079 | .832 | 9.067 |
| r | -4.949 | 1.866 | -8.645 | -1.253 |
| al | .287 | .113 | .062 | .511 |

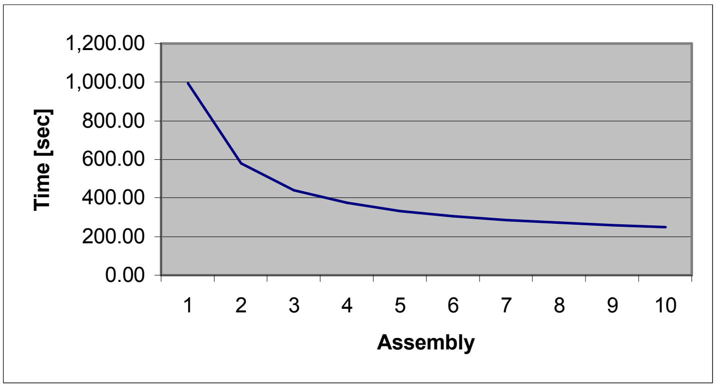



**Fig 6.8** Approximate learning and forgetting curve of somebody who will do task B (with additional parameters)

### 6.3.3. Results: Task C

To finish this section we have done the same calculations like preceding sub-sections in order to verify how the modification of Nembhard's model works properly.

Task C, as we said previously, only has in common with the other two assemblies the laboratory's instrumentation used. If we analyse the results of the parameters after having done the regression of all volunteers we can notice that A has no repercussion in C while B has a 0.138, probably due to its difficulty. This is because if you have previously done task B, when you do C you are used to the difficulties of the assemblies and the material needed. Otherwise if we do C before B it is not the same because, as B is more complete, C is not enough complicated for acquiring any kind of experience.

With regard to the final estimated time when the learning process is finished the value is 73.341 sec. As we can see, this number is lower than the previous tasks because this assembly is quick when the task has been done one or two times.

The forgetting factor is 0.631. This number is due to the difficulty of adding one electric component to the assembly. You have to remember the correct position.

All this values and the limitations and errors are shown in the Table 6.9. Fig 6.9, for his part, shows the tendency of the curve towards the maximum productivity level.

**Table 6.9** Estimated parameters of task C adding new parameters

| Parameter | Estimation | Typical error | Interval of confidence of 95% | |
|---|---|---|---|---|
| | | | Low limit | High limit |
| k | 73.341 | 40.153 | -6.202 | 152.884 |
| a | .000 | .054 | -.107 | .107 |
| b | .138 | .043 | .053 | .223 |
| e | 13.702 | 11.473 | -9.026 | 36.430 |
| r | -13.620 | 11.193 | -35.793 | 8.554 |
| al | .613 | .116 | .382 | .843 |

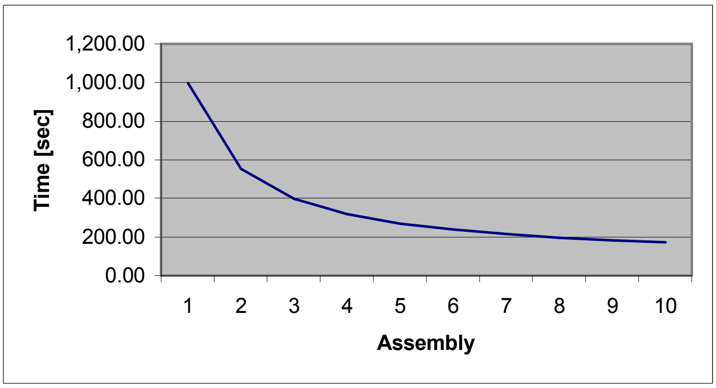



**Fig. 6.9** Approximate learning and forgetting curve of somebody who will do task C (with additional parameters)

### 6.3.4. Comparison between the results of Nembhard original

This section sums up the results obtained. Table 6.10 shows the values of all the estimated parameters. The relation of each task with itself was not taken into account because it is cause by the number of assemblies.

**Table 6.10** Estimated parameters of tasks

| Parameter | A | B | C |
|---|---|---|---|
| K | 114.636 | 167.014 | 73.341 |
| A | - | .241 | .000 |
| B | .110 | - | .138 |
| C | .010 | .000 | - |
| E | 6.456 | 4.949 | 13.702 |
| R | -6.456 | -4.949 | -13.620 |
| Al | .548 | .287 | .613 |

As in the results of original Nembhard's model the elapsed time to do the task B is the highest and the elapsed time of C is the lowest. All the times are lower than the ones obtained in the original model. This is due to the fact that we take into account the experience in other tasks.

New estimated parameters are *a, b* and *c*. We can see how the task A and B are highly related between them. The values are 0.110 i 0.241 respectively. On the other hand the relation between C and A is 0 and between C and B is 0.138. It is because task C has few characteristics in common with A and B.

These new parameters have modified the values of $\alpha$. Currently the value of $\alpha$ in the task B (the longest) has increased considerably but it is still the easiest task to remember.

As we can see in this last sub-section, the objectives are achieved and through these modifications the relation between the different tasks has been quantified. We see how the model fits well to the data obtained from the experiment. The parameters representing the influence of the experience on the task to the performance of another were basically the expected ones.

All these values will be used to do a task of planning in future.

# CHAPTER 7. FUTURE RESEARCH

The activity of planning tasks taking into account learning and forgetting is currently being developed. For this reason, our project has not still finished.

Although we have done an extensive work, there are points which are not considered because of the lack of time. This means that, there are possible extensions for this project.

The aim of this chapter is to detail all the aspects that can be taken into account in the future. With all this information another researcher or institutions who are interested in this project, can continue working, developing it.

Firstly, we have to point out that despite we all students did a CPS test in order to get their features, these data had not been included as a material of study. In business sector can be useful to do a planning taking into account these factors. They can be related to the volunteers' output doing the task. Other applications would be add the factors to the Nembhard's learning and forgetting model as we did with the influence of another tasks. According to another researches when the difficulty doing the task increases the productivity decreases. Moreover slow tasks are associated with slow learning. In annex 2 shows all the individual results of the test.

Secondly, is important to mention that we designed seven different tasks at the beginning of the experiment (we can consult them in the annex 1). Due to the lack of time and the number of volunteers we chose only three of them. This section wants to explain the relation between them for helping someone who wants to carry out another sequence. The tasks are divided in three types. The first one take in the ones related to Resistor circuits (tasks 0 and 1). The second refers to Operational Amplifier (tasks from 2 to 5) and finally the last are about Transistors (tasks 6 and 7). Resistors circuits are easy. They consist in placing resistors in a protoboard. Task 0 is easier than 1 because of the material used. Concerning the ones about operational amplifiers there are different types. Task 2 and 3 has a medium difficulty (you have to consider a range of things about the amplifier). Their similarity is high. The last ones are more difficult than previous tasks but there are also similar between them. Finally, there is the type of circuits about transistors. Their difficulty appears at the beginning because it is difficult to insert the transistor in the right position. Given this information there are multiple possible combinations between them. It is important to previously evaluate in each case which is the goal of the experiment.

Thirdly, despite we have estimated, thanks to Nembhard model, the relation between tasks. These relations have not been evaluated due to the lack of time. This data allows an accurate planning task. Table 7.1 shows the relation between tasks. As we have said before, task A and B are more related between them than C.

**Table 7.1** Relation between tasks

| Parameter | A | B | C |
|---|---|---|---|
| k | 114.636 | 167.014 | 73.341 |
| a | - | .241 | .000 |
| b | .110 | - | .138 |
| c | .010 | .000 | - |
| e | 6.456 | 4.949 | 13.702 |
| r | -6.456 | -4.949 | -13.620 |
| al | .548 | .287 | .613 |

As we can see the relation between a task and itself has not been taken into account. The value would be considered 1 (they are from 0 to 1). Following this rule you have to substitute the variable $\alpha_{k,k'_i}$ for the previous values. It is advisable to group together the tasks of the same type. Each tasks i belongs to a different type of task k.

Another aspect to consider in future researches is the variable performance. In the example of planning tasks done with new model (Chapter 4), the assigned output is constant and its value is 0.1. This means that each assembly done retains a 10 per cent.

As we know, the learning of a person who does a manual task increases following a logarithmic behaviour. It is defined in curves of learning and forgetting. In order to add this characteristic to the new model, this learning function has to be linearizated. In our case it is the function of Nembhard. Solving it, the use of vectors or groups of data is needed. They contain the different levels of learning depending on the assembly. The number of vectors is the same as the number of tasks.

Finally, we have to confirm that new model works properly solving a complex planning task. It has to take into account different kinds of tasks with variable output, that is, it consists in apply all the improvements commented before. This fact will improve the functionalities of the software. It is advisable to continue developing software’s version because this is an useful tool and with few modifications it will be a powerful software.

# CHAPTER 8. CONCLUSION

In this chapter we are going to show the main conclusions obtained after the development of the project. They have been divided in two parts: conclusions about curves of learning and forgetting and conclusions about the planning task.

Concerning the first type, Nembhard's learning and forgetting model, without modifications, shows that task B is the longest whereas C is the quickest. On the other hand, it has been proved that the more complex tasks are better remembered than the easy ones, which are quickly forgotten. We have also observed that while complexity is low, productivity is high. Moreover, if tasks complexity is high (task B), the previous experience does not affect as if it was easy (task C). Finally, studied complex tasks cause slow learning.

Thanks to the modification of the Nembhard model, we have taken into account the experience in other tasks into the task whom performance we are predicting. We obtained a numeric value of it. The obtained results followed the previous hypotheses. For example, we have determined that A have more influence over B than over C, while B has more influence over C than over A. The results have confirmed the validity of the model.

The main conclusion about the new model of planning proposed by Albert Coromines is that the model is proved to be solvable and to provide correct solutions for an example. Although in the example we did not apply the minimum knowledge of each task for every worker, we did it in the solution of subsequently planning problems.

In relation to the whole research project from which this work is part, we conclude that these partial results are favourable. The new research proposed in section 7 will be necessary for further conclusions.

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