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LOGISTICAL STUDY OF PHOTONICS PRACTICES

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1 INTRODUCTION

1.1 SUMMARY

The following master's thesis consists of the development of a discrete event model implemented with Arena software to describe the operations that students must carry out during the practical sessions of a university subject. The introduction of video tutorials improved students' autonomy, which significantly reduced waiting times when they needed to ask the teacher questions. This discrete event model describes this improvement logistically. It also studies the influence of the main variables of the system through a statistical analysis. This has made it a useful predictive tool for implementing future improvements.

1.2 PRESENTATION

This study is focused on the subject “Photonics. Optics Applied to Engineering” which is provided by the ESEIAAT in the Degrees of Engineering. The required resources to carry out the practice sessions are limited, disallowing students to perform the same practice in the same session. Its practical sessions take place once a week for 5 consecutive weeks. There is also the possibility of a sixth session to complete the activities that some teams were unable to complete due to lack of time.

Therefore, students are divided into 5 groups and each group performs a different practice. Often students cannot complete activities during the two-hour class. For this reason, during the spring of 2017 I carried out a final degree project consisting of the development of video tutorials that explained the procedure that students must follow to successfully complete these practices. This digital resource significantly reduced the queue generated to attend to the students, thus reducing the teacher's stress level.

1.3 AIM OF THE MASTER’S THESIS

The purpose of this master's thesis is to achieve three objectives. The first one is to develop a discrete event model with Arena software to describe the logistic performance of 5 photonics practices. The second one is to validate this model. For this purpose, the results obtained from simulations are compared with real data obtained through personal observations of photonics practices. In this sense, the model is used to simulate the management of practices when students do not have video tutorials and then simulated with this digital resource. The results are compared with the real observed data and allow

validating the correct functioning of the model. It is precisely at this point that the model becomes a useful analysis tool that allows linking with the third objective of this work. This consists of determining which input variables have a greater logistic effect on the development of the practices. It also seeks to quantify the relationship between input and output variables through a risk analysis, which is subdivided into a sensitivity study, an uncertainty study, and a significance study. It will then be when the model acquires a predictive character.

1.4 SCOPE OF THE MASTER'S THESIS

This work links with my final degree project developed in 2017, in which I proposed to improve the autonomy of the students with the edition of 47 tutorial videos explaining the procedure to perform each of the practices. Since the problem is already solved, this master's final work should corroborate this improvement by means of discrete event simulations. In this sense, it is important to emphasize that the model, in the first place, will only justify the incorporation of the videos to improve the management of the aforementioned practices.

Secondly, it will seek to be more efficient by optimizing existing resources. That is to say, to reduce student waiting times and teacher assistance time, to increase the percentage of practices carried out, as well as to study the appropriate duration of the sessions or the most appropriate way for the teams to work.

Thirdly and finally, a post-optimization scenario is proposed, which consists of determining the most appropriate way to improve the practices. The aim is to identify the key aspects with the greatest impact. In this regard, the following questions could be answered:

- Is more space needed in the laboratory?
- Should more videos be edited?
- Should more teachers be hired?
- Should the duration of working sessions in the laboratory be lengthened?
- Should some activities be eliminated?
- Should students receive more training to improve their English?

1.5 SPECIFICATIONS OF THE MASTER'S THESIS

First, I will describe the physical space where the practices are developed and then the relevant logistical aspects that must be considered to implement a discrete event model that resembles what happens in reality.

The physics laboratory where the photonics practices are developed is a shared resource, which means that some workbenches are used to perform general physics practices and those that are free are used for photonics practices.

The first image shows the areas of the laboratory set up for photonics practices and the second specifies which workbench is used for each of the five practices. Finally, the third drawing shows the places where eye protection devices must be used.

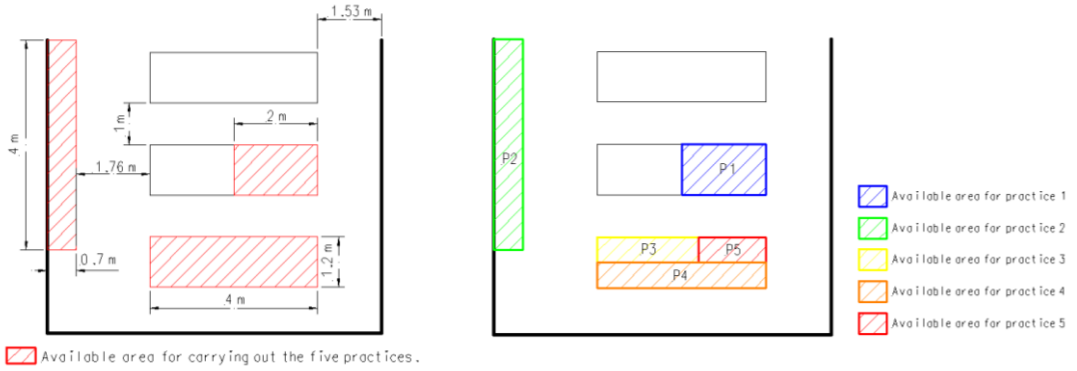


Illustration 1: drawings of the photonics laboratory

Considering on the one hand the safety measures to be respected to avoid eye damage by the laser light and on the other hand the available surface in the laboratory, the maximum number of students is 20, which must be grouped in teams of 4 people maximum.

The Arena model must also consider these other specifications:

- The duration of each practice session.
- The attendance level of the students in class.
- The students' level of English.
- The visualization of the tutorial videos explaining the procedure to be followed in each practice.
- The way of working, which describes whether or not the teams subdivide the tasks of the same practice.
- The number of practices completed.
- The time used by the teacher to assist their students.
- The time the students had to wait for the teacher's assistance.

The validation of the model will be correct if it can reflect basic aspects of operation, such as, for example, that the higher the number of students attending, the more practices must

be completed, or the decrease in student queues thanks to the use of video tutorials that facilitate autonomous learning.

In this sense, the following conditions must be considered in order to carry out the simulations with the model:

- The level of class attendance is between 95% and 100%.
- The percentage of times in which a team is left empty is less than 10%.
- Teams have a high tendency to subdivide into two subgroups to perform tasks of the same practice.
- Between 5% and 25% of the students have an advanced English level.
- Most of the students can easily access the videos.
- The percentage of completed practices after the end of the first five weeks should be around 70% if the learners have access to the videos and the queuing time should be incredibly low.

Finally, for the sensitivity and uncertainty analyses, Monte Carlo simulations with more than 10000 different input vectors should be performed. The input variables will respond to uniform distributions with a range between 0 and 100 and will be randomly paired. This should make it easier to determine the correlation between input and output variables (sensitivity analysis). In addition, it should also make it possible to obtain the histograms or probability density functions of the output variables (uncertainty analysis).

1.6 JUSTIFICATION OF THE USEFULNESS OF THE MASTER'S THESIS

In an educational context where the use of new technologies and English are becoming increasingly important as complements to the physical and human resources already available, this study will make it possible to statistically specify the influence of these variables on the quality of a learning process. It will also make it possible to determine other logistical factors such as the appropriate duration of the work sessions or whether extra sessions are needed to ensure the completion of all activities or even whether it is necessary to hire more teachers to attend to the students.

2 DEVELOPMENT

The method followed for the creation of the discrete event model has been adjusted to the Pareto and GIGO criteria. First, the Pareto criterion establishes that about 80% of the model's responses must be explained by 20% of the input variables. Secondly, the GIGO

(Garbage In, Garbage Out) criterion determines that the model must be accurate in order to obtain results adjusted to reality.

The creation of the model initially starts from personal observations made during my attendance to the photonics practices conducted in May 2018. First, the English level of the students was measured through a digital questionnaire. Subsequently, during the six weeks of duration of these practices, I was collecting information regarding the students' attendance level, their most frequently asked questions, their way of working in teams, whether or not they had access to the tutorial videos through their laptops or cell phones, the queue generated to request assistance from the teacher and the number of completed practices. This information has been key to obtain the PERT diagrams of the five practices, which have served as a structure to develop the model with the Arena software and subsequently validate it.

2.1 STATE OF THE ART

In the field of education, there are two clear precedents related to the improvement of the learning process through video tutorials. The first is the case of Professor Shapiro's videos on fluid mechanics developed in the 1960s. These facilitated the understanding of the procedures to be followed by the students to perform the practices of this subject.

More recently we have the case of Professor Salman Khan, who has described in detail the advantages of using videos in a learning process.

2.2 APPROACH TO DIFFERENT SOLUTIONS

There are many computer tools that allow the creation of discrete event models. The following table obtained from Wikipedia shows the most important ones.

Software	Publisher	Description	Last Updated
AnyLogic	The AnyLogic Company	A general purpose multimethod modeling tool.	August 13, 2020[1]
Arena (software)	Rockwell Automation	A discrete event simulation program that also allows modeling of continuous processes.	August 28, 2019[2]
Care pathway simulator	SAASoft Ltd.	A discrete event simulation program specifically designed for service industries e.g. healthcare.	Unknown
Enterprise Dynamics	INCONTROL Simulation Solutions	A simulation software platform to model and analyze virtually any manufacturing, material handling and logistics challenge.	July 18, 2018[3]
ExtendSim	Imagine That Inc.	A general purpose simulation software package.	September 6, 2019[4]
DELMIA	Dassault Systemes	Part of the 3DEXPERIENCE platform of Dassault Systemes	June 7, 2019[5]
FlexSim	FlexSim Software Products, Inc.	A discrete event simulation software with a drag-and-drop interface for modeling simulations in 3D.	January 27, 2019[6]
GoldSim	GoldSim Technology Group LLC	Combines system dynamics with aspects of discrete event simulation, embedded in a Monte Carlo framework.	September 21, 2015[7]
GPSS	Various	A discrete event simulation language. Different implementations are available through vendors.	Various
Micro Saint Sharp	Alion Science	A general purpose discrete event modeling tool that uses a drag and drop interface and the C# programming language.	May 20, 2019[8]
MS4 Modeling Environment	RTSync Corporation	A general purpose DEVS methodology based software environment for discrete event and hybrid models.	July 23, 2015[9]
Plant Simulation	Siemens PLM Software	Software that enables the simulation and optimization of production systems and processes.	May 3, 2019[10]
Simcad Pro	CreateASoft, Inc	Discrete event simulation software. On-The-Fly model changes while the simulation is running. Visual interface with no coding environment. Includes VR and Physics engine.	August 11, 2016[11]
SimEvents	MathWorks	Adds discrete event simulation to the MATLAB/Simulink environment.	September 14, 2016[12]
SIMUL8	SIMUL8 Corporation	Object-based simulation software	January 22, 2019[13]
VisualSim	Mirabilis Design Inc.	Model-based system architecture exploration of electronics, embedded software and semiconductors based on timing, power consumption and functionality	June 11, 2017
WITNESS	Lanner Group Ltd.	Discrete event simulation with VR available on desktop and cloud	July 7, 2017

Illustration 2: Table with different software tools to simulate discrete events. Source: Wikipedia.

Arena is a powerful modeling and simulation software developed by Rockwell Automation (https://www.arenasimulation.com). The choice of this software has to do with the fact of having descriptive graphs of the different tools, as well as enabling access to global variables and attributes for programming routines and functions. Although it does not have the best animation tools, I have chosen Arena because it was the software studied in the Process Automation course taught in this master's degree in management engineering.

In relation to the validation of the model, the direct observation of the photonics practices has been decisive to corroborate the results of the simulations. It must be considered that simulation tools allow us to represent problems, but reality is usually complex and therefore artificial models only serve to obtain an approximation. Its quality will depend on the accuracy of the initial data.

Finally, to carry out the risk analysis, different computer tools such as SPSS, mathematics or Matlab are available. I selected Excel because it has a package of statistical tools that allowed me to perform correlation analysis and to obtain histograms in a simple way.

Therefore, the selected solution is the following: the development of the discrete event model will be carried out with the Arena software, which will be structured with the information provided by the PERT diagrams and the real data obtained from the photonics laboratory, which will also help to validate the model. Finally, the results will be statistically analyzed with Excel.

2.3 INFORMATION TO MAKE THE MODEL

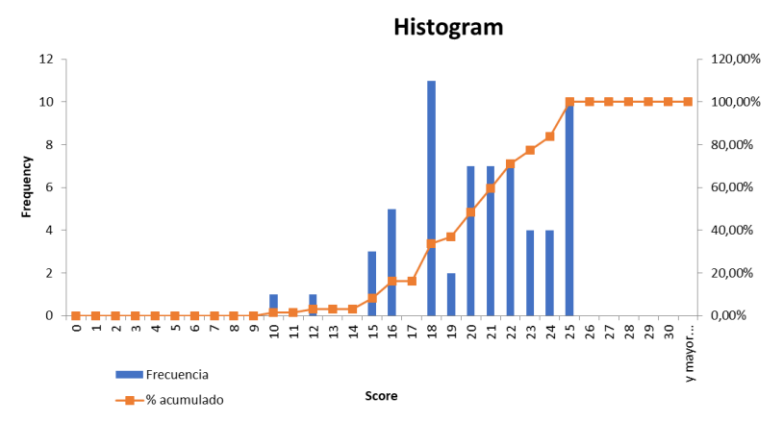
2.3.1 ASSESSMENT OF THE ENGLISH LEVEL

The teaching material used in this subject is written entirely in English, therefore, in the Arena model those students with an advanced level in this language will be able to work faster.

In May 2018 I conducted a questionnaire of 30 multiple-choice questions to assess the students' knowledge of English. The questionnaire has as reference an English level test developed by the Vaughan Group company and some questions were adapted to the working environment of a photonics laboratory.

The evaluation scale follows the following criteria: high level is achieved by getting between 25 and 30 questions right, intermediate level between 15 and 24 and low level between 0 and 14.

The following graph shows the histogram of the questionnaire scores and the table next to it describes the statistical values of this variable.



Score	
Media	20,3548387
Error típico	0,44299398
Mediana	21
Moda	18
Desviación estándar	3,48813809
Varianza de la muestra	12,1671074
Curtosis	0,09551552
Coeficiente de asimetría	-0,5639294
Rango	15
Mínimo	10
Máximo	25
Suma	1262
Cuenta	62
Nivel de confianza(95,0%)	0,88582121

Illustration 3: Histogram of English language test scores

According to this statistical study, for the modeling of the advanced level of English, it will be considered that about 20% of the students demonstrate this level.

The 30 questions of this test are shown below.

1. Which sentence is grammatically correct in relation to this image?

   a) It is a red laser beam.
   b) Is a red laser beam.
   c) It's a laser beam red.

2. Which sentence is grammatically correct in relation to this image?

   a) The one here is an Abbe Refractometer.
   b) That what is here is an Abbe Refractometer.
   c) The one that's here is the Abbe Refractometer.

3. One student says that it is 13.2 mm in diameter and his teacher replies:

   a) You're right.
   b) You have right.
   c) You're wrong.

4. Which sentence is grammatically correct?

   a) You listen to your teacher if you want to pass this subject.
   b) Listen to your teacher if you want to pass this subject.
   c) Listen your teacher if you want to pass this subject.

5. Which question is grammatically correct?

   a) Where is the laser beam coming from?
   b) From where is the laser beam coming?
   c) Where is the laser beam coming of?

6. Which sentence is grammatically correct?

   a) Students normally plan to write a report after leaving the laboratory.
   b) Students normally plan to write a report later leaving the laboratory.
   c) Students normally think to write a report after leaving the laboratory.

7. One student is measuring this piece of glass and says that it is 3.05 mm thick. His classmate replies...

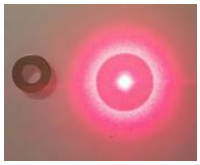
   a) I think so.
   b) I think yes.
   c) I believe that yes.

8. Which sentence is grammatically correct?

   a) I feel bad when I find out that my results are incorrect.
   b) I feel me bad when I find out that my results are incorrect.
   c) I feel badly when I find out that my results are incorrect.

9. Given that the metal piece is called a washer, which sentence is grammatically correct in relation to this image?

a) The washer's diameter is not as long like the red one.
b) The washer's diameter is not so long as the red one.
c) The washer's diameter is not as long as the red one.



10. Which sentence is grammatically correct?

a) Have care with the laser beam.
b) Be careful with the laser beam.
c) Take care with the laser beam.

11. Which sentence is grammatically correct?

a) Measuring the refractive index variation takes more than one hour.
b) Measuring the refractive index variation lasts more than an hour.
c) Students take more than one hour to measure the refractive index variation.

12. Which question is grammatically correct?

a) What was the teacher doing when you talked to him?
b) What was the teacher doing when did you speak to him?
c) What was the teacher doing when did you speak to him?

13. Which sentence is grammatically correct?

a) You'll never return to study photonics.
b) You won't return to study photonics.
c) You'll never study photonics again.

14. Which sentence is grammatically correct?

a) I don't know why the teacher wants me to do it.
b) I don't know why does the teacher want me to do it.
c) I don't know why the teacher wants that I do it.

15. Which question is grammatically correct if you are holding a pen?

a) Whose is this pen?
b) Whose pen is that?
c) Whose that pen is?

16. The lesson is over, and the teacher says to their students...

a) I'll see you this Tuesday coming.
b) We'll see us this Tuesday coming.

c) We see each other Tuesday coming.

17. Which question is grammatically correct?

a) Why didn't our teacher say us anything?
b) Why didn't our teacher tell us anything?
c) Why didn't our teacher tell to us anything?

18. Which question is grammatically correct?

a) Who came with you during the last practice session?
b) Who did you come with during the last practice session?
c) Who did come with you during the last practice session?

19. Which sentence is grammatically correct? Marca solo un óvalo.

a) Let me make you a question.
b) Let me ask you a question.
c) Let me to ask you a question.

20. Which sentence is grammatically correct?

a) There are no longer practice sessions, are there?
b) There is no longer practice sessions, is there?
c) There aren't practice sessions anymore, aren't there?

21. Which sentence is grammatically correct?

a) The teacher is waiting for the student to hand his report in a week.
b) The teacher's been waiting for the student to hand his report in for a week.
c) The teacher's been a week waiting for the student to hand his report in.

22. In connection with this picture, which sentence is grammatically correct?Marca solo un óvalo.

a) The more you move, the more blurred the picture of the curve will be.
b) How much more you move, how much more blurred the picture of the curve will be.
c) How more you move, more blurred the picture of the curve will be.

23. Which sentence is grammatically correct?

a) I would do it if you explain how to me.
b) I would do it if you explained me how.

c) I would do it if you explained to me how.

24. If 37 students have enrolled in this subject and all of them are attending the first class, the teacher can say...

a) There are 38 of us.
b) We are 38.
c) We have 38.

25. Which sentence is grammatically correct?

a) I haven't studied physics in a long time.
b) It's been a long time since I don't study physics.
c) It makes a long time that I don't study physics.

26. Which sentence is grammatically correct?

a) I'd have finished all laboratory activities in time if I have studied the instructions.
b) I would have finished all laboratory activities in time if I had studied the instructions.
c) I would've finished all laboratory activities in time if I would have studied the instructions.

27. Which sentence is grammatically correct?

a) You should've read the instructions before coming to the laboratory.
b) You should've read the instructions before you came to the laboratory.
c) You should've read the instructions before you come.

28. Which sentence is grammatically correct?

a) If he won still more money, he would spend all of it.
b) If he made even more money, he would spend all of it.
c) If he would make still more money, he'd spend it all.

29. Which sentence is grammatically correct?

a) Why should I have to spill some water on the desk during last practice session?
b) Why I should have spilt some water on the desk during last practice session?
c) Why should I have spilt some water on the desk during last practice session?

30. Which sentence is grammatically correct?

a) If you don't know how to make it, ask your teacher it.
b) If you don't know do it, ask your teacher about it.
c) If you don't know how to do it, ask your teacher.

2.3.2 VIDEO TUTORIALS

Students have at their disposal a total of 47 videos where the procedures of each practice are explained in detail. They can access them through the digital educational platform Moodle or also through YouTube.

The use of this digital resource considerably improves the autonomy of the students, thus reducing the time required to perform the practices, as well as the time spent waiting for help from the teacher. In many cases, during the observation of the practices in the laboratory, many students worked autonomously without the need to be assisted by the teacher.

In the following table I show links to five of these videos.

PRACTICE 1	This video explains how to measure the concentration of alcohol in water using a laser beam. **https://youtu.be/df0Y6-f53hA**
PRACTICE 2	This video explains a compound microscope. **https://youtu.be/f49DwyLhm4o**
PRACTICE 3	This video explains how to measure the reflectance and transmitance of a piece of glass. **https://youtu.be/7JnT6h9_vEw**
PRACTICE 4	This video explains how to measure a small thickness by means of a interference pattern created with two glass plates. **https://youtu.be/TGsqDlXrgmQ**
PRACTICE 5	This video explains how to measure the wavelength of the lines in the spectra produced by Mercury. **https://youtu.be/HI3prJNIdQw**

Illustration 4: table with some video tutorials.

2.3.3 WORKING MODE

While some teams remain cohesive and perform all the activities of each practice together, others tended to split into subgroups to perform different tasks. This way of working based on work specialization was different depending on whether the team consisted of two, three or four people. Groups of four had the greatest tendency to subdivide and groups of two had the least one.

In the Arena model this fact has been considered and the first four practices have been modeled in two halves. In the case of the fifth practice such a division was not possible because students needed to use the same instrument for the entire session. The variable ***way_of_working*** graduates this tendency to subdivide. For example, a value of 100 in this variable will indicate that all teams will subdivide while a value of 0 will determine that all teams will remain together. In the case of a more in-depth study, the model also allows different percentages to be assigned depending on the number of team members. Thus, for example, if necessary, it could be determined that groups of 2 people have a 10% probability of subdividing, groups of 3 people a 20% probability and groups of 4 people a 40% probability of subdividing.

Suppose that a team of 4 people wants to perform practice 1 without subdividing. In such a case the entity modeling the team will go through process 1A and then 1B. 1A being the first half of all the activities that make up practice 1 and 1B being the other half. The measurement of the time taken to complete the practice will begin at the time the group enters process 1A and end when they exit process 1B. If, for example, this team has reconsidered its way of working and wants to subdivide itself to be more efficient in the next practice, then the model allows for two subgroups to be created. In such circumstances, one subgroup would start in process 1A and the other in process 1B. The time the entire team has spent on the practice will correspond to the time of the subgroup that has taken the longest to complete its part. Prior to the start of each practice session, the Arena model allows you to determine the probabilities that each team will or will not subdivide.

2.3.4 CLASS ATTENDANCE

Under normal conditions, students' attendance was very high, between 95 and 100%. This was taken into account in the Arena model through the attendance variable.

On the other hand, it was also possible that some teams were not completed for reasons related to a low number of students enrolled. In this sense, the Arena model assigns the following probabilities: there are 5 teams in 83.5% of the cases, 4 teams in 8%, 3 teams in 2%, 2 teams in 1.5% and just one team in only 0.05%.

2.4 MODELING OF THE FIVE PRACTICES

2.4.1 GENERAL ASPECTS

The first four practices have been divided into two parts and the fifth remains whole in the model developed. Therefore, a total of 9 processes have been created representing all halves of the first four practices (identified with these characters 1A, 1B, 2A, 2B, 3A, 3B, 4A and 4B) and practice 5.

The time required by the learners to complete each process has been modeled according to a normal distribution with a mean value and standard deviation that depend on their level of English and whether they have access to the videos. The following table shows an example of the assigned times. The first numerical value in parentheses corresponds to the mean value and the second to its standard deviation (both expressed in minutes).

	No access to videos	Access to videos
Intermediate level of English	NORM(130,33)	NORM(110,28)
Advanced level of English	NORM(120,30)	NORM(100,25)

Illustration 5: Table with an:example of time allocation according to the level of English and access to videos

Next, it is important to keep in mind that students can work individually or in groups of 2, 3 or 4, which will determine the allocation of time to complete the activities. The criterion followed is as follows: the English attribute in the Arena model is 1 when the level is intermediate or low and 5 when the level is high. The same happens with the attribute videos: when there is no access it equals 1 and if there is access then it is 5. When a team is created in the Arena simulation, this new entity has as its attribute the sum of the value of the attributes of each of the students that make up the team. For example, let's suppose a team formed by three students where 2 have a low level and one has a high level. Under these circumstances, the team has one attribute with value (1+1+5=7). Next, four different cases have to be specified to determine the time allocated to each team. In case 1, no one in the team has a high level of English or access to videos, so this group receives the longest time. In case two, we would have at least someone with a high level of English, but without any access to videos. Then the time allocated to the team is the second longest. In the third case, no one in the team has an advanced level of English, but at least someone has access to the videos. In that case the team receives the third longest time. The fourth case is where at least someone in the team has an advanced level of English and access to the videos. In such circumstances this team obviously receives the shortest time.

The following table explains graphically all the possible combinations that can arise. If the team consists of one person, the time allotted has four possible combinations colored

in blue in the table below. If the team has 2 people, then the combinations increase to 9 (colored in yellow). If the team has 3 people, then there are 16 combinations (colored in red). Finally, if 4 people work together in the same team, there are 25 combinations highlighted in green.

English level of the students	Access to video tutorials																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(130,33)				NORM(110,28)															
2		NORM(130,33)				NORM(110,28)				NORM(110,28)										
3			NORM(130,33)				NORM(110,28)				NORM(110,28)				NORM(110,28)					
4				NORM(130,33)				NORM(110,28)				NORM(110,28)				NORM(110,28)				NORM(110,28)
5	NORM(120,30)				NORM(100,25)															
6		NORM(120,30)				NORM(100,25)				NORM(100,25)										
7			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
8				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
9																				
10		NORM(120,30)				NORM(100,25)				NORM(100,25)										
11			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
12				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
13																				
14																				
15			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
16				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
17																				
18																				
19																				
20				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)

Illustration 6: Table with an example of time allocation according to team size

For example, in a team of 3 people, there is a student with a high level of English and a laptop computer that allows him to watch the tutorial videos that explain the procedures of the practice. The rest of the team members have a low level of English, but both have access to the videos. Under these circumstances, in the simulation model the team receives a value of (1+1+5=7) for the English attribute and (5+5+5=15) for the videos attribute. The cell whose row number is 7 and column number 15 contains the time assigned to this group. It is a normal distribution with a mean of 100 minutes and a standard deviation of 25 minutes.

Regarding the modeling of the teacher's assistance, all practices follow the same criterion. Both the probabilities of requesting it and the parameters assigned to model the normal distributions followed by the duration of this assistance are the same in all five practices. They could have been differentiated according to the difficulty of each one of them, but I have chosen to simplify this aspect.

To assign probabilities of assistance and its temporal duration, both the level of English and the access to the videos have been taken into account. The following table shows these probabilities.

	No access to videos	Access to videos
Intermediate level of English	UNIF(0,1)<=0.8	UNIF(0,1)<=0.2
Advanced level of English	UNIF(0,1)<=0.6	UNIF(0,1)<=0.1

Illustration 7: Table with the probabilities of asking the teacher for help

In the Arena simulation software, the UNIF(0,1) function allows to obtain random numbers between 0 and 1 with equal probability. For example, using the condition UNIF(0,1)<=0.8, the probability that this condition is true is 80%.

Considering again the number of members in each team, the following table shows all possible combinations:

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	UNIF(0,1)<=0.8				UNIF(0,1)<=0.2															
2		UNIF(0,1)<=0.8				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2										
3			UNIF(0,1)<=0.8				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2					
4				UNIF(0,1)<=0.8				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2				UNIF(0,1)<=0.2
5	UNIF(0,1)<=0.6				UNIF(0,1)<=0.1															
6		UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1										
7			UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1					
8				UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1
9																				
10		UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1										
11			UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1					
12				UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1
13																				
14																				
15			UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1					
16				UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1
17																				
18																				
19																				
20				UNIF(0,1)<=0.6				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1				UNIF(0,1)<=0.1

Illustration 8: Table showing the probability of requesting the teacher's assistance according to the size of the team

Regarding the duration time of this aid, the normal distribution has also been used with the parameters shown in the following table expressed in minutes.

	No access to videos	Access to videos
Intermediate level of English	NORM(9,2)	NORM(5,1)
Advanced level of English	NORM(7,2)	NORM(3,1)

Illustration 9: Time allocated to teacher assistance

Finally, the following table shows all possible combinations depending on the number of members in each team.

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students	Access to video tutorials																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(9,2)				NORM(5,1)															
2		NORM(9,2)				NORM(5,1)				NORM(5,1)										
3			NORM(9,2)				NORM(5,1)				NORM(5,1)				NORM(5,1)					
4				NORM(9,2)				NORM(5,1)				NORM(5,1)				NORM(5,1)				NORM(5,1)
5	NORM(7,2)				NORM(3,1)															
6		NORM(7,2)				NORM(3,1)				NORM(3,1)										
7			NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)					
8				NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)				NORM(3,1)
9																				
10		NORM(7,2)				NORM(3,1)				NORM(3,1)										
11			NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)					
12				NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)				NORM(3,1)
13																				
14																				
15			NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)					
16				NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)				NORM(3,1)
17																				
18																				
19																				
20				NORM(7,2)				NORM(3,1)				NORM(3,1)				NORM(3,1)				NORM(3,1)

Illustration 10: Duration of the teacher's assistance depending on the characteristics of the team.

Returning to the previous example of the 3-person team where their English attribute is 7 and their video attribute is 15, their probability of asking for assistance would be 10% and if they were attended by the teacher, the duration would last for a value that follows a normal distribution of mean 3 minutes and standard deviation 1 minute.

2.4.2 MODELING OF PRACTICE 1: REFRACTIVE INDEX MEASUREMENT. LIGHT PROPAGATION IN HOMOGENEOUS AND NON-HOMOGENEOUS MEDIA

2.4.2.1 DESCRIPTION OF PRACTICE 1

In the experiments of practice 1, the propagation of light in uniform and non-uniform media is studied. The deflection of light propagating through non-uniform media is used to measure the concentration of liquids, their spatial distribution, and their time evolution. In addition, straight light propagation is used to measure the refractive index of liquids and the thickness of flat layers.

Illustration 11: Workbench where practice 1 is carried out.

First, the following table shows all the activities that make up practice 1 and the estimated average times for their completion.

ACTIVITY	TASK DESCRIPTION	Average estimated time (minutes)
A	To verify all the material is available	5
B	To take the first picture	25
C	To take the second picture	2
D	To take the third picture	2
E	To take the fourth picture	2
F	To measure refractive indexes of two liquids	5
G	To measure the refractive index of a plate	10
H	To explain why the laser beam can not be seen through the air	5
I	To explain the observation of points on a miror	5
J	To observe the Pffund effect in two different materials	10
K	To observe the Pffund effect on plane-parallel glasses	10
L	To measure bright diameters on plane-parallel glasses	10
M	To verify a formula	5
N	To observe the Pffund effect on plane-parallel glasses with a water layer underneath	10
O	To measure bright diameters on plane-parallel glasses with a water layer underneath	10
P	To verify a formula	5
Q	To measure how deep a water layer is.	10
R	To put away the material used	5
	Total average estimated time	**136**

		Average estimated time (minutes)
Activities belonging to the first part of the simulation.	A-B-C-D-E-F-G	51
Activities belonging to the second part of the simulation.	H-I-J-K-L-M-N-O-P-Q-R	85

Illustration 12: Table with the average times assigned to each activity in practice 1.

Second, the PERT diagram determines that the critical path has an estimated duration of about 90 minutes.

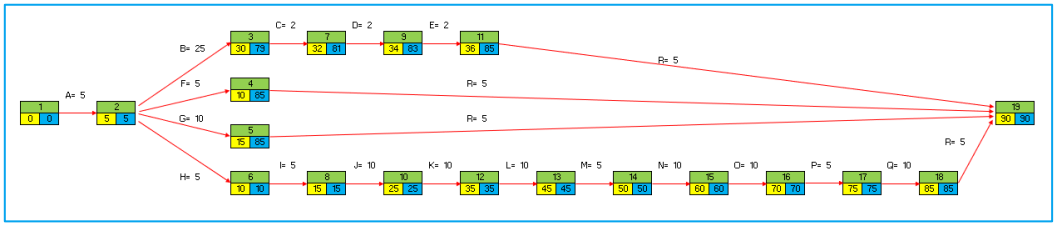


Illustration 13: PERT diagram of the activities that make up practice 1.

It is also possible to subdivide all the activities into two blocks because the instruments needed to perform the measurements in this practice allow it. The first block groups activities A, B, C, D, E, F and G with an estimated duration of about 51 minutes. The second block groups activities H, I, J, K, L, M, N, O, P, Q and R with an estimated duration of 85 minutes. This division has been taken into account for modeling this practice with the Arena simulation software.

2.4.2.2 MODELING OF TIME DISTRIBUTIONS WITH ARENA SOFTWARE

The time required for students to complete the first part of Practice 1 has been modeled with the normal distributions shown in the table below (times are measured in minutes):

	No access to videos	Access to videos
Intermediate level of English	NORM(130,33)	NORM(110,28)
Advanced level of English	NORM(120,30)	NORM(100,25)

Illustration 14: Table with normal distributions to model the duration of the first part of practice 1.

This other table specifies the assigned distribution depending on the characteristics of each team:

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students	Access to video tutorials																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(130,33)				NORM(110,28)															
2		NORM(130,33)				NORM(110,28)				NORM(110,28)										
3			NORM(130,33)				NORM(110,28)				NORM(110,28)				NORM(110,28)					
4				NORM(130,33)				NORM(110,28)				NORM(110,28)				NORM(110,28)				NORM(110,28)
5	NORM(120,30)				NORM(100,25)															
6		NORM(120,30)				NORM(100,25)				NORM(100,25)										
7			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
8				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
9																				
10		NORM(120,30)				NORM(100,25)				NORM(100,25)										
11			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
12				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
13																				
14																				
15			NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
16				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
17																				
18																				
19																				
20				NORM(120,30)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)

Illustration 15: Table with the normal distributions to model the duration of the first part of practice 1 according to the characteristics of each team.

As explained above, the tables related to the second part of practice 1 are shown:

	No access to videos	Access to videos
Intermediate level of English	NORM(115,29)	NORM(95,24)
Advanced level of English	NORM(105,26)	NORM(85,21)

Illustration 16: Table with normal distributions to model the duration of the second part of practice 1.

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students	Access to video tutorials																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(115,29)				NORM(95,24)															
2		NORM(115,29)				NORM(95,24)				NORM(95,24)										
3			NORM(115,29)				NORM(95,24)				NORM(95,24)				NORM(95,24)					
4				NORM(115,29)				NORM(95,24)				NORM(95,24)				NORM(95,24)				NORM(95,24)
5	NORM(105,26)				NORM(85,21)															
6		NORM(105,26)				NORM(85,21)				NORM(85,21)										
7			NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)					
8				NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)				NORM(85,21)
9																				
10		NORM(105,26)				NORM(85,21)				NORM(85,21)										
11			NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)					
12				NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)				NORM(85,21)
13																				
14																				
15			NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)					
16				NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)				NORM(85,21)
17																				
18																				
19																				
20				NORM(105,26)				NORM(85,21)				NORM(85,21)				NORM(85,21)				NORM(85,21)

Illustration 17: Table with the normal distributions to model the duration of the second part of practice 1 according to the characteristics of each team.

For example, in a team of 3 people where their English attribute is 7 and their video attribute is 15, the time taken to complete the first part of practice 1 follows a normal distribution of mean 100 minutes and standard deviation 25 minutes. On the other hand, for the second part, the time spent belongs to a normal distribution of mean 85 and standard deviation 21 minutes.

2.4.3 MODELING OF PRACTICE 2: IMAGE FORMATION AND CONSTRUCTION OF MICROSCOPES AND TELESCOPES

2.4.3.1 DESCRIPTION OF PRACTICE 2

In this experiment the students become familiar with lenses and various classical optical instruments. First, the main characteristics of image formation are studied, and then optical systems are constructed with simple lens combinations.

Illustration 18: Workbench where practice 2 is carried out.

In this practice there are a total of fifteen activities to be developed, which are specified in the following table:

ACTIVITY	TASK DESCRIPTION	Average estimated time (minutes)
A	To verify all the material is available	5
B	To experiment with the camera obscura.	5
C	To measure the focal length of a lens	10
D	To measure the focal length of a converging lens	8
E	To measure the focal length of a diverging lens	8
F	To measure the near point of the eye	5
G	To study a pinhole	5
H	To calculate the eye resolving power	5
I	To check that the image formed on the retina of the human eye is inverted.	5
J	To find the blind spot of human eye	5
K	To study a magnifying glass	10
L	To study a compound microscope	8
M	To study a refractive astronomical telescope	10
N	To study a terrestrial telescope	10
O	To put away the material used	5
	Total estimated time	**104**

		Average estimated time (minutes)
Activities belonging to the first part of the simulation.	A-C-D-E-K-L-M-N-O	69
Activities belonging to the second part of the simulation.	A-B-F-G-H-I-J-O	40

Illustration 19: Table with the average times assigned to each activity in practice 2.

Their PERT diagram shows a critical path of about 48 minutes.

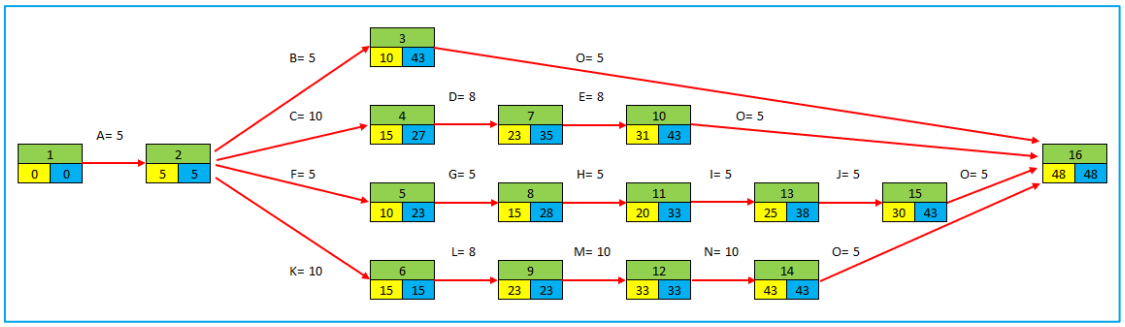


Illustration 20: PERT diagram of the activities that make up practice 2.

As was the case with practice 1, this practice is also subdivided into two parts in order to facilitate its modeling in Arena. The first one includes activities A-C-D-D-E-K-L-M-N-O and the second one includes activities A-B-F-G-H-I-J-O.

2.4.3.2 MODELING OF TIME DISTRIBUTIONS WITH ARENA SOFTWARE

The time required for students to complete the first part of Practice 2 has been modeled with the normal distributions shown in the following table (times are measured in minutes):

	No access to videos	Access to videos
Intermediate level of English	NORM(58,15)	NORM(46,12)
Advanced level of English	NORM(52,13)	NORM(40,10)

Illustration 21:Table with normal distributions to model the duration of the first part of practice 2.

This other table specifies the assigned distribution depending on the characteristics of each equipment:

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(58,15)				NORM(46,12)															
2		NORM(58,15)				NORM(46,12)				NORM(46,12)										
3			NORM(58,15)				NORM(46,12)				NORM(46,12)				NORM(46,12)					
4				NORM(58,15)				NORM(46,12)				NORM(46,12)				NORM(46,12)				NORM(46,12)
5	NORM(52,13)				NORM(40,10)															
6		NORM(52,13)				NORM(40,10)				NORM(40,10)										
7			NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)					
8				NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)				NORM(40,10)
9																				
10		NORM(52,13)				NORM(40,10)				NORM(40,10)										
11			NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)					
12				NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)				NORM(40,10)
13																				
14																				
15			NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)					
16				NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)				NORM(40,10)
17																				
18																				
19																				
20				NORM(52,13)				NORM(40,10)				NORM(40,10)				NORM(40,10)				NORM(40,10)

Illustration 22: Table with the normal distributions to model the duration of the first part of practice 2 according to the characteristics of each team.

As explained above, the tables related to the second part of practice 2 are shown:

	No access to videos	Access to videos
Intermediate level of English	NORM(87,22)	NORM(75,19)
Advanced level of English	NORM(81,20)	NORM(69,17)

Illustration 23: Table with normal distributions to model the duration of the second part of practice 2.

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(87,22)				NORM(75,19)															
2		NORM(87,22)				NORM(75,19)				NORM(75,19)										
3			NORM(87,22)				NORM(75,19)				NORM(75,19)				NORM(75,19)					
4				NORM(87,22)				NORM(75,19)				NORM(75,19)				NORM(75,19)				NORM(75,19)
5	NORM(81,20)				NORM(69,17)															
6		NORM(81,20)				NORM(69,17)				NORM(69,17)										
7			NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)					
8				NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)				NORM(69,17)
9																				
10		NORM(81,20)				NORM(69,17)				NORM(69,17)										
11			NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)					
12				NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)				NORM(69,17)
13																				
14																				
15			NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)					
16				NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)				NORM(69,17)
17																				
18																				
19																				
20				NORM(81,20)				NORM(69,17)				NORM(69,17)				NORM(69,17)				NORM(69,17)

Illustration 24: Table with the normal distributions to model the duration of the second part of practice 2 according to the characteristics of each team.

For example, in a team of 3 people where their English attribute is 7 and their video attribute is 15, the time taken to complete the first part of practice 2 follows a normal distribution of mean 40 minutes and standard deviation 10 minutes. On the other hand, for the second part, the time spent belongs to a normal distribution of mean 69 and standard deviation 17 minutes.

2.4.4 MODELING OF PRACTICE 3: LIGHT POLARIZATION. POLARIZATION BY REFLECTION AND SCATTERING. POLARIMETRY. BIREFRINGENCE, PHOTOELASTICITY AND OPTICAL ACTIVITY.

2.4.4.1 DESCRIPTION OF PRACTICE 3

These are the objectives of practice 3:

- To analyze if one kind of light is polarized or not.
- To verify the Malus' Law.
- To measure the reflectance and transmittance of a piece of glass.
- To analyze the reflected light at a Brewster's angle.
- To observe the polarization due to light scattering and by Rayleigh scattering.
- To observe the phenomenon of birefringence and photoelasticity.
- To measure the specific rotation of sucrose.

Illustration 25: Workbench where practice 3 is carried out.

In this practice there are a total of eleven activities to be developed, which are specified in the following table:

ACTIVITY	TASK DESCRIPTION	Average estimated time (minutes)
A	To verify all the material is available	5
B	To analyse if one kind of light is polarised or not.	5
C	To verify the Malus' Law	10
D	To measure the reflectance and transmitance of a piece of glass	15
E	To analyse the reflected light at Brewster's angle	5
F	To observe polarization due to light scattering	5
G	To observe polarization by Rayleigh scattering	8
H	To observe the phenomenon of birefringence	5
I	To observe internal strains	20
J	To measure the specific rotation of sucrose	15
K	To put away the material used	5
	Total average estimated time	98

		Average estimated time (minutes)
Activities belonging to the first part of the simulation.	B-C-F-G-H-I-J-K	73
Activities belonging to the second part of the simulation.	A-D-E-K	30

Illustration 26: Table with the average times assigned to each activity in practice 3.

Their PERT diagram shows a critical path of about 35 minutes.

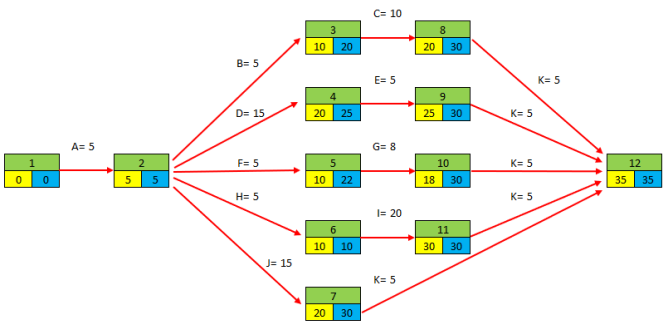


Illustration 27: PERT diagram of the activities that make up practice 3.

As was the case with practice 1, this practice is also subdivided into two parts in order to facilitate its modeling with Arena. The first one includes activities B-C-F-G-H-I-J-K and the second one includes activities A-D-E-K.

2.4.4.2 MODELING OF TIME DISTRIBUTIONS WITH ARENA SOFTWARE

The time required for students to complete the first part of Practice 3 has been modeled with the normal distributions shown in the following table (times are measured in minutes):

	No access to videos	Access to videos
Intermediate level of English	NORM(91,23)	NORM(79,20)
Advanced level of English	NORM(85,21)	NORM(73,18)

Illustration 28: Table with normal distributions to model the duration of the first part of practice 3.

This other table specifies the assigned distribution depending on the characteristics of each equipment:

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(91,23)				NORM(79,20)															
2		NORM(91,23)				NORM(79,20)				NORM(79,20)										
3			NORM(91,23)				NORM(79,20)				NORM(79,20)				NORM(79,20)					
4				NORM(91,23)				NORM(79,20)				NORM(79,20)				NORM(79,20)				NORM(79,20)
5	NORM(85,21)				NORM(73,18)															
6		NORM(85,21)				NORM(73,18)				NORM(73,18)										
7			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
8				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
9																				
10		NORM(85,21)				NORM(73,18)				NORM(73,18)										
11			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
12				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
13																				
14																				
15			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
16				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
17																				
18																				
19																				
20				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)

Illustration 29: Table with the normal distributions to model the duration of the first part of practice 3 according to the characteristics of each team.

As explained above, the tables related to the second part of practice 3 are shown:

	No access to videos	Access to videos
Intermediate level of English	NORM(43,11)	NORM(31,8)
Advanced level of English	NORM(37,9)	NORM(25,6)

Illustration 30: Table with normal distributions to model the duration of the second part of practice 3.

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(43,11)				NORM(31,8)															
2		NORM(43,11)				NORM(31,8)				NORM(31,8)										
3			NORM(43,11)				NORM(31,8)				NORM(31,8)				NORM(31,8)					
4				NORM(43,11)				NORM(31,8)				NORM(31,8)				NORM(31,8)				NORM(31,8)
5	NORM(37,9)				NORM(25,6)															
6		NORM(37,9)				NORM(25,6)				NORM(25,6)										
7			NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)					
8				NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)				NORM(25,6)
9																				
10		NORM(37,9)				NORM(25,6)				NORM(25,6)										
11			NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)					
12				NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)				NORM(25,6)
13																				
14																				
15			NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)					
16				NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)				NORM(25,6)
17																				
18																				
19																				
20				NORM(37,9)				NORM(25,6)				NORM(25,6)				NORM(25,6)				NORM(25,6)

Illustration 31: Table with the normal distributions to model the duration of the second part of practice 3 according to the characteristics of each team.

For example, in a team of 3 people where their English attribute is 7 and their video attribute is 15, the time taken to complete the first part of practice 3 follows a normal distribution of mean 73 minutes and standard deviation 18 minutes. On the other hand, for the second part, the time spent belongs to a normal distribution of mean 25 and standard deviation 6 minutes.

2.4.5 MODELING OF PRACTICE 4: INTERFERENCE AND DIFFRACTION

2.4.5.1 DESCRIPTION OF PRACTICE 4

The aim of this practice is the observation of several interference and diffraction phenomena related to the wave nature of light. Students use the most common interferometers, wave-front division and amplitude division interferometers, like Michelson-Morley, and apply them to measure micrometric lengths and light wavelengths.

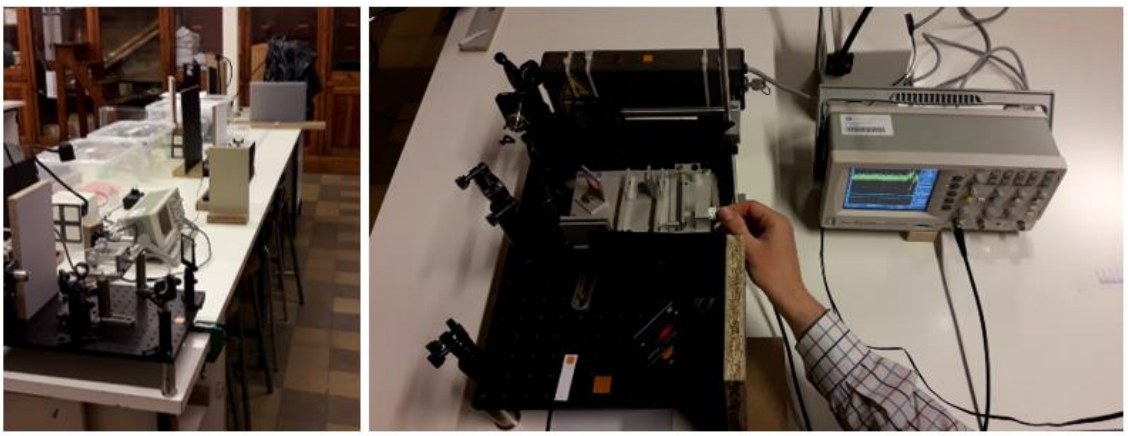


Illustration 32: Workbench where practice 4 is carried out.

In this practice there are a total of eleven activities to be developed, which are specified in the following table:

ACTIVITY	TASK DESCRIPTION	Average estimated time in minutes
A	To verify all the material is available	5
B	To perform the Young experiment	15
C	To measure the wavelength of a laser beam	15
D	To observe the Haidinger rings with a Michelson interferometer	6
E	To observe the variations of the Haidinger rings	5
F	To measure the wavelength of a laser beam with a Michelson interferometer	20
G	to check the proporcionality between the radius square and its ring number "p"	10
H	To measure the coherence distance of light	8
I	To measure a small thickness by means of an interference pattern	20
J	To measure the width of a slit by analysing a difraction pattern	10
K	To observe a hologram	4
L	To put away the material used	5
	Total average estimated time	123

		Average estimated time (minutes)
Activities belonging to the first part of the simulation.	B-C-H-I-J	73
Activities belonging to the second part of the simulation.	A-D-E-F-G-K-L	45

Illustration 33: Table with the average times assigned to each activity in practice 4.

Their PERT diagram shows a critical path of about 55 minutes.

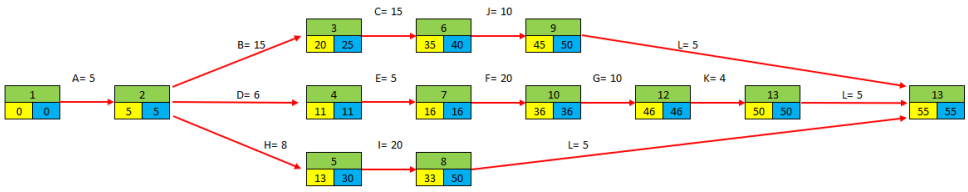


Illustration 34: PERT diagram of the activities that make up practice 4.

As was the case with practice 1, this practice is also subdivided into two parts in order to facilitate its modeling in Arena. The first one includes activities B-C-H-I-J and the second one includes activities A-D-E-F-G-K-L.

2.4.5.2 MODELING OF TIME DISTRIBUTIONS WITH ARENA SOFTWARE

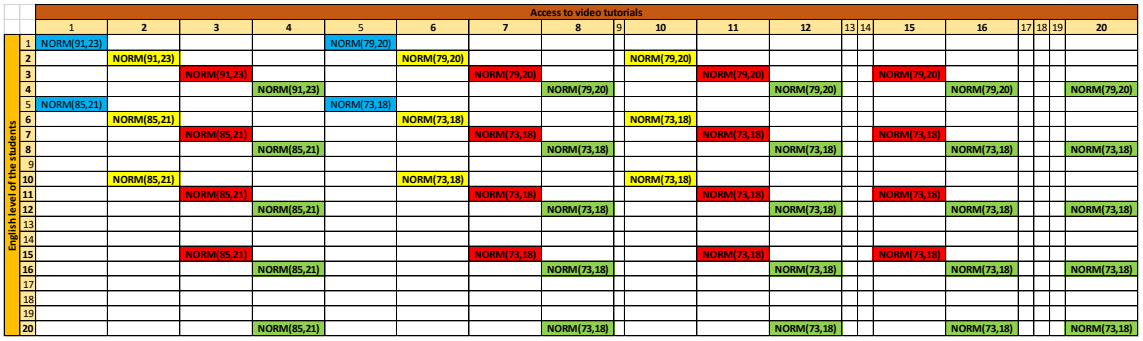
The time required for students to complete the first part of Practice 4 has been modeled with the normal distributions shown in the following table (times are measured in minutes):

	No access to videos	Access to videos
Intermediate level of English	NORM(91,23)	NORM(79,20)
Advanced level of English	NORM(85,21)	NORM(73,18)

Illustration 35: Table with normal distributions to model the duration of the first part of practice 4.

This other table specifies the assigned distribution depending on the characteristics of each equipment:

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.



English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(91,23)				NORM(79,20)															
2		NORM(91,23)				NORM(79,20)				NORM(79,20)										
3			NORM(91,23)				NORM(79,20)				NORM(79,20)				NORM(79,20)					
4				NORM(91,23)				NORM(79,20)				NORM(79,20)				NORM(79,20)				NORM(79,20)
5	NORM(85,21)				NORM(73,18)															
6		NORM(85,21)				NORM(73,18)				NORM(73,18)										
7			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
8				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
9																				
10		NORM(85,21)				NORM(73,18)				NORM(73,18)										
11			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
12				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
13																				
14																				
15			NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)					
16				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)
17																				
18																				
19																				
20				NORM(85,21)				NORM(73,18)				NORM(73,18)				NORM(73,18)				NORM(73,18)

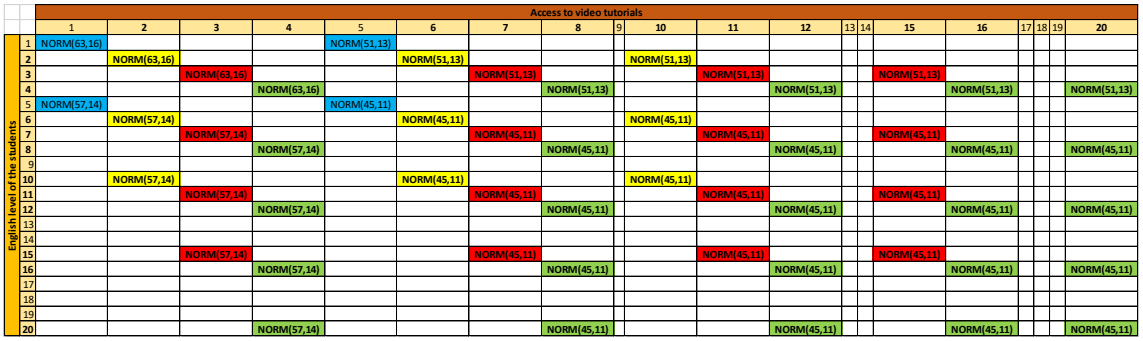
Illustration 36: Table with the normal distributions to model the duration of the first part of practice 4 according to the characteristics of each team.

In the same way as explained above, the tables related to the second part of practice 4 are shown:

	No access to videos	Access to videos
Intermediate level of English	NORM(63,16)	NORM(51,13)
Advanced level of English	NORM(57,14)	NORM(45,11)

Illustration 37: Table with normal distributions to model the duration of the second part of practice 4.

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.



English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(63,16)				NORM(51,13)															
2		NORM(63,16)				NORM(51,13)				NORM(51,13)										
3			NORM(63,16)				NORM(51,13)				NORM(51,13)				NORM(51,13)					
4				NORM(63,16)				NORM(51,13)				NORM(51,13)				NORM(51,13)				NORM(51,13)
5	NORM(57,14)				NORM(45,11)															
6		NORM(57,14)				NORM(45,11)				NORM(45,11)										
7			NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)					
8				NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)				NORM(45,11)
9																				
10		NORM(57,14)				NORM(45,11)				NORM(45,11)										
11			NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)					
12				NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)				NORM(45,11)
13																				
14																				
15			NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)					
16				NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)				NORM(45,11)
17																				
18																				
19																				
20				NORM(57,14)				NORM(45,11)				NORM(45,11)				NORM(45,11)				NORM(45,11)

Illustration 38: Table with the normal distributions to model the duration of the second part of practice 4 according to the characteristics of each team.

For example, in a team of 3 people where their English attribute is 7 and their video attribute is 15, the time taken to complete the first part of practice 4 follows a normal distribution of mean 73 minutes and standard deviation 18 minutes. On the other hand, for the second part, the time spent belongs to a normal distribution of mean 45 and standard deviation 11 minutes.

2.4.6 MODELING OF PRACTICE 5: SPECTROMETRY. WAVELENGTH MEASUREMENT

2.4.6.1 DESCRIPTION OF PRACTICE 5

In this experiment, the spectrometer is used to measure the wavelengths of the lines in the spectra produced by various atoms. The spectra contain bright lines at particular wavelengths, which correspond to light emitted during the transition between different energy states of the atoms.

In the first part students take advantage of the prism dispersion to determine some wavelengths that make up the spectrum of different atoms. In the second part, a diffraction grating is used to obtain similar results. The spectrum of other light sources is also analysed.

Illustration 39: Workbench where practice 5 is carried out.

In this practice there are a total of five activities to be developed, which are specified in the following table:

ACTIVITY	TASK DESCRIPTION	Average estimated time (minutes)
A	To verify all the material is available	5
B	To calibrate a spectrometer	30
C	To calculate the Hartsmann constants	30
D	To measure the wavelength of the lines in the spectra produced by Mercury	40
E	To put away the material used	5
	Total average estimated time	**110**

Illustration 40: Table with the average times assigned to each activity in practice 5.

Their PERT diagram shows a critical path of about 110 minutes.

Illustration 41: PERT diagram of the activities that make up practice 5.

Unlike the previous practices, this one cannot be subdivided into two parts because the spectrometer is needed in all activities. Consequently, in the Arena model it has been represented with a single process.

2.4.6.2 MODELING OF TIME DISTRIBUTIONS WITH ARENA SOFTWARE

The time required for students to complete this practice 5 has been modeled with the normal distributions shown in the following table (times are measured in minutes):

	No access to videos	Access to videos
Intermediate level of English	NORM(118,30)	NORM(106,27)
Advanced level of English	NORM(112,28)	NORM(100,25)

Illustration 42: Table with normal distributions to model the duration of practice 5.

This other table specifies the assigned distribution depending on the characteristics of each equipment:

Team formed by one person.
Team formed by two people.
Team formed by three people.
Team formed by four people.

English level of the students \ Access to video tutorials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	NORM(118,30)				NORM(106,27)															
2		NORM(118,30)				NORM(106,27)				NORM(106,27)										
3			NORM(118,30)				NORM(106,27)				NORM(106,27)				NORM(106,27)					
4				NORM(118,30)				NORM(106,27)				NORM(106,27)				NORM(106,27)				NORM(106,27)
5	NORM(112,28)				NORM(100,25)															
6		NORM(112,28)				NORM(100,25)				NORM(100,25)										
7			NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
8				NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
9																				
10		NORM(112,28)				NORM(100,25)				NORM(100,25)										
11			NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
12				NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
13																				
14																				
15			NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)					
16				NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)
17																				
18																				
19																				
20				NORM(112,28)				NORM(100,25)				NORM(100,25)				NORM(100,25)				NORM(100,25)

Illustration 43: Table with the normal distributions to model the duration of the practice 5 according to the characteristics of each team.

For example, in a team of 4 people where their English attribute is 8 and their videos attribute is 12, the time they taken to complete practice 5 follows a normal distribution of mean 100 minutes and standard deviation 25 minutes.

2.5 EXPLANATION OF THE DISCRETE EVENT MODEL IMPLEMENTED WITH ARENA SOFTWARE

2.5.1 OVERVIEW OF THE DISCRETE EVENT MODEL

I have created the following video to facilitate the understanding of my Arena model (https://youtu.be/1yxhP-IKLnc).

My discrete event model has 4 inputs (attendance, English level, access to videos and way of working) and four outputs (time spent by the students in each practice, number of completed practices, the time spent by the teacher to answer the questions of their students and the time that the students have been waiting to be attended by the teacher.

In this Arena model, two entities have been created: the students and the transition of a week. The students have been classified into 5 teams, which could also be subdivided into subgroups. Their characteristics have been modeled through attributes (learners' level of English and their access to video tutorials) and through variables (level of attendance or their tendency to specialise in different tasks).

Its programming is divided into a total of nine parts. The first of which creates learners and their subsequent assignment to a team, to an English level and to a level of access to the video tutorials. The model has described the formation of the teams in a realistic way, e.g., it correctly models the fact that in some cases there are empty groups. Once the team has been formed, its components remain in place throughout the 5 sessions.

Part two controls the schedule of the five practice sessions and the management of the students' attendance.

Part three models the start of each session with an initial explanation for all students, which has been represented as a process. The teacher has been modeled as a resource.

Afterwards each team is assigned a working mode, which determines whether or not the teams are subdivided to specialize in different tasks within the same practice. There is the possibility that they may vary their way of working in each session. For example, a team of 4 students may work together during practice 1, but in practice 2 they may decide to subdivide into two subgroups.

Part four assigns each team the practice to be performed weekly.

Part five represents the five practices. In the case of the first four, these have been subdivided into two parts. However, practice 5 does not allow this subdivision, because the same measuring instrument is always used.

Part six manages the completion of each session. It also allows to record the results for further statistical study in an Excel spreadsheet.

Finally, parts seven, eight and nine are aimed at visualizing the results obtained: the time taken by the students to carry out the activities of their corresponding practices, the time the teacher has used to answer the questions of their students and the time the students have had to wait to get their teacher's assistance.

2.5.2 PART 1: CREATION OF THE STUDENTS AND DISTRIBUTION BETWEEN FIVE TEAMS

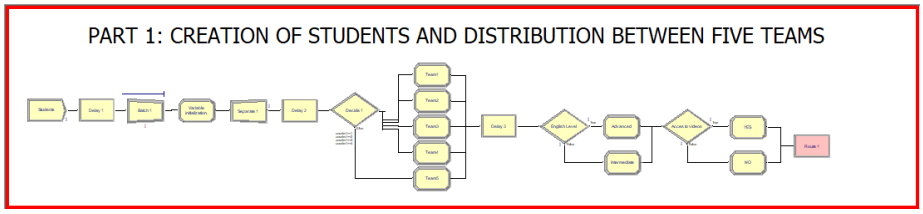
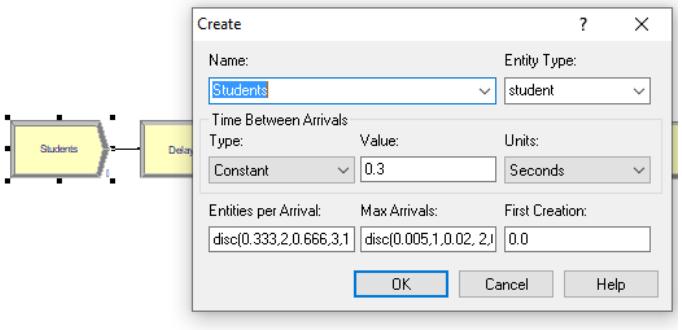


Illustration 44: Graph of the Part 1 of the Discrete Event Model made with Arena software.

Part 1 models the creation of students and their subsequent assignment to one of 5 teams. The teams consist of two, three or four members. The maximum number of students allowed during a session in the laboratory is 20, which would be distributed in 5 teams of 4 people. Sometimes some of these teams may remain empty if enrolment is low.



Entities per Arrival:
disc(0.333,2,0.666,3,1,4)

Max Arrivals:
disc(0.005,1,0.02, 2,0.04,3,0.1,4,1,5)

Illustration 45: Description of module Students

The create module called *Students* is designed to make student entities at a constant rate every 0.3 seconds. The first creation takes place at instant zero. Entities per Arrival is programmed so that the probability of creating 2, 3 or 4 students is 33.33% each. *Max Arrivals* on the other hand deals with determining the number of teams in each simulation. Thus, the probability of 5 teams is 83.5%, 4 teams 8%, 3 teams 2%, 2 teams 1.5% and a single team 0.5%.

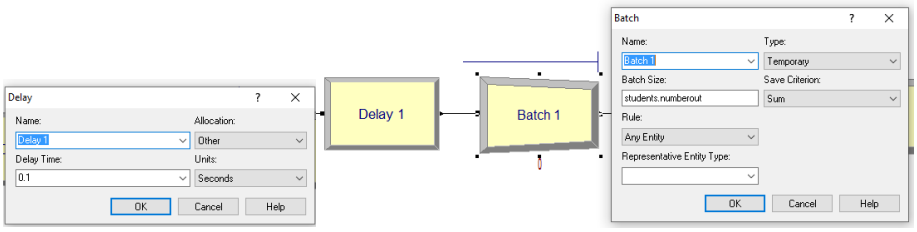
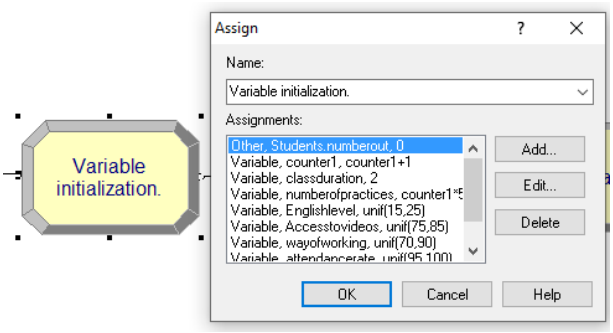


Illustration 46: batch 1 description

Students who arrive first will belong to team 1. To do this, the *delay 1* module puts all these first students on a 0.1 second wait. They will then be grouped through *batch 1*, which is programmed so that its size corresponds to the number of students that have been

created (variable *students.numberout*). It is a temporary grouping because they can be grouped and ungrouped throughout the simulation.



Variables

- Students.numberout
- Counter1
- Classduration
- Numberofpractices
- Englishlevel
- Accesstovideos
- Wayofworking
- Attendancerate

The assign module called *variable Initialization* has an important function for the correct management of the creation of teams. First, it initializes the *Students.numberout* variable to zero and makes a new variable called counter1 to count the number of teams created.

Secondly, this module initializes the variables corresponding to the system inputs: *classduration*, *Englishlevel*, *AccesstoVideos*, *Wayofworking* and *Attendancerate*. Finally, it creates the variable *numberofpractices* to determine the total number of practices that students should theoretically complete after the 5 weeks. For example, if 4 teams have been generated, then there should be a total of 20 practices (five practices per team).

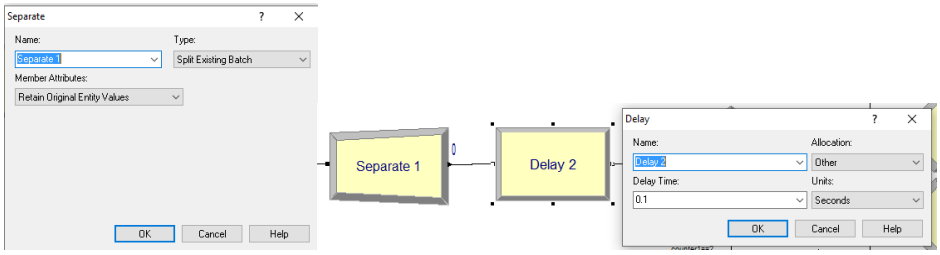


Illustration 47: description of modules separate 1 and delay 2

Separate 1 module ungroups the students and *delay 2* makes them wait 0.1 seconds to better coordinate the creation of the remaining teams.

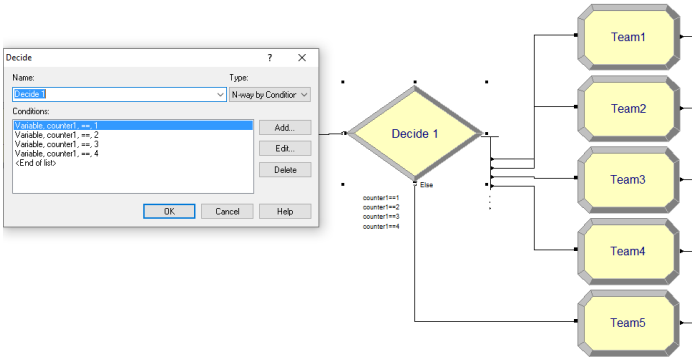
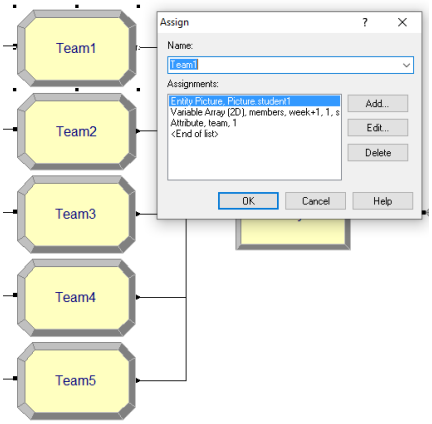


Illustration 48: description of conditional module Decide 1

The conditional module called *Decide 1* distributes the students into teams by means of the variable counter1. This has the advantage that the teams are made in ascending order. For example, if there were only 3 teams, teams 4 and 5 would remain empty. In this way it could never be the case that only team 3 is left empty.



The five assign modules called *Team1*, *Team2*, *Team3*, *Team4* and *Team5* have three functions each. The first one is to set a different icon to each student depending on the team they belong to. Team 1's icon is a blue number 1, team 2's icon is a green number 2, team 3's icon is a yellow number 3, team 4's icon is an orange number 4, and team 5's icon is a red number 5.

The second one is to fill in the first row of the matrix *members* with the number of members of each team. Cell (1,1) for the number of members of team 1, cell (1,2) for team 2, cell (1,3) for team 3, cell (1,4) for team 4 and cell (1,5) for team 5.

The third one is to assign a value to the team attribute. In the case of the students in team 1, this attribute will be 1, in team 2, 2 and so on up to the fifth team.

Delay 3 module delays the next phase by 0.1 seconds to coordinate the creation of the remaining teams. The conditional module "*English Level*" separates the students according to the value of the variable called *englishlevel*. If it were 20, then the condition would only be met in 20% of the cases.

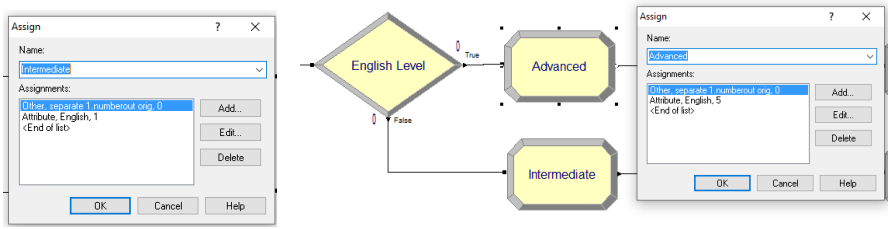


Illustration 49: description of the conditional module English level

The modules *Advanced* and *Intermediate* deal with assigning a 1 to the English attribute if the student has an intermediate level and a 5 if he or she has an advanced level. They also reset the value of the variable "*separate 1.numberout orig*" to zero in order to complete the creation of all the teams.

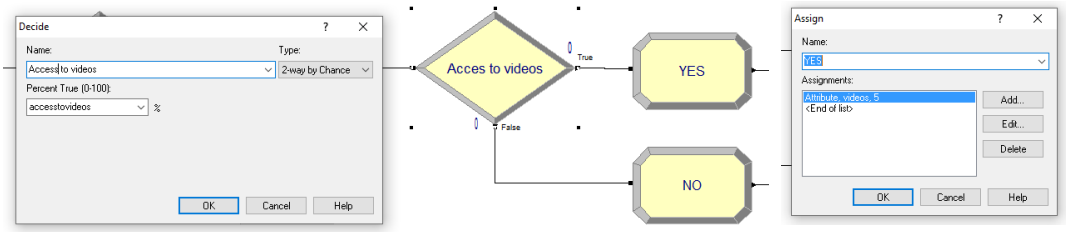


Illustration 50: Illustration 54: description of the conditional module English level

The conditional module *Access to videos* works according to the value of the variable "*accesstovideos*". For example, if it were 80, the condition would be true in 80% of the cases and this would cause the *YES* module to assign a value of 5 in the attribute called *videos*. Otherwise, the *NO* module will assign a value of 1, indicating that the student cannot view the video tutorials.

2.5.3 PART 2: CALENDAR AND ATTENDANCE MANAGEMENT

Part two has two different functions. The first one is to model that five weeks have passed and the second one is to manage student attendance during that period.

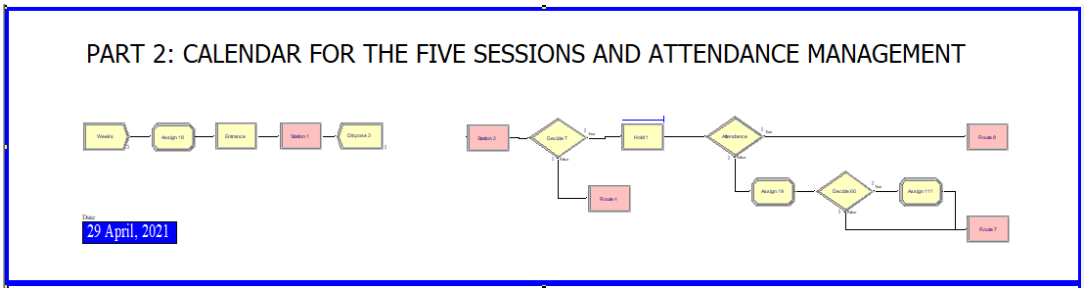


Illustration 51: Graph of the second part of the discrete event model made with Arena software.

The create module *Weeks* generates five entities called *week_gone* at a rate of 1 every 7 days (10080 minutes). The first of which must be made after the 1.5 seconds needed to create 5 teams.

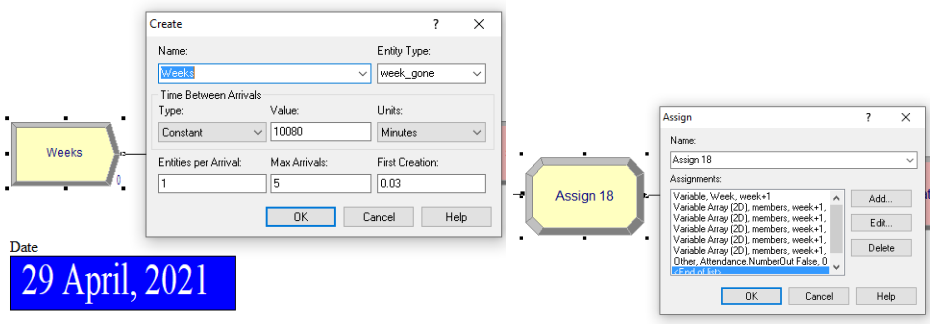


Illustration 52: description of modules Weeks and Assign 18

The Assign 18 module updates the variable called *week* and initializes the values of each row of the matrix *members* with the number of students enrolled in the subject. It also resets the variable *Attendance.NumberOut False* to zero.

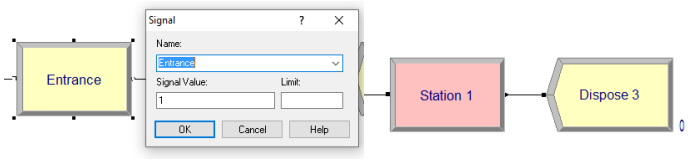


Illustration 53: description of module Entrance

Entrance sends a signal to indicate that it is the start time of the session and therefore students are allowed to access the lab. Finally, *Station 1* centers upon disposing all entities through *Dispose 3*.

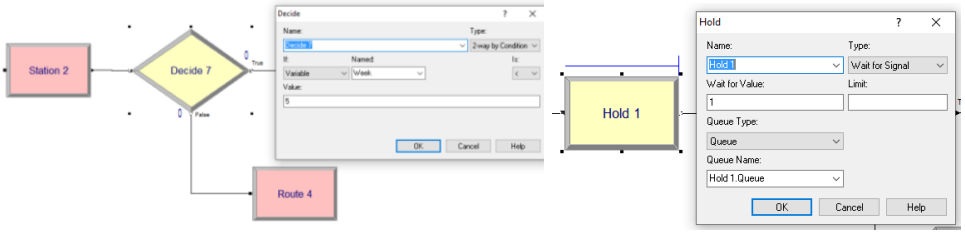


Illustration 54: description of module Decide 7 and Hold 1

Attendance management starts with the *Decide 7* module, which checks whether the fifth week has been reached and the students must leave the simulation. If not, they remain waiting in *hold 1* until the signal coming from *Entrance* module allows the students to enter the lab.

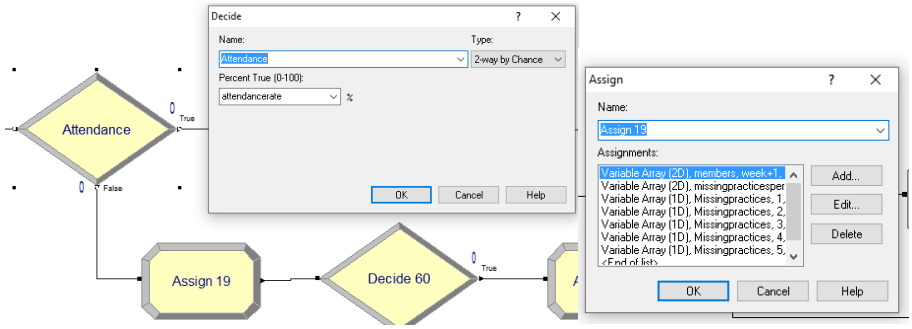


Illustration 55: description of module Attendance and Assign 19

Attendancerate is the variable that stores the percentage of attendance of the students to the classes. For example, a value of 90 means that the condition of the *Attendance* module will be true in 90% of the cases.

Otherwise, the members matrix is updated with the actual number of students in each practice. The *missingpracticesperweek* variable and the *missingpractices* matrix deal with managing the practices not performed by teams where no student has attended.

Students who do not attend are sent to *hold 1* to wait for the following week. Those who do attend are sent to Part 3.

The panels are especially useful for keeping track of student absences. In the first case, the first row indicates the total number of students enrolled and the following rows display how many students finally perform the practices. The last row informs about the number of students who did not attend each practice. In the case that no one in a team has attended the session, the panel on the right will indicate with a 1 the practice to be made up.

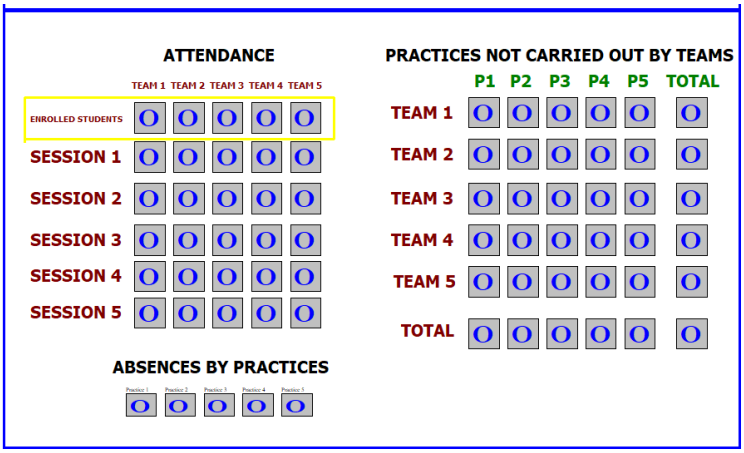


Illustration 56: control of the weekly attendance and of the practices not carried out.

2.5.4 PART 3: BEGINNING OF EACH SESSION AND DISTRIBUTION BETWEEN SUBGROUPS

This part has two different functions. While the first one manages the start of each session, the second one centers upon the way each team will work after the teacher's initial explanation.

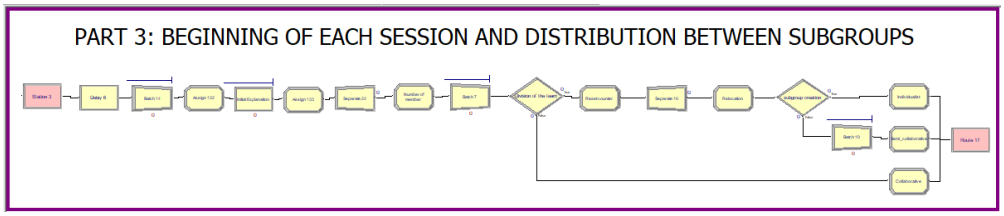


Illustration 57: Graph of the Part 3 of the Discrete Event Model

In the first section, all the students attending the practice session are grouped into a single entity, which accesses the process that represents the initial explanation given by the teacher at the beginning of the class. Its duration has been modeled with a normal distribution with a mean of 10 minutes and a standard deviation of 2 minutes. Since it is necessary to specify later whether the students have completed the practice in the two hours of each session, the duration of the initial explanation must be measured.

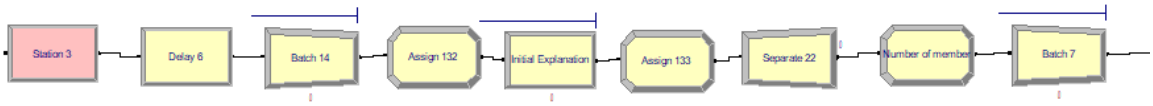


Illustration 58: modeling of the teacher's initial explanation.

The part that controls the working mode has a more complex programming. The decision module "*Division of the team*" allows to subdivide each team with a different probability depending on whether the number of members is 2, 3 or 4 persons.

The *way_of_working* attribute will take a different value depending on whether the teams are subdivided or not. The Individualist, semi-collaborative and collaborative Parts take care of this function.

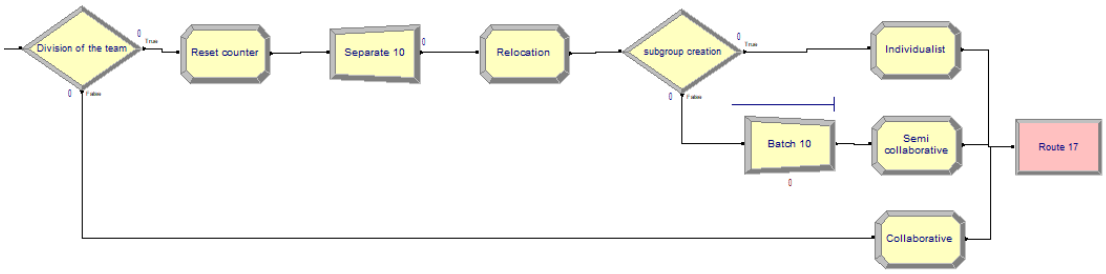


Illustration 59: modeling of the way the teams work.

2.5.5 PART 4: WEEKLY ASSIGNMENT OF PRACTICES TO EACH TEAM

This part has the function of assigning to each team the practice to be performed according to the current week. It is programmed to follow the calendar represented in the following table:

	TEAM 1	TEAM 2	TEAM 3	TEAM 4	TEAM 5
1st WEEK	PRACTICE 1	PRACTICE 2	PRACTICE 3	PRACTICE 4	PRACTICE 5
2nd WEEK	PRACTICE 2	PRACTICE 3	PRACTICE 4	PRACTICE 5	PRACTICE 1
3rd WEEK	PRACTICE 3	PRACTICE 4	PRACTICE 5	PRACTICE 1	PRACTICE 2
4th WEEK	PRACTICE 4	PRACTICE 5	PRACTICE 1	PRACTICE 2	PRACTICE 3
5th WEEK	PRACTICE 5	PRACTICE 1	PRACTICE 2	PRACTICE 3	PRACTICE 4

Illustration 60: timetable for carrying out the five practices.

For example, in the third week, team 2 must perform practice 4 and team 5 must perform practice 2.

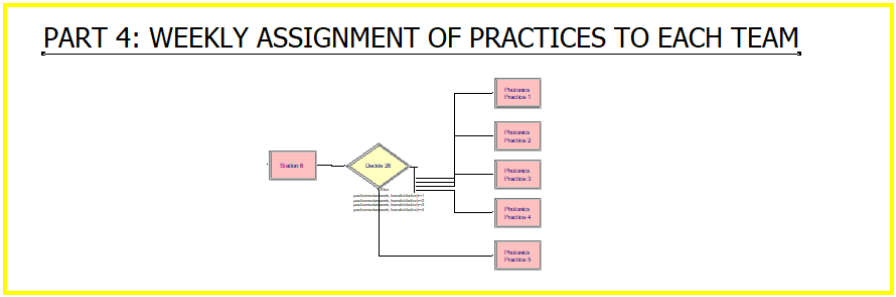


Illustration 61: Graph of the fourth part of the Discrete Event Model.

2.5.6 PART 5: THE FIVE PRACTICES

This is undoubtedly the most complex part. It represents the five practices subdivided into two halves in the first four ones.

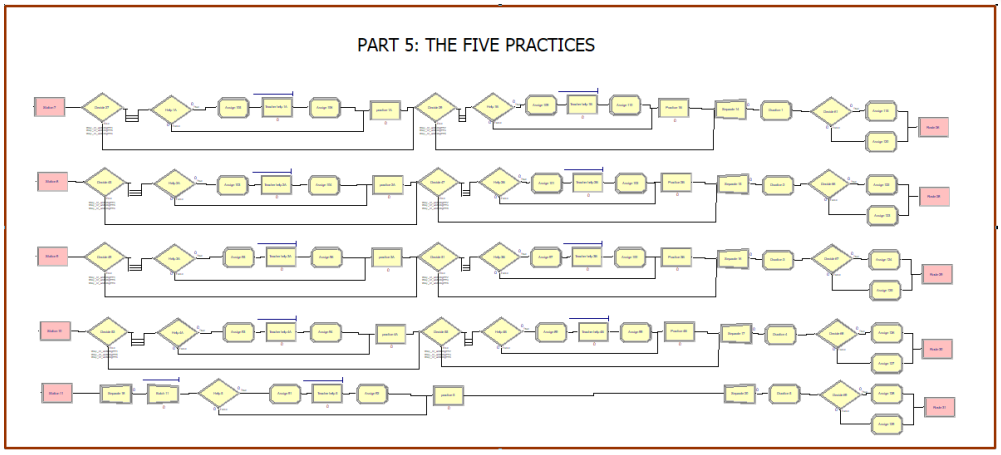


Illustration 62: Graph of the fifth part of the Discrete Event Model.

The following graph shows the first part of practice 1. The *Decide 17* decision module manages who performs these activities. For example, all teams working cohesively must go through here. In the case of a team that has decided to subdivide, only one subgroup will access process *1A* and the other subgroup will skip this section and directly access process *1B.*

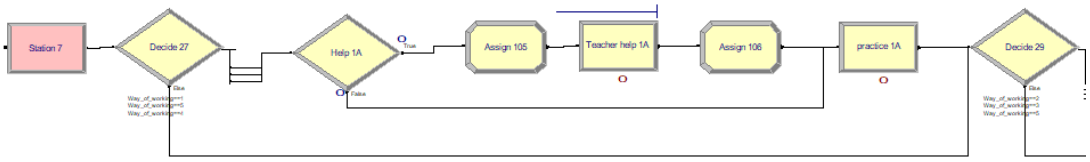


Illustration 63: modeling of the first part of practice 1.

The *Help 1A* decision module takes care of determining whether to request assistance from the teacher. In case students have a question, the *help 1A* process models the time the students wait to be attended. Regarding the time the teacher has been assisting them, the *Assign 105* and *Assign 106* modules are needed to measure it. In the case of not having questions, students directly access the process called *practice 1A.*

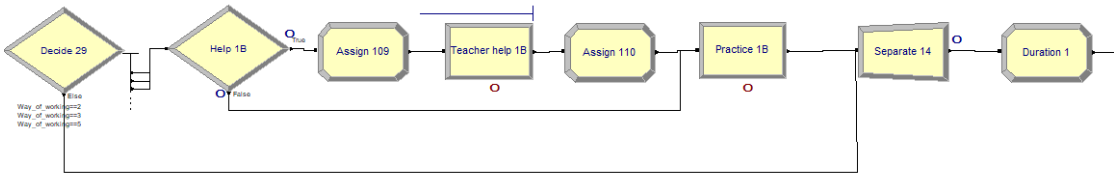


Illustration 64: modeling of the second part of practice 1

Regarding the second part of the practice, the model follows a similar pattern to the previous one. The decision module *Decide 29* determines which subgroup does not

perform this part and is sent directly to the *separate 14* module. On the other hand, when these activities are accessed, initially there will be a decision module called *Help 1B* that will determine whether the teacher is required or not, and then the *Practice 1B* process will be performed. The *Duration 1* module is particularly important because it measures the time taken by the team to complete the practice.

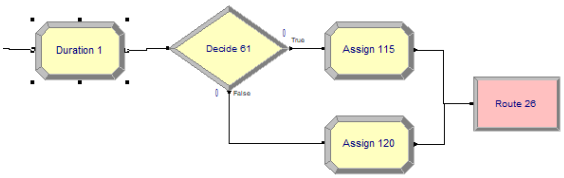


Illustration 65: measurement of completed practices.

Depending on whether this time has been less than the two hours of duration of each session minus the time of the initial explanation, the variable measuring whether practice 1 has been completed will be updated to 1 or 0.

Regarding practices 2, 3, 4 and 5 all of them follow a similar pattern as explained for the modeling of practice 1.

2.5.7 PART 6: END OF EACH SESSION

The final part of each session has been modeled with part 6. All students are grouped into a single entity and when the fifth week arrives, the data of the variables is recorded for subsequent statistical study in Excel.

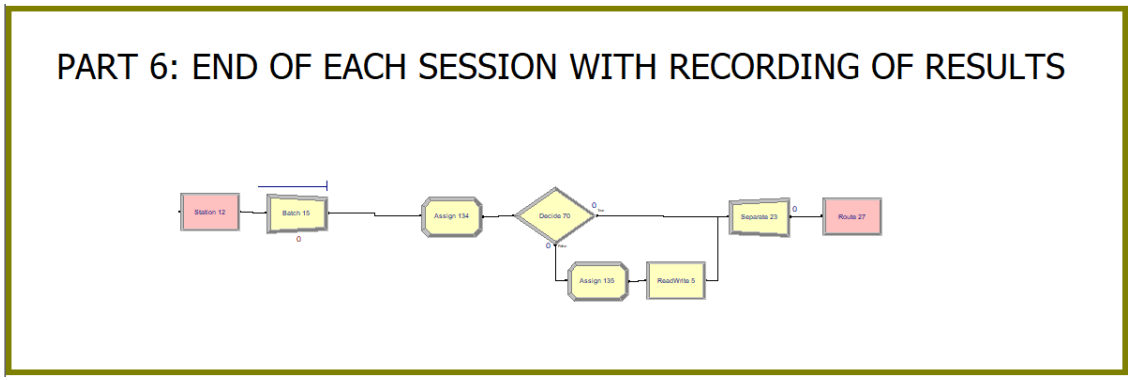


Illustration 66: Graph of the sixth part of the Discrete Event Model.

2.5.8 PART 7: TIME SPENT BY STUDENTS AND NUMBER OF PRACTICES FINISHED

Two panels are shown in this part. The left panel shows the time taken by each team to complete the practice. The right panel indicates with a number one whether the students were able to complete it before leaving the class. For each simulation, the number of completed practices is calculated over the total number of practices that should have been

completed. For example, if there were five teams in a simulation, the number of practices that should be completed would be 25 (5 practices per team).

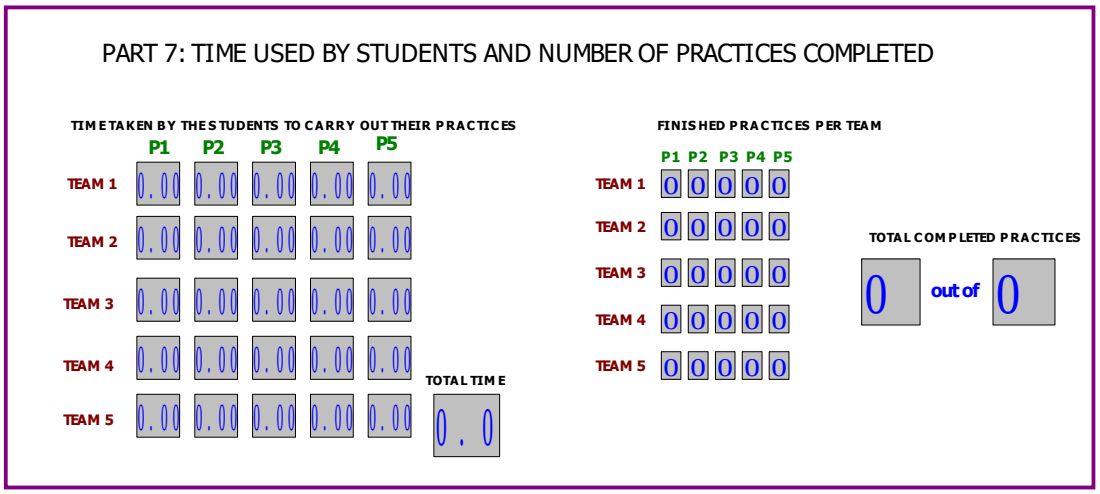


Illustration 67: Graph of the seventh part of the Discrete Event Model

2.5.9 PART 8: TIME SPENT BY THE TEACHER TO ASSIST THEIR STUDENTS

This part has a complete panel for the study of the time taken by the teacher to attend the teams. There are nine columns representing the different parts into which the practices have been divided. The rows on the other hand represent each of the five sessions. In blue color the times belonging to team 1 have been highlighted, in green to team 2, in yellow to team 3, in orange to team 4 and in red to team 5. The last column on the right indicates the total time spent by the teacher in each session. The last row indicates the total time in which the teacher has assisted in each of the practices. The total time spent by the teacher attending their students during the five sessions is shown in the lower right box. In case it was necessary to study whether the teams are equally attended to, there is a panel at the bottom that breaks down the teacher's time by team.

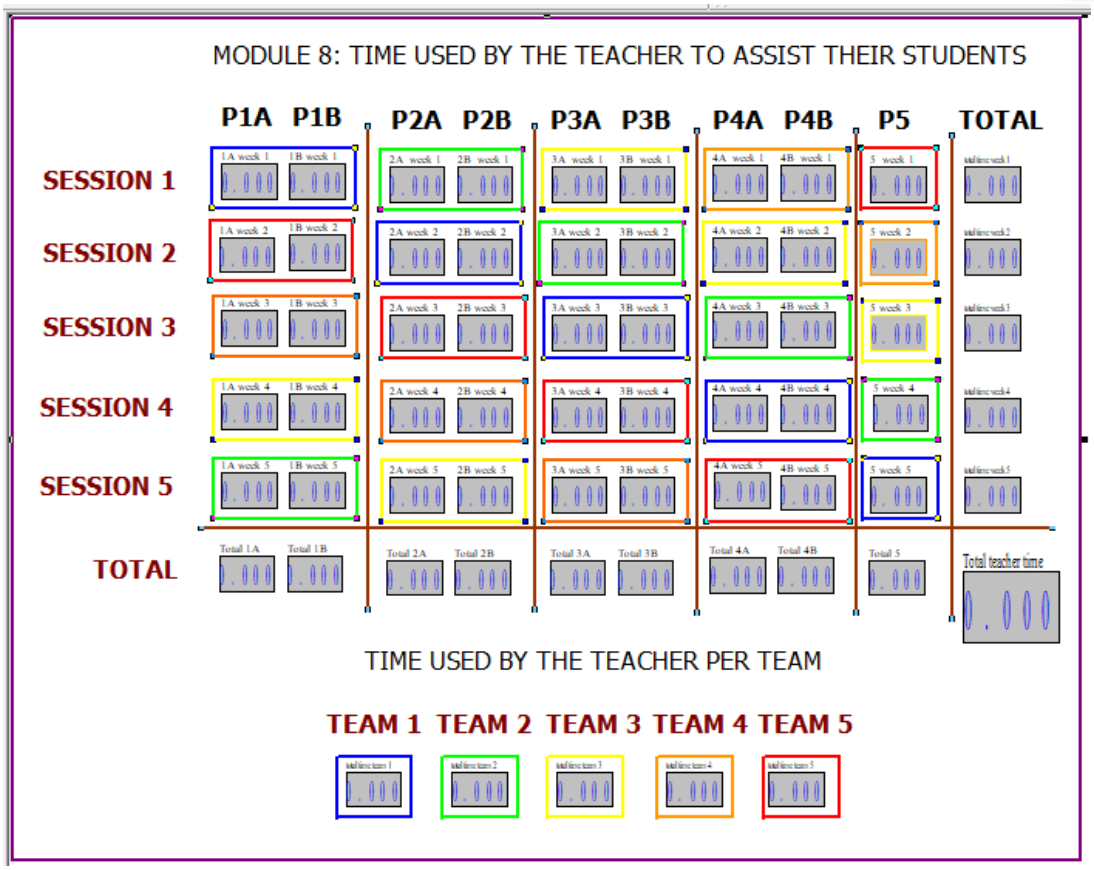


Illustration 68: Graph of the eighth part of the Discrete Event Model.

2.5.10 PART 9: WAITING TIME TO BE ATTENDED BY THE TEACHER

Part 9 has a similar structure to the previous one, but its purpose is different. Here the aim is to visualize the waiting times of the students to be attended by the teacher.

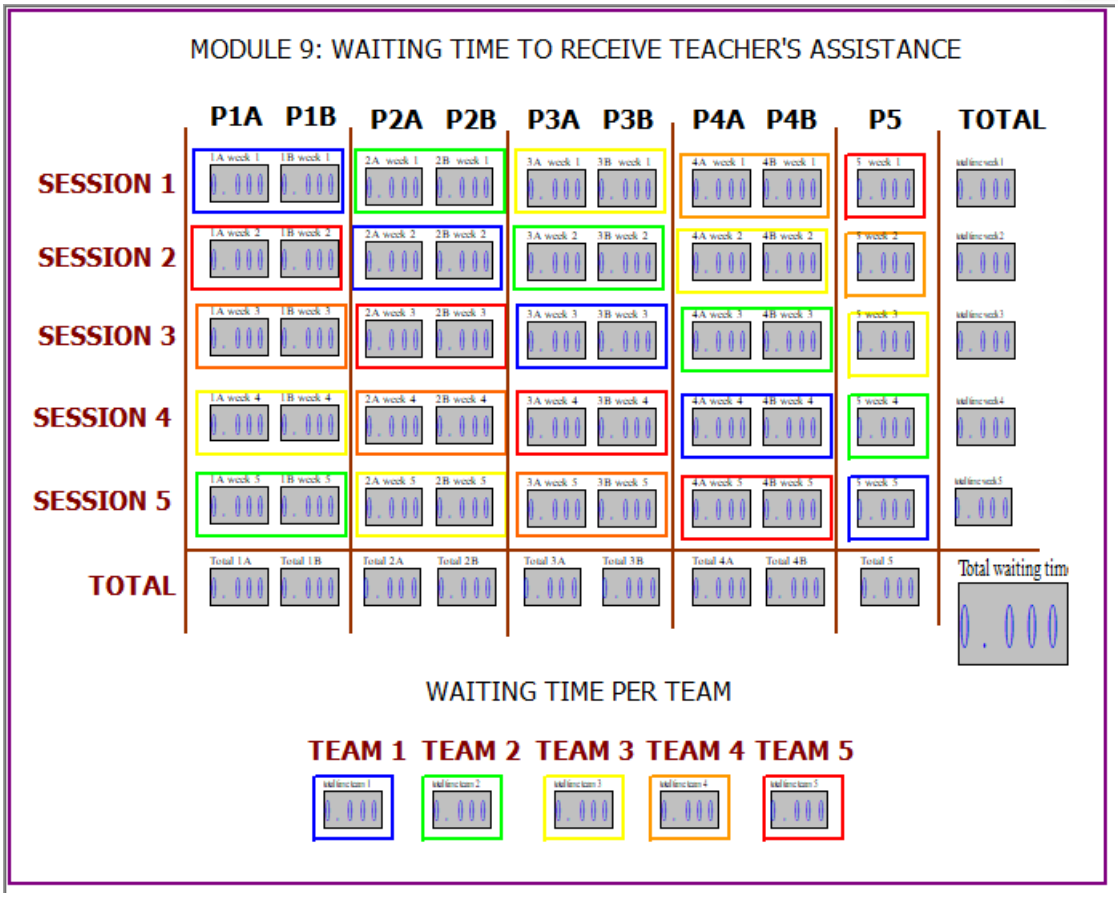


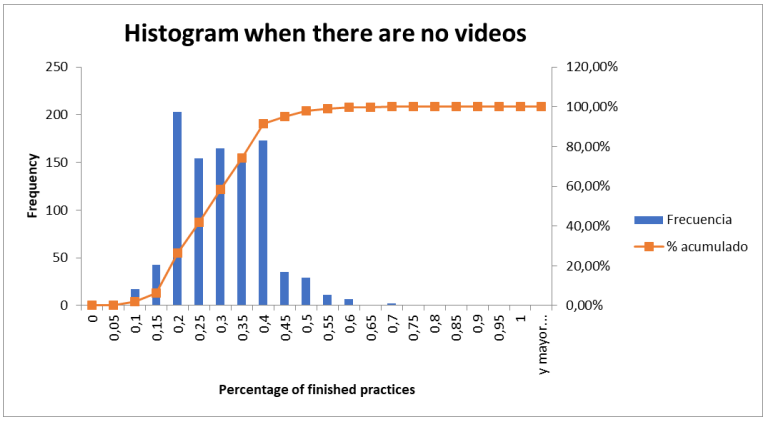
Illustration 69: Graph of the ninth part of the Discrete Event Model.

2.6 COMPARISON BETWEEN THE MANAGEMENT OF PRACTICAL SESSIONS WITH AND WITHOUT VIDEOS.

After performing a simulation with 1000 input vectors, I proceeded to perform an uncertainty analysis with the output variables of the model under conditions like those observed in the photonics laboratory. While in the first simulation the students do not have videos, in the second one they do. The statistical study specified for each of the different output variables is shown below.

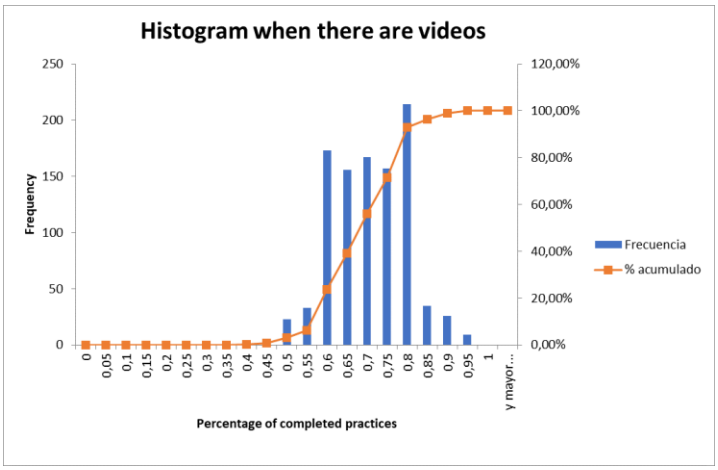
2.6.1 STUDY OF THE PERCENTAGE OF PRACTICES COMPLETED

The statistical study obtained for the output variable representing the percentage of completed practices is shown below.



Percentage of finished practices	
Media	0,28551667
Error típico	0,00314697
Mediana	0,28
Moda	0,28
Desviación estándar	0,0995159
Varianza de la muestra	0,00990341
Curtosis	0,44332218
Coeficiente de asimetría	0,42237699
Rango	0,7
Mínimo	0
Máximo	0,7
Suma	285,516667
Cuenta	1000
Nivel de confianza(95,0%)	0,00617543

Illustration 70: Histogram of the percentage of practices completed without videos.



Percentage of finished practices	
Media	0,68824667
Error típico	0,0029823
Mediana	0,68
Moda	0,72
Desviación estándar	0,09430847
Varianza de la muestra	0,00889409
Curtosis	-0,19693098
Coeficiente de asimetría	-0,04606308
Rango	0,53333333
Mínimo	0,4
Máximo	0,93333333
Suma	688,246667
Cuenta	1000
Nivel de confianza(95,0%)	0,00585228

Illustration 71: Histogram of the percentage of practices completed with videos.

The line representing the cumulative percentage of completed practices has shifted uniformly to the right by about 40%. This justifies the great contribution that the incorporation of videos has made to the students' learning process.

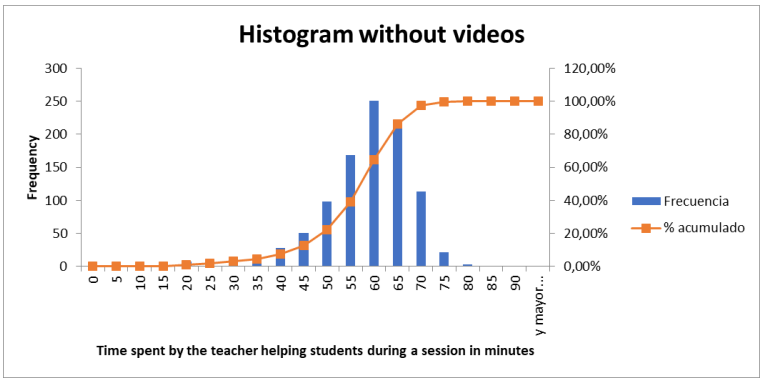
The probability density function observed both with and without videos conforms to the same statistical pattern except for the 40% shift.

The mean provided by the statistical study (68.82%) conforms with an error of less than 1% to the 68% of practices completed by the students I studied during my actual observations. This is one of the keys to validate this model.

2.6.2 STUDY OF THE TIME USED BY THE TEACHER TO ATTEND THEIR STUDENTS

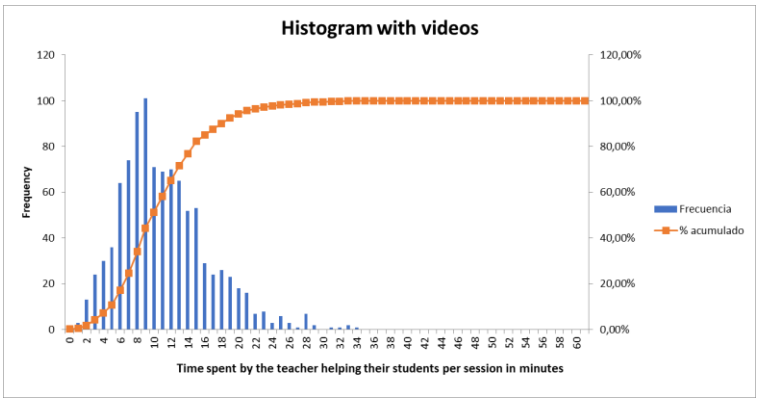
In this study, it is important to know that the measure of the time the teacher spends attending to the students is expressed in minutes and that this time corresponds to a

weekly session. In the first initial case, the mean of 55 minutes indicates that in a session in which the students do not have videos, the teacher dedicated 55 minutes out of a total of two hours available.



Teacher(minutes/session)	
Media	55,4700743
Error típico	0,32233061
Mediana	57,16347
Moda	#N/D
Desviación estándar	10,1929887
Varianza de la muestra	103,897019
Curtosis	2,41958483
Coeficiente de asimetría	-1,28722305
Rango	66,661128
Mínimo	13,911144
Máximo	80,572272
Suma	55470,0743
Cuenta	1000
Nivel de confianza(95,0%)	0,63252271

Illustration 72: Histogram of the duration of the teacher's assistance without videos.



Teacher (minutes)	
Media	10,7063499
Error típico	0,16882291
Mediana	9,787332
Moda	8,39532
Desviación estándar	5,33864904
Varianza de la muestra	28,5011736
Curtosis	1,31581908
Coeficiente de asimetría	0,93836492
Rango	33,088764
Mínimo	0
Máximo	33,088764
Suma	10706,3499
Cuenta	1000
Nivel de confianza(95,0%)	0,33128819

Illustration 73: Histogram of the duration of the teacher's assistance with videos.

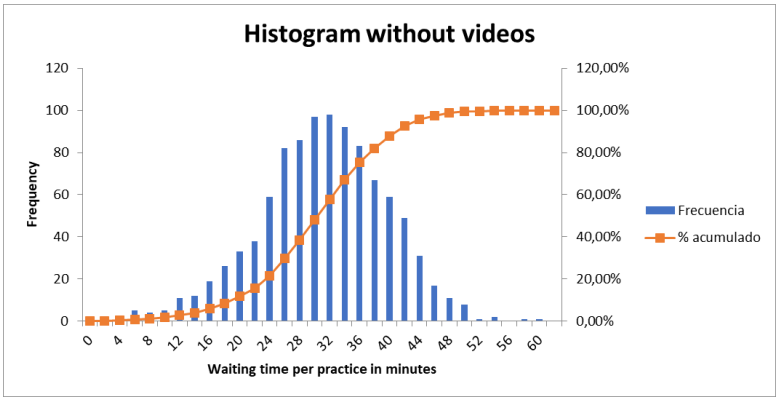
When videos are available, the mean of this variable has decreased to about 10 minutes. Compared to my personal observations, I must say that the teacher used to be busy about 90% of the time when there were no videos and this percentage decreased drastically to less than 5% when videos were edited.

Although the model reflects this improvement, it does not quite match reality. This can be explained by the fact that the model simplifies the way in which students ask for help. For example, in reality students can ask for help several times as they progress in their practice, but in the model it is not possible to ask the teacher again if their assistance has already been requested a first time.

The distribution of the variable resembles a lognormal distribution. To corroborate it a hypothesis test such as the Kolmogorov test would have to be carried out. But in this master's thesis this is not relevant information. What is important is to emphasize that the reduction in consultation times is a second key to validate the model as well as to justify again the usefulness of the videos.

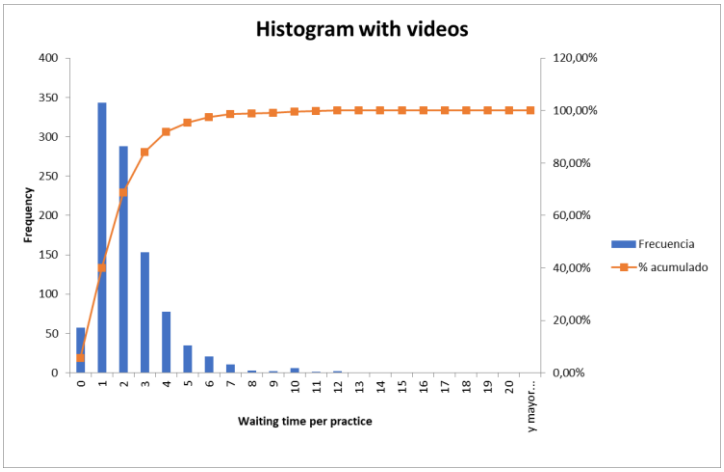
2.6.3 STUDY OF THE WAITING TIME OF THE STUDENTS TO BE ATTENDED

This study measures the average time that students have been waiting for assistance per practice. If in the first case a team waits a total of 30 minutes to receive assistance in the practice they are performing, in the second case this wait is reduced to 1.7 minutes.



Q/p (minutes)	
Media	30,0928517
Error típico	0,27164152
Mediana	30,4863228
Moda	#N/D
Desviación estándar	8,59005909
Varianza de la muestra	73,7891151
Curtosis	0,28983587
Coeficiente de asimetría	-0,26248837
Rango	58,2341544
Mínimo	1,58148
Máximo	59,8156344
Suma	30092,8517
Cuenta	1000
Nivel de confianza(95,0%)	0,53305342

Illustration 74: Histogram of the waiting time without videos.



Q/p (minutes)	
Media	1,72319491
Error típico	0,05107242
Mediana	1,2576528
Moda	0
Desviación estándar	1,6150516
Varianza de la muestra	2,60839168
Curtosis	6,49035325
Coeficiente de asimetría	2,09165191
Rango	11,6470968
Mínimo	0
Máximo	11,6470968
Suma	1723,19491
Cuenta	1000
Nivel de confianza(95,0%)	0,10022152

Illustration 75: Histogram of the waiting time with videos.

This marked decrease is quite similar to what I personally observed in reality. However, something similar to what I described in the previous section occurs. The model does not contemplate second waiting times when a group has already requested assistance from the teacher previously.

In the first case the distribution closely resembles a normal distribution and in the second case it would be a lognormal distribution. Again, what is important to highlight is that this reduction of the waiting time is the third key to validate the model.

2.7 MODEL VALIDATION

The model is quite close to reality. The histograms obtained in the uncertainty analysis of the previous section demonstrate the similarity with the data observed in the photonics laboratory.

The sensitivity analysis explained in the next section has shown that the chosen input variables explain the changes that happen in the model. For example, increasing the access to videos reduces the queue and increases the percentage of completed practices. Also, access to videos has more influence than the level of English. This is because when at least someone in the team has an advanced English level, the entire team adopts the attributes of the most proficient. Bayes' theorem of conditional probability can explain this phenomenon. As class attendance decreases, the percentage of completed practices also decreases.

17 out of the 25 practices were completed during my personal observation in May 2018. This corresponds with 68% of the total number of practices, a percentage remarkably similar to the 68.8% of completed practices predicted by the model under similar circumstances. This allows me to conclude that the model provides consistent data. This can be explained by the fact that the internal logical structure of the model and its operating mechanism resembles the logical decision-making processes of the students. In fact, the PERT diagram provided a solid basis for the modeling and the data collected from personal observations (attendance, English level, access to videos and task specialization) complemented this modeling.

2.8 SENSITIVITY STUDY BETWEEN INPUT AND OUTPUT VARIABLES.

First, it should be noted that the input variables to the model are these 4:

- The students' class attendance level.
- The students' level of English.

- The visualization of the tutorial videos that explain the procedure to be followed in each practice.
- The work mode, which describes whether or not the teams subdivide the tasks of the same practice.

And that the output variables are these three:

- The number of practices completed.
- The time taken by the teacher to attend to the students.
- The time the students had to wait for the teacher's assistance.

Secondly, the correlations between the four input variables and the three output variables are sought. The R^2 value will determine this level of correlation. The closer to the value one the more correlated the variables will be.

Thirdly, when there is a strong correlation, then a regression study will be performed to find the mathematical function that best describes the point cloud created. For this purpose, the input variable is divided into ten intervals of 10% amplitude each. Subsequently, the mean of the values of the output variable that also belong to the same interval into which the input variable has been divided is calculated.

2.8.1 CORRELATION STUDY OF THE OUTPUT VARIABLES AS A FUNCTION OF ATTENDANCE

In this study the attendance variable has been divided into 10 intervals of 10% amplitude.

2.8.1.1 CORRELATION BETWEEN THE LEVEL OF ATTENDANCE AND THE PERCENTAGE OF PRACTICES COMPLETED

The correlation study of the variable percentage of practices completed as a function of attendance has provided an R^2 value of 0.9838, which means that 98.38% of the change in the percentage of practices completed can be explained by the change in the percentage of students' attendance in class. Moreover, the range where this change occurs is wide, ranging from 5% to 49%. This indicates the importance of this variable.

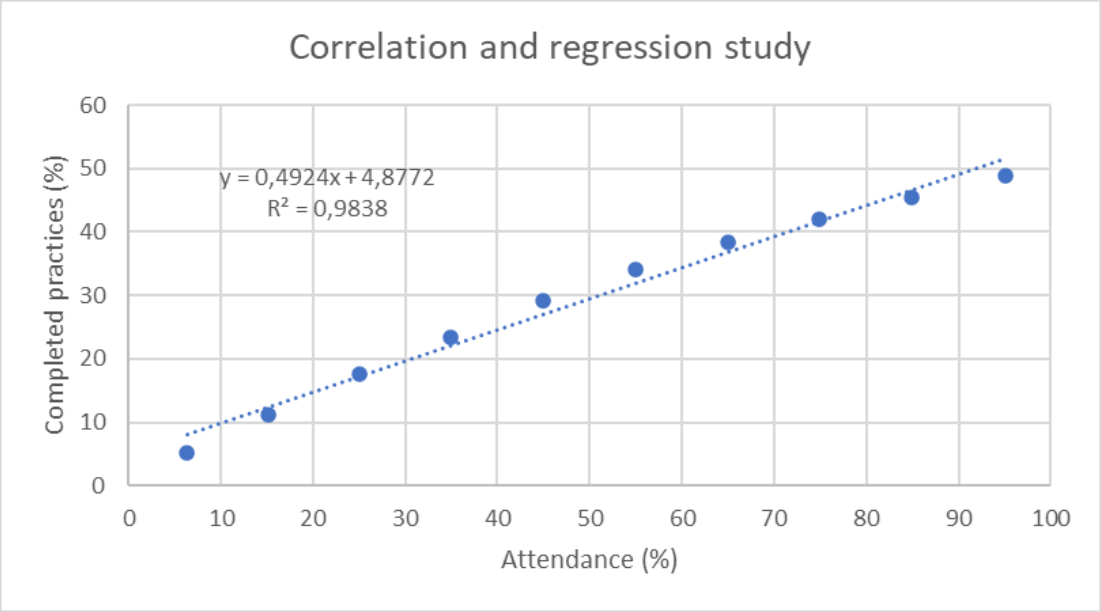


Illustration 76: correlation and regression study between attendance and percentage of completed practices.

On the other hand, the regression study has determined that the mathematical function that best describes the point cloud created is a first-degree equation (y=0.4924x+4.8772).

2.8.1.2 CORRELATION BETWEEN THE LEVEL OF ATTENDANCE AND THE TEACHER'S TIME TO ATTEND TO STUDENTS

Regarding the time the teacher spends to solve the students' questions, the graph shows a high quadratic correlation with an R^2 close to 99%. As attendance increases, the time the teacher needs to attend to the students increases, but it reaches a higher level because the number of teams is limited to 5. Its significance has been moderate because the range is from 1.12 to 4.31 minutes per practice.

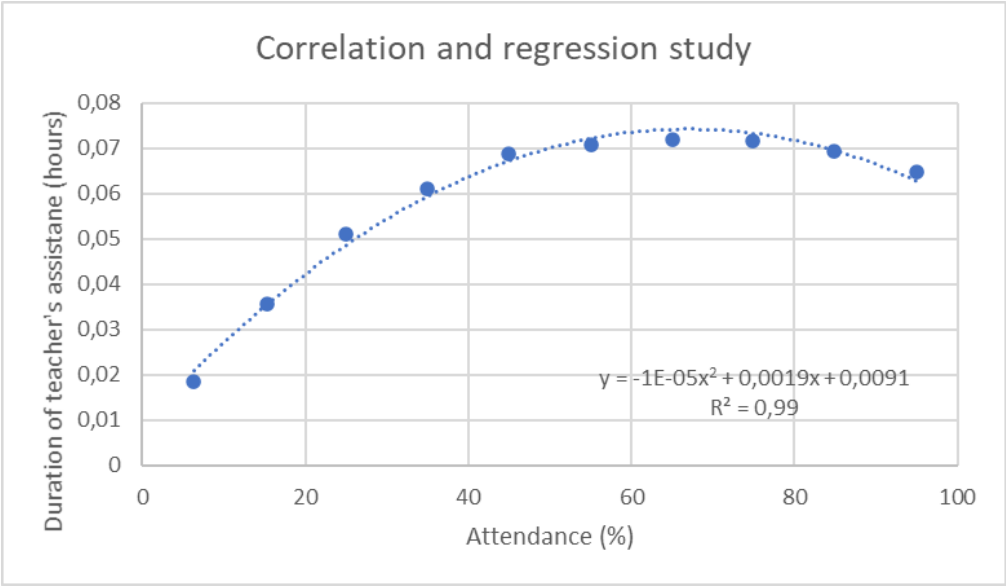


Illustration 77: correlation and regression study between attendance and duration of teacher's assistance.

On the other hand, the regression study has determined that the mathematical function that best describes the point cloud created is the following second-degree equation: ($y=-0.00001x^2+0.0019x+0.0091$).

2.8.1.3 CORRELATION BETWEEN THE LEVEL OF ATTENDANCE AND THE WAITING TIME OF STUDENTS

In this case, the time that students must wait to be attended by the teacher can be adjusted by a polynomial function of second degree ($\mathbf{y}=-7\cdot10^{-6}\mathbf{x^2}+1{,}3\cdot10^{-3}\mathbf{x}-9{,}5\cdot10^{-3}$).

The correlation is extremely high, in the order of 98.96%, and its significance is moderate, given that it ranges from 0.11 to 3.37 minutes of waiting time per practice.

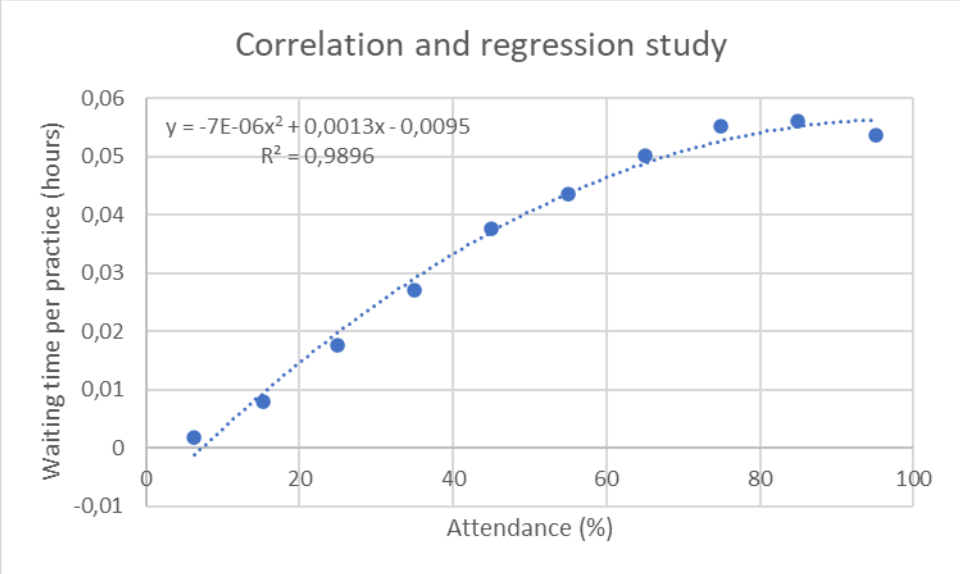


Illustration 78: correlation and regression study between attendance and waiting time.

2.8.2 CORRELATION STUDY OF THE OUTPUT VARIABLES AS A FUNCTION OF THE WORKING MODE OF THE TEAM

In this second study, the work mode variable has been divided into 10 intervals of 10% amplitude each.

2.8.2.1 CORRELATION BETWEEN THE WORK MODE AND THE PERCENTAGE OF COMPLETED PRACTICES

In this case, the percentage of completed practices can be fitted by a first-degree polynomial function ($y=0.1671x+22.91$).

A remarkably high linear correlation is observed ($R^2=0.9946$). This indicates that 99.46% of the change in the percentage of completed practices can be explained by the way the teams decide to work. The significance is considerable given that the range is between 24% and 39%.

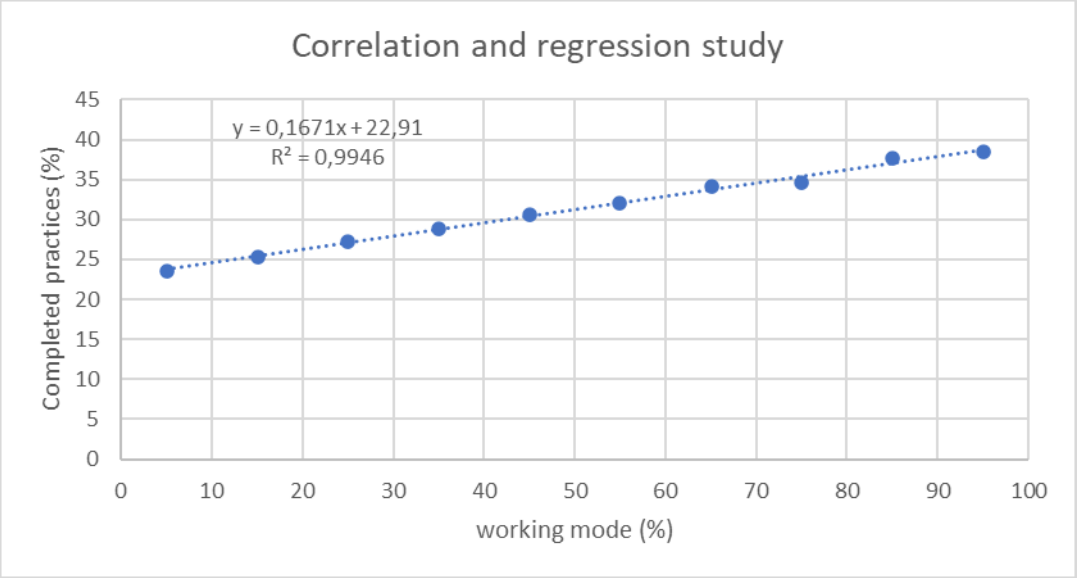


Illustration 79: correlation and regression study between working mode and percentage of completed practices.

2.8.2.2 CORRELATION BETWEEN THE WAY OF WORKING AND THE TEACHER'S TIME FOR ATTENDING STUDENTS

In this case, the study shows that the teacher's time can be fitted by a first-degree polynomial function (y=0.0001x+0.0543).

An extremely high linear correlation is observed (R2=0.9679). However, the significance is low because the range is between 3 and 4 minutes.

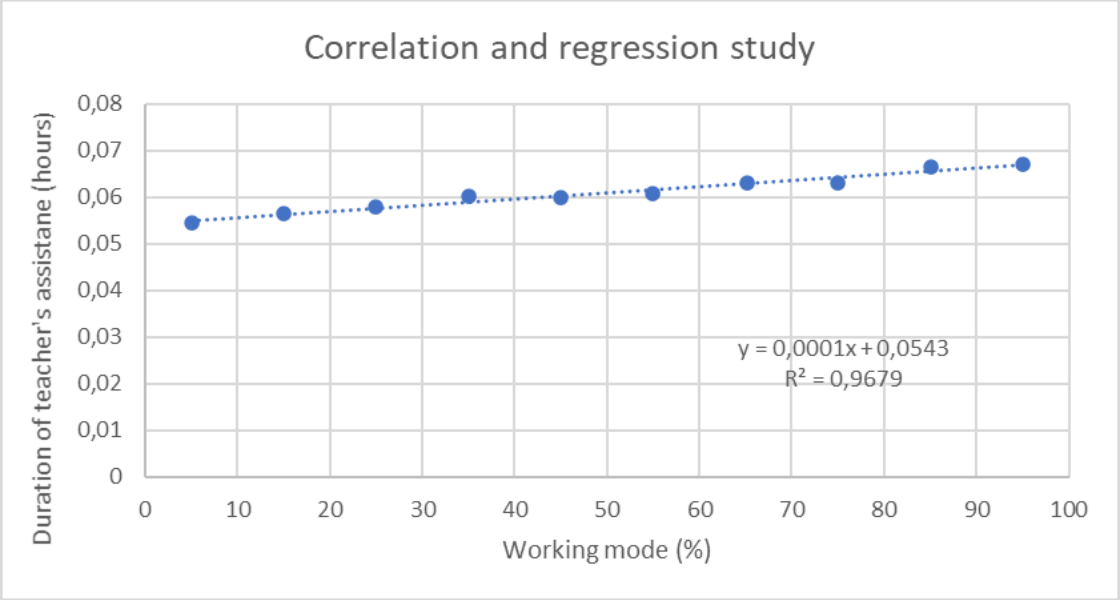


Illustration 80: correlation and regression study between working mode and duration of teacher's assistance.

2.8.2.3 CORRELATION BETWEEN THE WORKING MODE AND THE WAITING TIME OF STUDENTS

In this case, the study shows that the students' waiting time can be adjusted by a first-degree polynomial function (**y**=0.0005**x**+0.0138).

A very high linear correlation is observed (R^2=0.9912). However, the significance is moderate since the range is between 1 and 3.62 minutes.

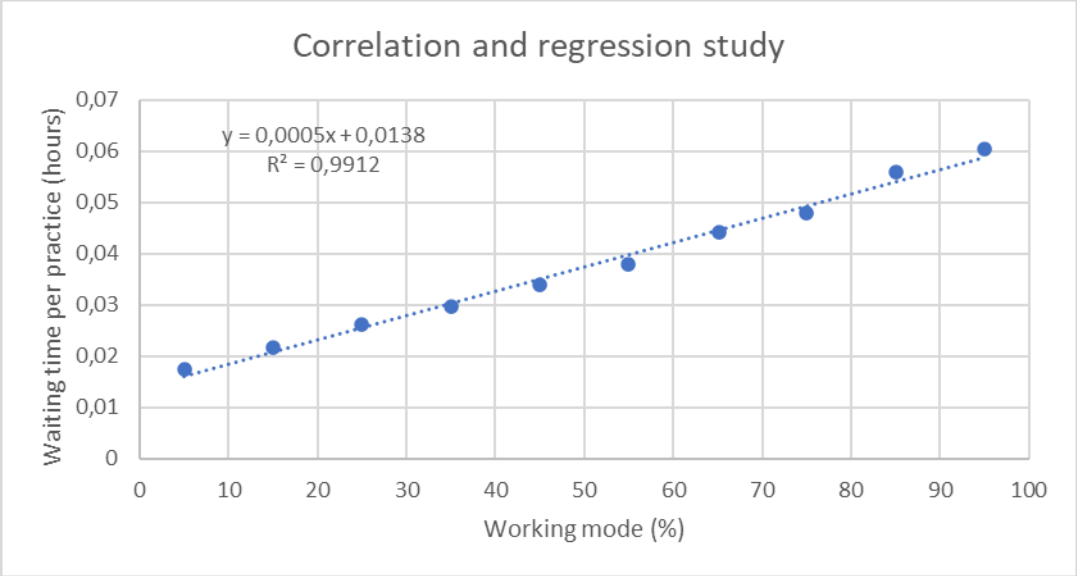


Illustration 81: Correlation and regression study between working mode and waiting time.

2.8.3 CORRELATION STUDY OF THE OUTPUT VARIABLES AS A FUNCTION OF THE VIDEO TUTORIALS

In this third study, as in the previous sections, the variable access to video tutorials was divided into 10 intervals of 10% amplitude each.

2.8.3.1 CORRELATION BETWEEN ACCESS TO VIDEOS AND THE PERCENTAGE OF COMPLETED PRACTICES

In this case, the percentage of completed practices can be adjusted by a first-degree polynomial function (**y**=0.0519**x**+28.688).

A high linear correlation was observed (R^2=0.9385). This indicates that 93.85% of the change in the percentage of practices completed can be explained by watching the videos. The significance is moderate given that the range is between 28.75% and 33.35%.

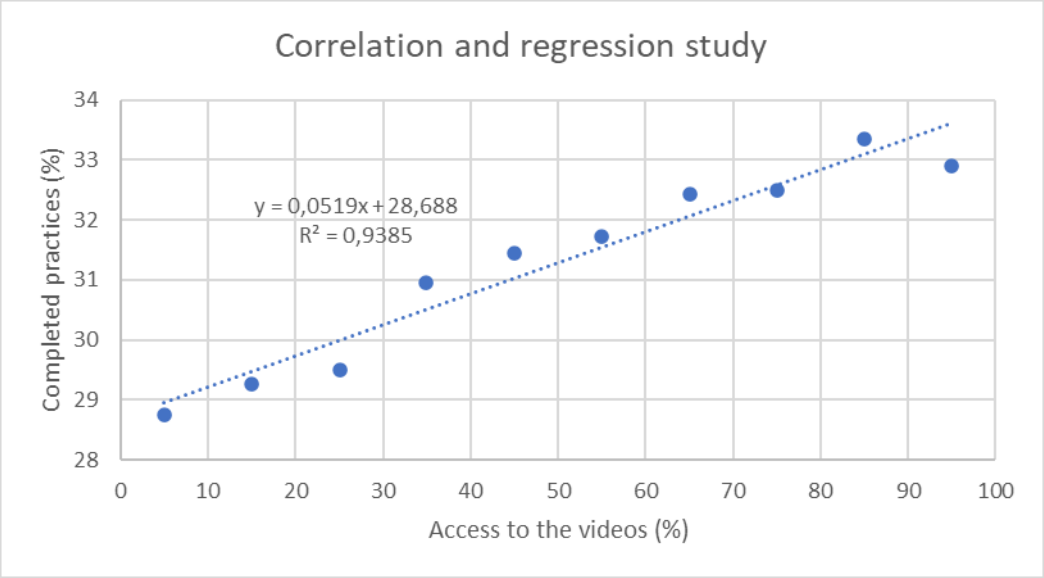


Illustration 82: correlation and regression study between access to videos and percentage of completed practices.

2.8.3.2 CORRELATION BETWEEN ACCESS TO VIDEOS AND THE TEACHER'S TIME TO ATTEND TO STUDENTS

In this case, the study shows that the teacher's time can be fitted by a first-degree polynomial function (y=0.0002x+0.0727).

An extremely high linear correlation is observed (R^2=0.9722). However, the significance is low because the range is between 4.4 and 3.1 minutes.

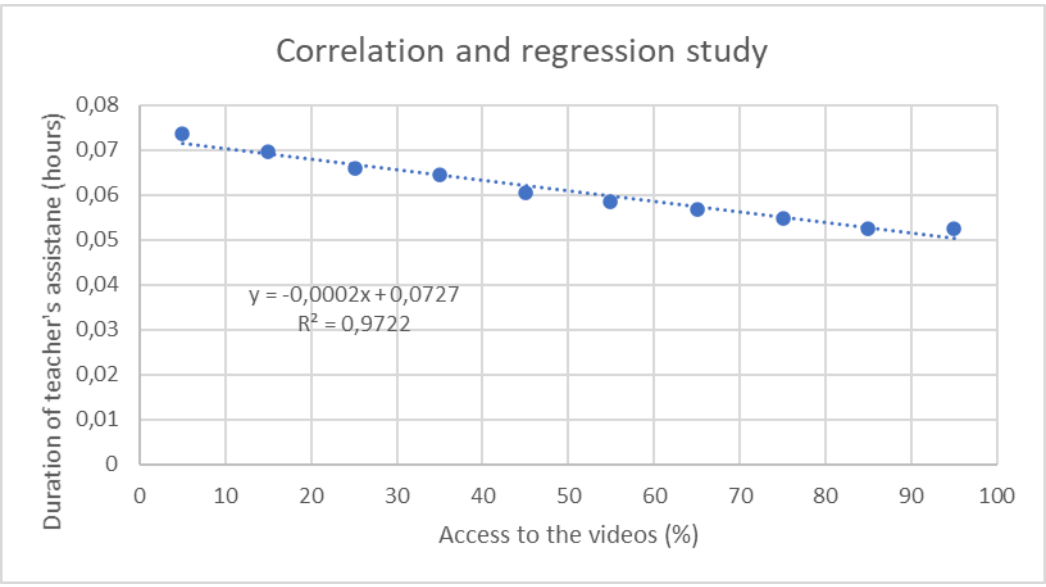


Illustration 83: correlation and regression study between access to videos and duration of teacher's assistance.

2.8.3.3 CORRELATION BETWEEN THE ACCESS TO VIDEOS AND STUDENTS' WAITING TIME

In this case, the study shows that the students' waiting time can be fitted by a first-degree polynomial function (y=-0.0002**x**+0.0497).

A high linear correlation is observed (R2=0.9595), but the significance is moderate as the range is between 3 and 1.7 minutes.

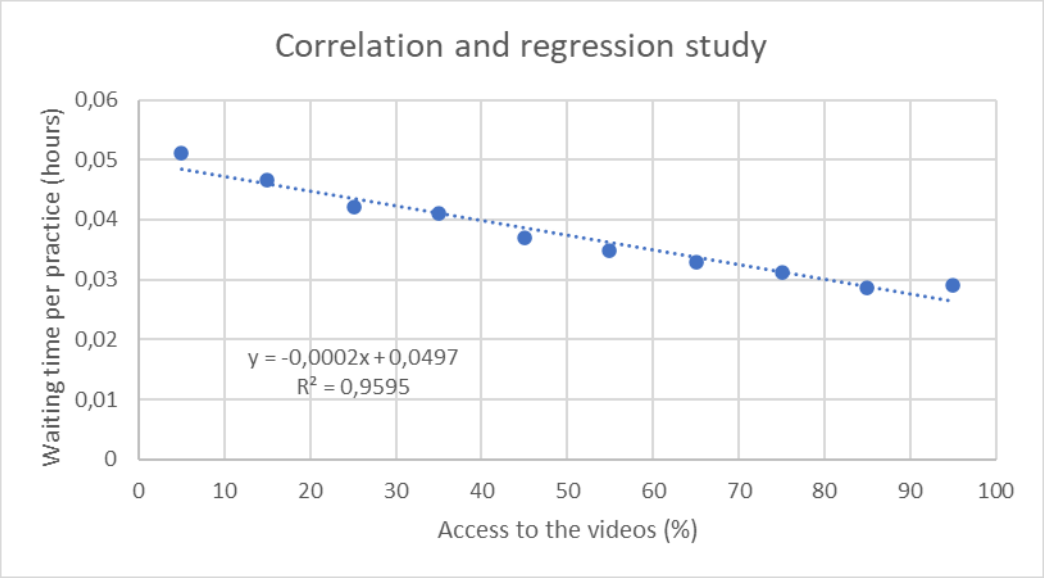


Illustration 84: Correlation and regression study between access to videos and waiting time.

2.8.4 CORRELATION STUDY OF THE OUTPUT VARIABLES AS A FUNCTION OF THE ENGLISH LEVEL

This fourth and final study analyzes the variable advanced English level by dividing it again into 10 intervals of 10% amplitude each.

2.8.4.1 CORRELATION BETWEEN THE STUDENTS' LEVEL OF ENGLISH AND THE PERCENTAGE OF COMPLETED PRACTICES

In this case, the percentage of completed practices can be fitted by a first-degree polynomial function (y=0.0196x+30.291).

A moderately high linear correlation is observed (R^2=0.864). However, the significance is relatively low given that the range is between 30% and 32%.

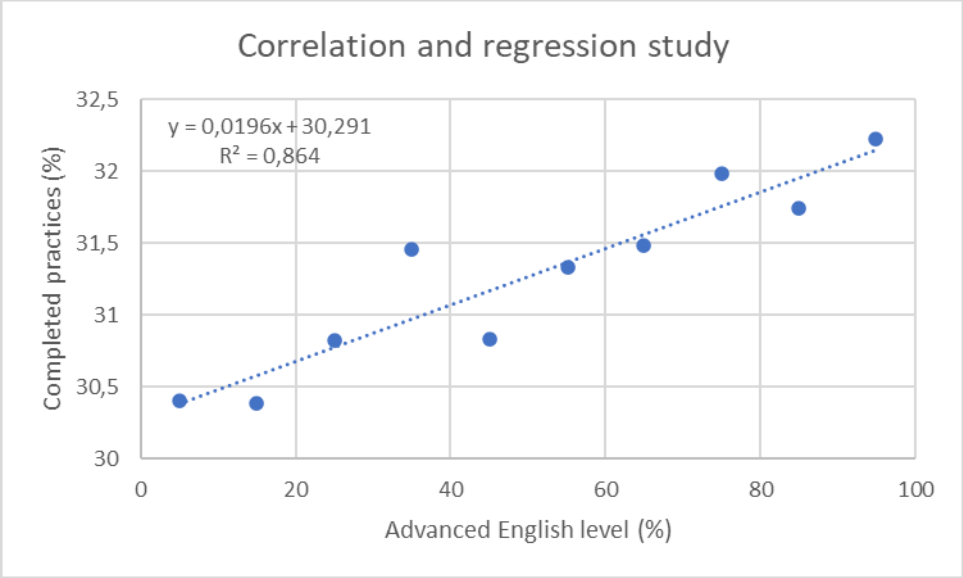


Illustration 85: correlation and regression study between advanced English level and percentage of completed practices.

2.8.4.2 CORRELATION BETWEEN ADVANCED ENGLISH LEVEL AND TEACHER'S ASSISTANCE TIME

In this case, the study shows that the teacher's time can be fitted by a polynomial first-degree function ($y=-9\cdot10^{-5}\mathbf{x}+0.0654$).

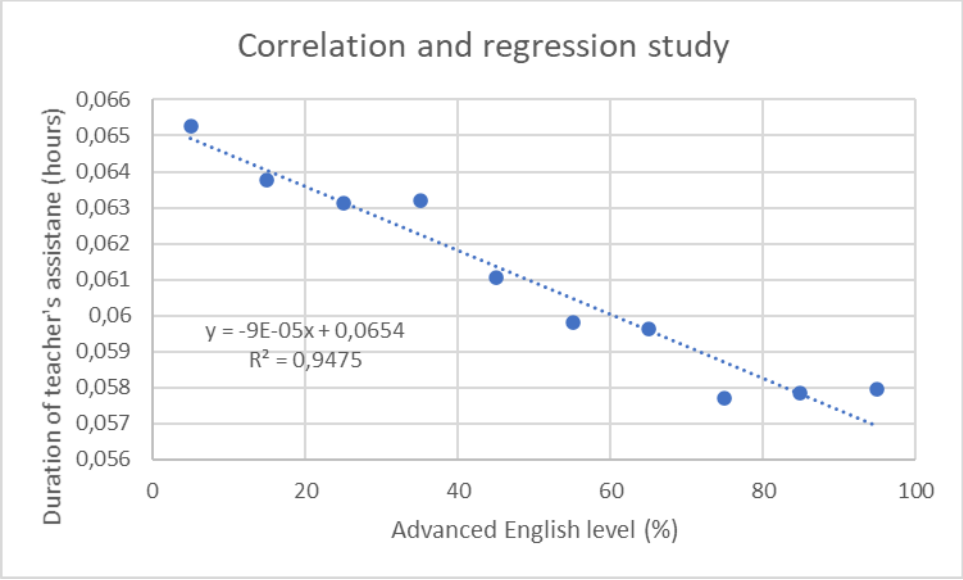


Illustration 86: correlation and regression study between advanced English level and duration of teacher's assistance.

A remarkably high linear correlation is observed (R2=0.9475). However, the significance is low because the range is between 3 and 4 minutes.

2.8.4.3 CORRELATION BETWEEN ADVANCED ENGLISH LEVEL AND STUDENT'S WAITING TIME

In this case, the study shows that the students' waiting time can be adjusted by a first-degree polynomial function ($\mathbf{y}=-8\cdot10^{-5}\mathbf{x}+0.0413$).

A high linear correlation is observed (R2=0.9263), but again the significance is low given that its range is between 2 and 2.5 minutes.

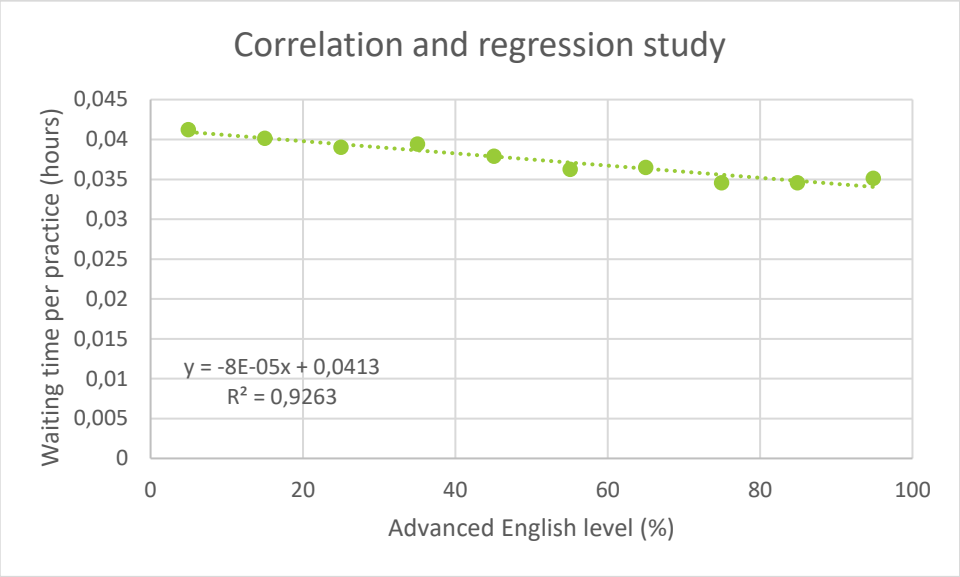


Illustration 87: Correlation and regression study between advanced English level and waiting time.

2.8.5 SUMMARY OF THE CORRELATION STUDY

In relation to the third objective of this master's thesis, these results allow me to classify the variables by importance for the effective operation of the photonics practice sessions. Attendance is undoubtedly the one that must be closely monitored because it determines with a wide range the percentage of completed practice sessions. Secondly, the working mode acquires considerable importance since the initial problem of long waiting time has been solved with the incorporation of video tutorials. In this sense, the videos play a decisive role in reducing the queue and the time of using the teacher's resource, but at present it would not be desirable to improve the quality of the videos. Finally, the level of English ranks fourth in importance. This can be explained by the fact that the videos provide a lot of graphical information that does not require much reading to understand. Likewise, when at least one person in a group is fluent in English, the rest of the classmates can get along easily.

The following table shows a summary of the sensitivity, regression, and significance studies between the four input variables and the three output variables.

			Output variables		
			Percentage of completed practices (%)	Teacher's assistance time (hours)	Students' waiting time (hours)
Input variables	Attendance (%)	Correlation (R2)	0,9838	0,99	0,9896
		Regression	y=0,4924x+4,8772	$\mathbf{y}=-1\cdot10^{-5}\mathbf{x}^{2}+1{,}9\cdot10^{-3}\mathbf{x}+9{,}1\cdot10^{-3}$	$\mathbf{y}=-7\cdot10^{-6}\mathbf{x}^{2}+1{,}3\cdot10^{-3}\mathbf{x}-9{,}5\cdot10^{-3}$
		Rank of importance	Between 5% and 49%	Between 1,12 and 4,31 minutes	Between 0,11 and 3,37 minutes
	Working mode (%)	Correlation (R2)	0,9946	0,9679	0,9912
		Regression	$\mathbf{y}=0.1671\mathbf{x}+22.91$	$\mathbf{y}=0.0001\mathbf{x}+0.0543$	$\mathbf{y}=0.0005\mathbf{x}+0.0138$
		Rank of importance	Between 24% and 39%.	Between 3 and 4 minutes	Between 1 and 3,62 minutes
	Access to videos (%)	Correlation (R2)	0,9385	0,9722	0,9595
		Regression	$\mathbf{y}=0.0519\mathbf{x}+28.688$	$\mathbf{y}=0.0002\mathbf{x}+0.0727$	$\mathbf{y}=-0.0002\mathbf{x}+0.0497$
		Rank of importance	Between 28,75% and 33,35%.	Between 3,1 and 4 minutes	Between 1,7 and 3 minutes
	Advanced English level (%)	Correlation (R2)	0,864	0,9475	0,9263
		Regression	$\mathbf{y}=0.0196\mathbf{x}+30.291$	$\mathbf{y}=-9\cdot10^{-5}\mathbf{x}+0.0654$	$\mathbf{y}=-8\cdot10^{-5}\mathbf{x}+0.0413$
		Rank of importance	Between 30% and 32%	Between 3 and 4 minutes	Between 2 and 2,5 minutes

Illustration 88::table with the results of the sensitivity, regression, and importance analyses between the four input variables and the three output variables.

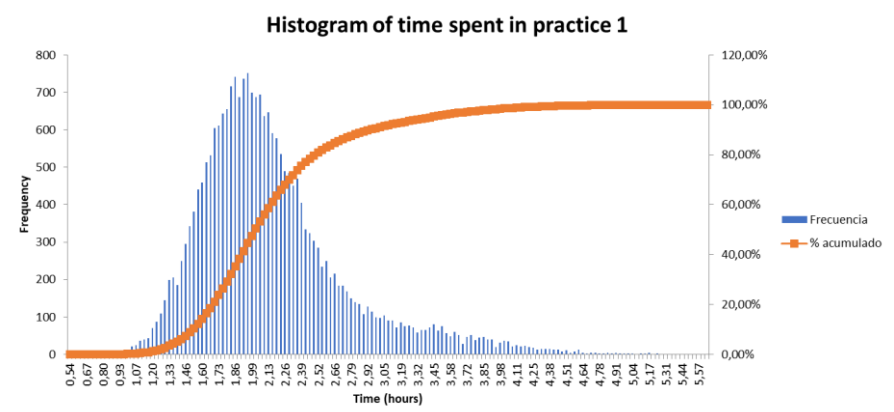
2.9 DURATION OF THE FIVE PRACTICES

In a simulation with 5000 different input vectors, the time required by the students to complete each of the five practices has been studied. The conditions chosen to assign values to the input variables were as follows:

- Class attendance level between 95% and 100%.
- The working mode with a tendency between 80% and 100% to specialize in different tasks within the same practice.
- A level of access to videos between 80% and 100%.
- Between 15% and 25% of students with an advanced English level.

2.9.1 DURATION OF PRACTICE 1

According to the cumulative probability line obtained in the histogram, in 47.49% of the simulated cases, the students were able to complete this practice in less than 2 hours. If the class lasted 30 minutes more, this percentage would increase to 80% and if it lasted one more hour, 90% would be reached.

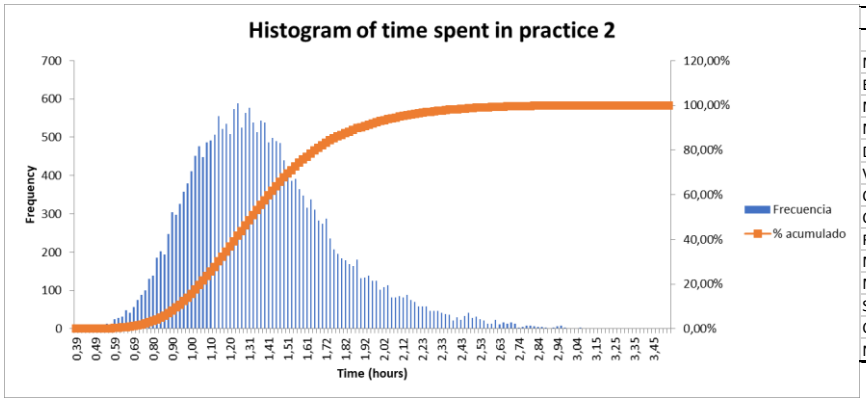


PRACTICE 1	
Media	2,1419767
Error típico	0,00393758
Mediana	2,02205
Moda	1,700073
Desviación estándar	0,60662984
Varianza de la muestra	0,36799977
Curtosis	2,43388693
Coeficiente de asimetría	1,34090262
Rango	5,099883
Mínimo	0,536579
Máximo	5,636462
Suma	50839,817
Cuenta	23735
Nivel de confianza(95,0%)	0,0077179

Illustration 89: Histogram of the duration of practice 1.

2.9.2 DURATION OF PRACTICE 2

According to the cumulative probability line obtained in the histogram, in 92.9% of the simulated cases, the students were able to complete this practice in less than 2 hours. If the class lasted 30 minutes longer, this percentage would increase to 98.9%.

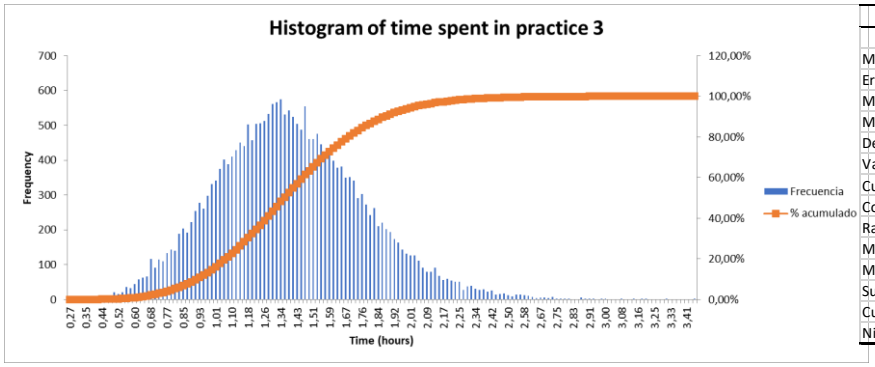


PRACTICE 2	
Media	1,37108354
Error típico	0,00252594
Mediana	1,319086
Moda	0,937589
Desviación estándar	0,38915009
Varianza de la muestra	0,15143779
Curtosis	1,08755674
Coeficiente de asimetría	0,84482607
Rango	3,145794
Mínimo	0,387505
Máximo	3,533299
Suma	32542,6679
Cuenta	23735
Nivel de confianza(95,0%)	0,004951

Illustration 89: Histogram of the duration of practice 2.

2.9.3 DURATION OF PRACTICE 3

According to the cumulative probability line obtained in the histogram, in 94% of the simulated cases, the students were able to complete this practice in less than 2 hours. If the class lasted 30 minutes longer, this percentage would increase to 99.5%.

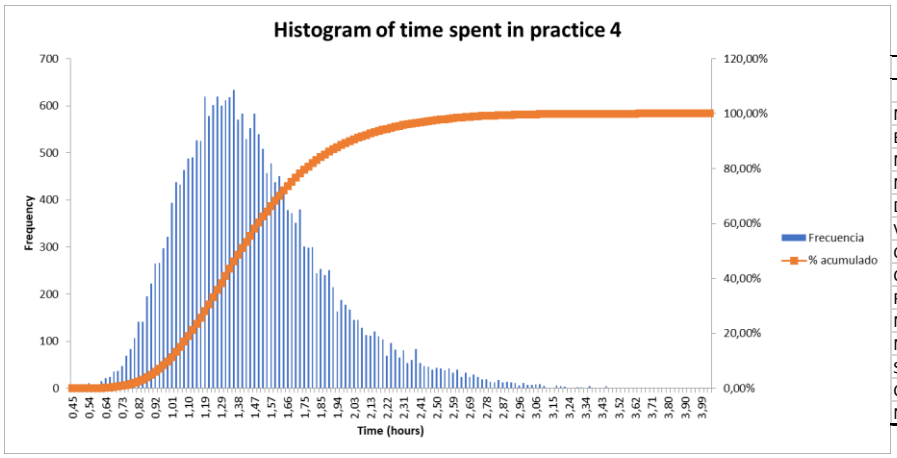


PRACTICE 3	
Media	1,38222112
Error típico	0,00243921
Mediana	1,360904
Moda	1,595413
Desviación estándar	0,37578831
Varianza de la muestra	0,14121685
Curtosis	0,31621356
Coeficiente de asimetría	0,36584081
Rango	3,181869
Mínimo	0,269861
Máximo	3,45173
Suma	32807,0183
Cuenta	23735
Nivel de confianza(95,0%)	0,004781

Illustration 90: Histogram of the duration of practice 3.

2.9.4 DURATION OF PRACTICE 4

According to the cumulative probability line obtained in the histogram, in 89.31% of the simulated cases, the students were able to complete this practice in less than 2 hours. If the class lasted 30 minutes longer, this percentage would increase to 97.62%.

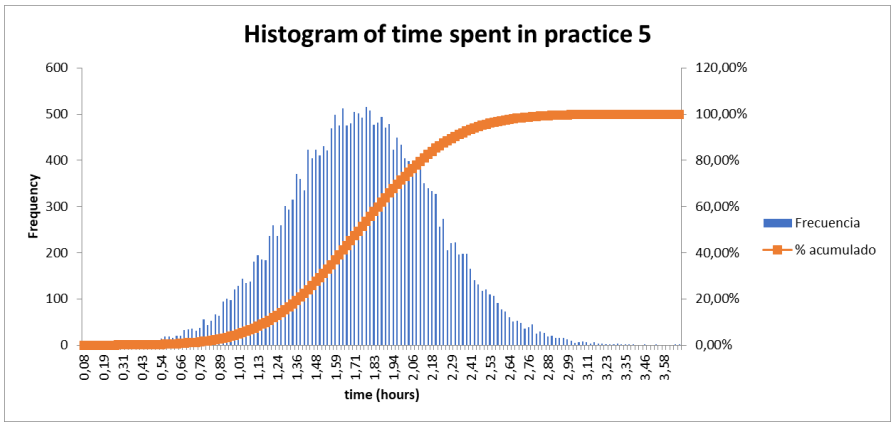


PRACTICE 4	
Media	1,45758898
Error típico	0,00271369
Mediana	1,394204
Moda	1,210366
Desviación estándar	0,41804035
Varianza de la muestra	0,17475774
Curtosis	1,30708887
Coeficiente de asimetría	0,93353626
Rango	3,586453
Mínimo	0,449424
Máximo	4,035877
Suma	34590,044
Cuenta	23731
Nivel de confianza(95,0%)	0,00531901

Illustration 91: Histogram of the duration of practice 4.

2.9.5 DURATION OF PRACTICE 5

According to the cumulative probability line obtained in the histogram, in 71.40% of the simulated cases, the students were able to complete this practice in less than 2 hours. If the class lasted 30 minutes longer, this percentage would increase to 95.60%.



P5	
Media	1,74249067
Error típico	0,00288171
Mediana	1,74104
Moda	1,364005
Desviación estándar	0,44390514
Varianza de la muestra	0,19705177
Curtosis	0,07542247
Coeficiente de asimetría	0,04527696
Rango	3,5972
Mínimo	0,075005
Máximo	3,672205
Suma	41347,561
Cuenta	23729
Nivel de confianza(95,0%)	0,00564834

Illustration 92: Histogram of the duration of practice 5.

2.9.6 SUMMARY OF THE FIVE PRACTICES

The following table shows a summary of the probabilities of completing each practice as a function of the time available.

	practice 1	practice 2	practice 3	practice 4	practice 5
Probability of finishing in less than 2 hours.	47,49%	92,90%	93,85%	89,31%	71,40%
Probability of finishing in less than 2.5 hours.	80,00%	98,90%	99,50%	97,62%	95,60%
Probability of finishing in less than 3 hours.	90,00%	99,93%	99,97%	99,67%	99,70%

Illustration 93: table with the probabilities of completing each practice

According to these results, the practice that generates the most difficulty is the first one.

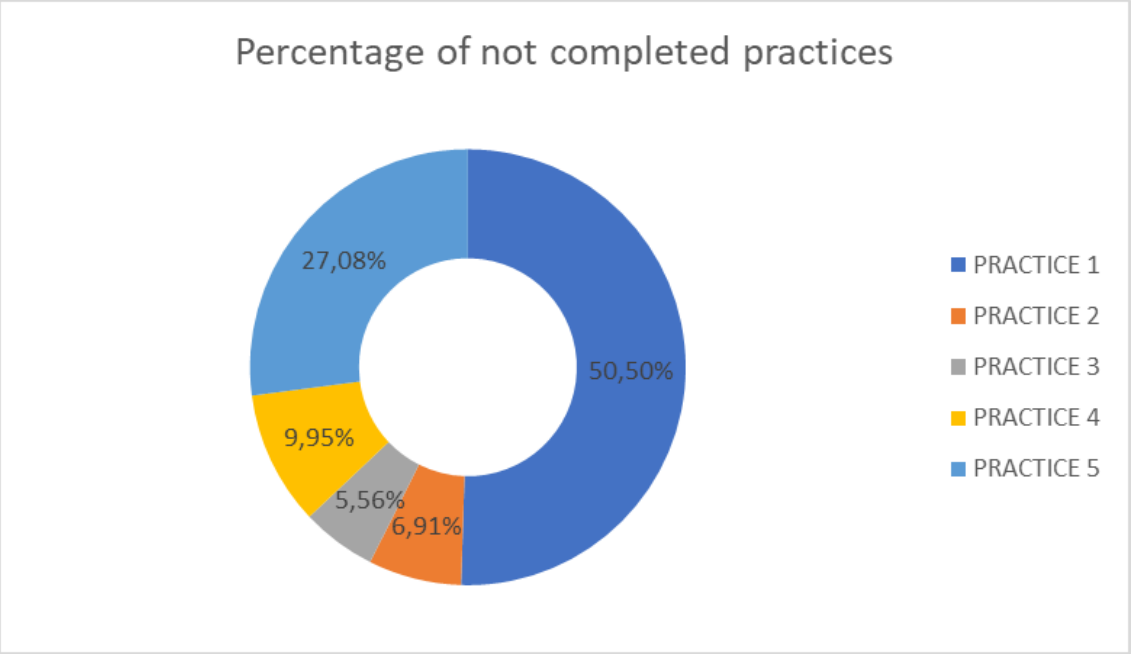


Illustration 94: graph to study not completed practices

This other comparative study shows that 50.50% of the total number of non-completed practices correspond to the first one, followed by practice 5 with 27.08%, the fourth with 9.95%, the second with 6.91% and the third with 5.56%. Practice 1 is the only one whose average time to complete it is more than two hours.

	PRACTICE 1	PRACTICE 2	PRACTICE 3	PRACTICE 4	PRACTICE 5
average time (hours)	2,14	1,37	1,38	1,46	1,74
Number of not completed practices	12341	1688	1358	2432	6618
Percentage of not completed practices	50,50%	6,91%	5,56%	9,95%	27,08%

Illustration 95: Table to study the average duration of each practice and the percentages of non-completed ones.

Given that the time available is less than two hours due to the teacher's initial explanation, the following table calculates the percentage of practices completed considering this explanation in the first case and without considering it in the second. The result shows that an improvement of 18.76% could be achieved if this explanation were reduced to the maximum.

Percentage of finished practices with teacher's explanation	70,17%
Percentage of finished practices without teacher's explanation	88,92%

Illustration 962: Table to study the effect of the reduction of the initial explanation.

The cumulative probability tables for the five practices are shown in annex 4.1.

3 SUMMARY OF RESULTS

3.1 ENVIRONMENTAL ANALYSIS

The realization of these practices of photonics does not generate any type of environmental problem. Disposing the mixture of alcohol and water in the sewerage system does not have any harmful effect for the environment since the amount of alcohol is only 10ml and it is also diluted in water.

The disposal of water containing sucrose does not have a relevant impact either. Finally, the proper disposal of photodiode and voltmeter batteries when they are worn out should be considered.

Finally, as far as safety measures are concerned, it is important to highlight the use of laser light protection devices. These are based on pieces of plywood lined with black cardboard. The following drawing indicates the places where they are to be used, mainly in practiceS 1 and 4.

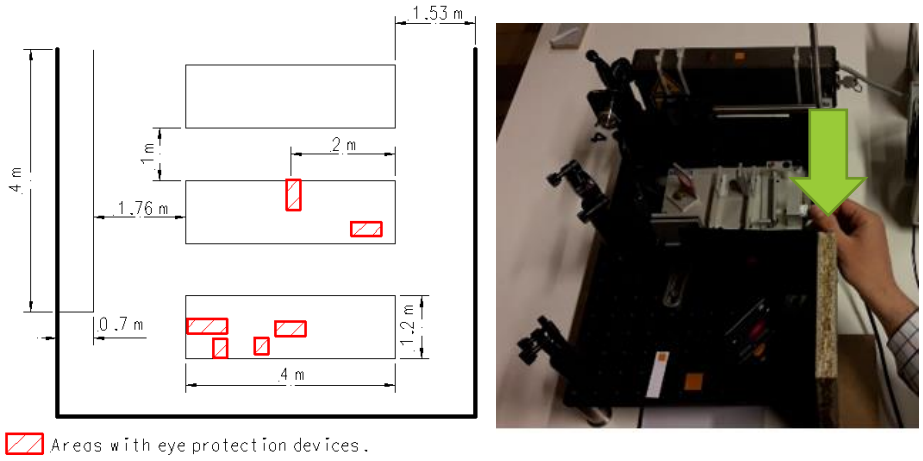


Illustration 973: Drawing indicating the locations where the laser light shielding devices are to be used. The green arrow points to one of these devices in practice 4.

3.2 CONCLUSIONS

The conclusions of this work are based on the analysis of whether the set objectives have been met while respecting the specifications.

In relation to the first objective, my discrete event model created with Arena software has correctly simulated the way the photonics practices work. This can be explained for two reasons. On the one hand, the choice of input and output variables has been appropriate and on the other hand, these have replicated the mechanisms and processes involved in a

learning process. Understanding these internal mechanics played a key role in satisfying the GIGO criterion.

The second objective was to validate the model against reality. The following information justifies that this objective has been successfully met:

- Queuing and teacher consultation times have been drastically reduced while at the same time the number of completed practices has increased. This corresponds to actual observations.
- The structure of the Arena model is organised based on PERT diagrams and has been supplemented with the processes studied in reality.
- The mechanics of the classes are well understood and the relevant aspects of the classes (attendance, videos, and the way the teams work) have been identified. These would also correspond to the 20% of variables that explain 80% of what happens (Pareto Principle).

The third objective was the most ambitious because it sought to find the variables with the greatest impact on the logistical improvement of practices. In this sense, the risk analysis carried out showed that watching the videos, either before or during the session, was the most important. On the other hand, absenteeism made more sense for validating the model. The working method based on the specialisation of tasks within each practice plays a relevant role. For the future, it would be advisable to recommend students to study these videos in advance and to specialise in different tasks within each practice, except for the fifth one which, as explained above, does not allow for such subdivision. Anecdotally, the larger the working groups formed, the less important it becomes to have an advanced level of English. On the other hand, if students were to work individually, the percentage of completed practices would depend much more on their level of English.

Given that in the current situation the students already have the videos, the waiting times are short and the duration of the consultations with the teacher are also short, the alternatives proposed to improve the logistical management of the practical sessions in the photonics laboratory would be the following:

1. Extending the duration of each session. According to the histograms in section 4.10, with a duration of two and a half hours, students would be able to complete all the practices with a probability of over 95%, except for practical session 1, which would have a probability of 80%.
2. Reducing the activities in practice 1. For example, the last activity related to the measurement of water depth using the Pffund effect could be left as an optional

activity. This reduction would increase the probability of completion by more than 90% of the cases.

3. Reducing the time of the initial explanation. By doing this, the percentage of completed exercises could increase up to 88%.
4. Maintaining the sixth make-up session. This would allow students to carry out the incomplete activities. However, although with a low probability, there could be some inconvenience. For example, if a team had to perform a practice that they could not perform on the scheduled day, then other teams would have difficulty using the material belonging to that practice. In this case, in order to avoid this type of logistical complications, it would be advisable for the students to take advantage of the free time when the practices have already been freed up to make up for the pending activities.

An appropriate way to conclude this section would be to answer the questions posed in the introduction:

- **Is more space needed in the laboratory?**

  The laboratory has adequate space for the 20 students. If the enrollment of students increased and teams with more students had to be organized, it would be advisable to set up an additional workbench in the current physics laboratory.

- **Should more videos be edited?**

  No, the current ones are already doing their job.

- **Should more teachers be hired?**

  No, the current teacher's consultation time means that he is not under a great deal of stress.

- **Should the duration of the working sessions in the laboratory be extended?**

  Yes, an extra 30 minutes would be sufficient in 90% of cases.

- **Should some activities be eliminated?**

  Yes, especially in practice 1. This could avoid a bottleneck in the sixth make-up session.

- **Should students be given more training to improve their English?**

  No, the current level allows them to function effectively in a team.

3.3 BIBLIOGRAPHY

- Manuel D. Rossetti - Simulation Modeling and Arena (2015, Wiley)
- Tayfur Altiok, Benjamin Melamed - Simulation Modeling and Analysis with ARENA (2007, Academic Press)
- W. David Kelton_ Randall P. Sadowski_ Nancy Swets - Simulation with Arena (2014, McGraw-Hill Education)
- Simulación un enfoque practico. Autor Raul Coss Bu. editorial Limusa
- Arena user guide.
- D.P. Loucks and E. van Beek, Water Resource Systems Planning and Management
- Variables and functions guide of Arena
- https://en.wikipedia.org/wiki/List_of_discrete_event_simulation_software
- Risto S. Andsten & Jussi K. Vaurio (1992) Sensitivity, Uncertainty, and Importance Analysis of a Risk Assessment, Nuclear Technology, 98:2, 160-170, DOI: 10.13182/NT92-A34671
- Web Oficial de Rockwell Arena: https://www.arenasimulation.com/

4 ANNEXES

4.1 TABLES WITH CUMULATIVE PROBABILITIES OF THE DURATION OF THE FIVE PRACTICES

4.1.1 CUMULATIVE PROBABILITY OF THE DURATION OF PRACTICE 1

Interval	*Frequency*	*% accumulated*
0,54	1	0,00%
0,57	0	0,00%
0,60	0	0,00%
0,64	0	0,00%
0,67	0	0,00%
0,70	1	0,01%
0,74	2	0,02%
0,77	1	0,02%
0,80	1	0,03%
0,83	3	0,04%
0,87	1	0,04%
0,90	6	0,07%
0,93	8	0,10%
0,97	8	0,13%
1,00	13	0,19%
1,03	22	0,28%
1,07	25	0,39%
1,10	36	0,54%
1,13	40	0,71%
1,17	44	0,89%
1,20	71	1,19%
1,23	87	1,56%
1,27	109	2,02%
1,30	145	2,63%
1,33	198	3,46%
1,36	206	4,33%
1,40	186	5,11%
1,43	249	6,16%
1,46	295	7,41%
1,50	342	8,85%
1,53	381	10,45%
1,56	441	12,31%
1,60	459	14,24%
1,63	513	16,41%
1,66	532	18,65%
1,70	604	21,19%

1,73	612	23,77%
1,76	643	26,48%
1,79	655	29,24%
1,83	716	32,26%
1,86	742	35,38%
1,89	687	38,28%
1,93	736	41,38%
1,96	751	44,54%
1,99	700	47,49%
2,03	688	50,39%
2,06	694	53,31%
2,09	637	56,00%
2,13	647	58,72%
2,16	591	61,21%
2,19	577	63,64%
2,23	536	65,90%
2,26	489	67,96%
2,29	485	70,01%
2,32	451	71,91%
2,36	470	73,89%
2,39	405	75,59%
2,42	334	77,00%
2,46	324	78,37%
2,49	304	79,65%
2,52	285	80,85%
2,56	235	81,84%
2,59	250	82,89%
2,62	206	83,76%
2,66	216	84,67%
2,69	184	85,44%
2,72	184	86,22%
2,76	169	86,93%
2,79	149	87,56%
2,82	139	88,14%
2,85	134	88,71%
2,89	107	89,16%
2,92	128	89,70%
2,95	114	90,18%
2,99	99	90,60%
3,02	97	91,00%
3,05	104	91,44%
3,09	91	91,83%
3,12	90	92,21%
3,15	72	92,51%
3,19	85	92,87%

3,22	76	93,19%
3,25	77	93,51%
3,29	72	93,82%
3,32	58	94,06%
3,35	66	94,34%
3,38	66	94,62%
3,42	72	94,92%
3,45	81	95,26%
3,48	63	95,53%
3,52	76	95,85%
3,55	56	96,08%
3,58	49	96,29%
3,62	61	96,55%
3,65	52	96,76%
3,68	28	96,88%
3,72	46	97,08%
3,75	51	97,29%
3,78	39	97,46%
3,82	45	97,64%
3,85	46	97,84%
3,88	40	98,01%
3,91	40	98,18%
3,95	19	98,26%
3,98	31	98,39%
4,01	37	98,54%
4,05	35	98,69%
4,08	22	98,78%
4,11	25	98,89%
4,15	21	98,98%
4,18	23	99,07%
4,21	19	99,15%
4,25	18	99,23%
4,28	13	99,28%
4,31	14	99,34%
4,34	15	99,41%
4,38	15	99,47%
4,41	13	99,52%
4,44	13	99,58%
4,48	8	99,61%
4,51	11	99,66%
4,54	5	99,68%
4,58	7	99,71%
4,61	13	99,76%
4,64	4	99,78%
4,68	3	99,79%

4,71	4	99,81%
4,74	4	99,83%
4,78	3	99,84%
4,81	2	99,85%
4,84	4	99,87%
4,87	3	99,88%
4,91	4	99,89%
4,94	3	99,91%
4,97	2	99,92%
5,01	3	99,93%
5,04	2	99,94%
5,07	0	99,94%
5,11	3	99,95%
5,14	2	99,96%
5,17	4	99,97%
5,21	0	99,97%
5,24	2	99,98%
5,27	0	99,98%
5,31	0	99,98%
5,34	1	99,99%
5,37	1	99,99%
5,40	0	99,99%
5,44	0	99,99%
5,47	0	99,99%
5,50	1	100,00%
5,54	0	100,00%
5,57	0	100,00%
5,60	0	100,00%
and bigger...	1	100,00%

4.1.2 CUMULATIVE PROBABILITY OF THE DURATION OF PRACTICE 2

interval	*Frequency*	*% accumulated*
0,39	1	0,00%
0,41	1	0,01%
0,43	5	0,03%
0,45	0	0,03%
0,47	5	0,05%
0,49	6	0,08%
0,51	4	0,09%
0,53	11	0,14%
0,55	14	0,20%
0,57	10	0,24%
0,59	25	0,35%

0,61	28	0,46%
0,63	32	0,60%
0,65	48	0,80%
0,67	42	0,98%
0,69	57	1,22%
0,71	75	1,53%
0,73	88	1,90%
0,76	100	2,33%
0,78	130	2,87%
0,80	139	3,46%
0,82	185	4,24%
0,84	203	5,09%
0,86	194	5,91%
0,88	248	6,96%
0,90	304	8,24%
0,92	297	9,49%
0,94	326	10,86%
0,96	357	12,37%
0,98	380	13,97%
1,00	412	15,70%
1,02	451	17,60%
1,04	476	19,61%
1,06	448	21,50%
1,08	487	23,55%
1,10	492	25,62%
1,12	506	27,75%
1,14	555	30,09%
1,16	521	32,29%
1,18	535	34,54%
1,20	509	36,68%
1,23	574	39,10%
1,25	589	41,58%
1,27	525	43,80%
1,29	564	46,17%
1,31	577	48,60%
1,33	539	50,87%
1,35	513	53,04%
1,37	543	55,32%
1,39	539	57,59%
1,41	486	59,64%
1,43	499	61,74%
1,45	490	63,81%
1,47	485	65,85%
1,49	440	67,71%
1,51	414	69,45%

1,53	386	71,08%
1,55	392	72,73%
1,57	364	74,26%
1,59	347	75,72%
1,61	316	77,05%
1,63	338	78,48%
1,65	311	79,79%
1,67	282	80,98%
1,69	274	82,13%
1,72	288	83,35%
1,74	236	84,34%
1,76	207	85,21%
1,78	196	86,04%
1,80	184	86,81%
1,82	178	87,56%
1,84	169	88,27%
1,86	163	88,96%
1,88	180	89,72%
1,90	132	90,28%
1,92	134	90,84%
1,94	138	91,42%
1,96	125	91,95%
1,98	125	92,48%
2,00	102	92,90%
2,02	109	93,36%
2,04	113	93,84%
2,06	82	94,19%
2,08	81	94,53%
2,10	85	94,89%
2,12	81	95,23%
2,14	89	95,60%
2,16	75	95,92%
2,19	70	96,21%
2,21	59	96,46%
2,23	59	96,71%
2,25	58	96,95%
2,27	46	97,15%
2,29	47	97,35%
2,31	46	97,54%
2,33	41	97,71%
2,35	38	97,87%
2,37	37	98,03%
2,39	21	98,12%
2,41	30	98,24%
2,43	24	98,34%

2,45	33	98,48%
2,47	41	98,66%
2,49	28	98,77%
2,51	32	98,91%
2,53	25	99,01%
2,55	22	99,11%
2,57	13	99,16%
2,59	14	99,22%
2,61	24	99,32%
2,63	12	99,37%
2,65	17	99,44%
2,68	13	99,50%
2,70	17	99,57%
2,72	14	99,63%
2,74	4	99,65%
2,76	5	99,67%
2,78	8	99,70%
2,80	8	99,73%
2,82	6	99,76%
2,84	5	99,78%
2,86	5	99,80%
2,88	4	99,82%
2,90	1	99,82%
2,92	4	99,84%
2,94	7	99,87%
2,96	8	99,90%
2,98	4	99,92%
3,00	2	99,93%
3,02	1	99,93%
3,04	1	99,94%
3,06	3	99,95%
3,08	2	99,96%
3,10	1	99,96%
3,12	0	99,96%
3,15	0	99,96%
3,17	0	99,96%
3,19	1	99,97%
3,21	0	99,97%
3,23	0	99,97%
3,25	1	99,97%
3,27	2	99,98%
3,29	0	99,98%
3,31	0	99,98%
3,33	0	99,98%
3,35	0	99,98%

3,37	0	99,98%
3,39	1	99,98%
3,41	2	99,99%
3,43	1	100,00%
3,45	0	100,00%
3,47	0	100,00%
3,49	0	100,00%
3,51	0	100,00%
and bigger…	1	100,00%

4.1.3 CUMULATIVE PROBABILITY OF THE DURATION OF PRACTICE 3

Interval	*Frequency*	*% accumulated*
0,27	1	0,00%
0,29	2	0,01%
0,31	0	0,01%
0,33	3	0,03%
0,35	4	0,04%
0,37	3	0,05%
0,39	2	0,06%
0,41	3	0,08%
0,44	13	0,13%
0,46	9	0,17%
0,48	13	0,22%
0,50	21	0,31%
0,52	15	0,37%
0,54	20	0,46%
0,56	36	0,61%
0,58	33	0,75%
0,60	45	0,94%
0,62	57	1,18%
0,64	62	1,44%
0,66	66	1,72%
0,68	116	2,21%
0,70	91	2,59%
0,72	115	3,08%
0,75	109	3,53%
0,77	133	4,10%
0,79	143	4,70%
0,81	140	5,29%
0,83	189	6,08%
0,85	203	6,94%
0,87	192	7,75%
0,89	223	8,69%
0,91	254	9,76%

0,93	277	10,92%
0,95	261	12,02%
0,97	298	13,28%
0,99	331	14,67%
1,01	342	16,12%
1,03	375	17,70%
1,05	402	19,39%
1,08	389	21,03%
1,10	410	22,76%
1,12	428	24,56%
1,14	451	26,46%
1,16	441	28,32%
1,18	503	30,44%
1,20	458	32,37%
1,22	505	34,49%
1,24	506	36,63%
1,26	512	38,78%
1,28	532	41,02%
1,30	562	43,39%
1,32	566	45,78%
1,34	575	48,20%
1,36	531	50,44%
1,39	543	52,72%
1,41	525	54,94%
1,43	505	57,06%
1,45	488	59,12%
1,47	555	61,46%
1,49	460	63,40%
1,51	461	65,34%
1,53	475	67,34%
1,55	446	69,22%
1,57	406	70,93%
1,59	429	72,74%
1,61	399	74,42%
1,63	379	76,01%
1,65	382	77,62%
1,67	350	79,10%
1,70	351	80,58%
1,72	342	82,02%
1,74	291	83,24%
1,76	303	84,52%
1,78	272	85,67%
1,80	243	86,69%
1,82	262	87,79%
1,84	210	88,68%

1,86	220	89,61%
1,88	202	90,46%
1,90	194	91,27%
1,92	173	92,00%
1,94	164	92,69%
1,96	144	93,30%
1,98	131	93,85%
2,01	127	94,39%
2,03	126	94,92%
2,05	111	95,39%
2,07	91	95,77%
2,09	80	96,11%
2,11	79	96,44%
2,13	91	96,82%
2,15	67	97,11%
2,17	56	97,34%
2,19	59	97,59%
2,21	55	97,82%
2,23	51	98,04%
2,25	51	98,25%
2,27	27	98,37%
2,29	38	98,53%
2,32	39	98,69%
2,34	31	98,82%
2,36	27	98,93%
2,38	29	99,06%
2,40	23	99,15%
2,42	25	99,26%
2,44	14	99,32%
2,46	15	99,38%
2,48	17	99,45%
2,50	12	99,50%
2,52	9	99,54%
2,54	14	99,60%
2,56	14	99,66%
2,58	12	99,71%
2,60	11	99,76%
2,63	7	99,79%
2,65	4	99,80%
2,67	6	99,83%
2,69	5	99,85%
2,71	4	99,87%
2,73	7	99,89%
2,75	2	99,90%
2,77	1	99,91%

2,79	3	99,92%
2,81	1	99,92%
2,83	0	99,92%
2,85	0	99,92%
2,87	5	99,95%
2,89	2	99,95%
2,91	1	99,96%
2,94	1	99,96%
2,96	0	99,96%
2,98	1	99,97%
3,00	1	99,97%
3,02	0	99,97%
3,04	0	99,97%
3,06	0	99,97%
3,08	1	99,97%
3,10	0	99,97%
3,12	0	99,97%
3,14	2	99,98%
3,16	0	99,98%
3,18	1	99,99%
3,20	1	99,99%
3,22	0	99,99%
3,25	0	99,99%
3,27	0	99,99%
3,29	0	99,99%
3,31	1	100,00%
3,33	0	100,00%
3,35	0	100,00%
3,37	0	100,00%
3,39	0	100,00%
3,41	0	100,00%
3,43	0	100,00%
y mayor...	1	100,00%

4.1.4 CUMULATIVE PROBABILITY OF THE DURATION OF PRACTICE 4

Interval	*Frequency*	*% accumulated*
0,45	1	0,00%
0,47	0	0,00%
0,50	2	0,01%
0,52	3	0,03%
0,54	12	0,08%
0,57	4	0,09%
0,59	6	0,12%

0,61	15	0,18%
0,64	22	0,27%
0,66	25	0,38%
0,68	36	0,53%
0,71	37	0,69%
0,73	47	0,88%
0,75	70	1,18%
0,78	84	1,53%
0,80	107	1,98%
0,82	142	2,58%
0,85	141	3,18%
0,87	196	4,00%
0,89	223	4,94%
0,92	265	6,06%
0,94	266	7,18%
0,96	297	8,43%
0,99	322	9,79%
1,01	394	11,45%
1,03	438	13,29%
1,05	433	15,12%
1,08	464	17,07%
1,10	488	19,13%
1,12	490	21,20%
1,15	526	23,41%
1,17	525	25,62%
1,19	619	28,23%
1,22	578	30,67%
1,24	601	33,20%
1,26	619	35,81%
1,29	600	38,34%
1,31	611	40,91%
1,33	618	43,52%
1,36	633	46,18%
1,38	571	48,59%
1,40	583	51,05%
1,43	529	53,28%
1,45	552	55,60%
1,47	583	58,06%
1,50	540	60,33%
1,52	509	62,48%
1,54	457	64,41%
1,57	478	66,42%
1,59	438	68,27%
1,61	451	70,17%
1,64	429	71,97%

1,66	379	73,57%
1,68	372	75,14%
1,71	351	76,62%
1,73	380	78,22%
1,75	301	79,49%
1,78	299	80,75%
1,80	300	82,01%
1,82	244	83,04%
1,85	254	84,11%
1,87	241	85,12%
1,89	251	86,18%
1,92	215	87,09%
1,94	163	87,78%
1,96	188	88,57%
1,99	177	89,31%
2,01	167	90,02%
2,03	145	90,63%
2,06	145	91,24%
2,08	129	91,78%
2,10	113	92,26%
2,13	112	92,73%
2,15	121	93,24%
2,17	111	93,71%
2,20	104	94,15%
2,22	70	94,44%
2,24	97	94,85%
2,27	82	95,20%
2,29	66	95,47%
2,31	81	95,82%
2,34	54	96,04%
2,36	60	96,30%
2,38	83	96,65%
2,41	54	96,87%
2,43	48	97,08%
2,45	46	97,27%
2,48	40	97,44%
2,50	44	97,62%
2,52	43	97,80%
2,55	38	97,96%
2,57	43	98,15%
2,59	33	98,28%
2,62	40	98,45%
2,64	25	98,56%
2,66	33	98,70%
2,69	24	98,80%

2,71	29	98,92%
2,73	25	99,03%
2,76	19	99,11%
2,78	19	99,19%
2,80	14	99,25%
2,82	13	99,30%
2,85	18	99,38%
2,87	13	99,43%
2,89	14	99,49%
2,92	13	99,54%
2,94	11	99,59%
2,96	6	99,62%
2,99	12	99,67%
3,01	7	99,70%
3,03	7	99,73%
3,06	9	99,76%
3,08	9	99,80%
3,10	5	99,82%
3,13	1	99,83%
3,15	1	99,83%
3,17	6	99,86%
3,20	5	99,88%
3,22	4	99,89%
3,24	1	99,90%
3,27	1	99,90%
3,29	2	99,91%
3,31	3	99,92%
3,34	0	99,92%
3,36	5	99,95%
3,38	1	99,95%
3,41	0	99,95%
3,43	0	99,95%
3,45	5	99,97%
3,48	1	99,97%
3,50	0	99,97%
3,52	1	99,98%
3,55	1	99,98%
3,57	0	99,98%
3,59	0	99,98%
3,62	1	99,99%
3,64	1	99,99%
3,66	1	100,00%
3,69	0	100,00%
3,71	0	100,00%
3,73	0	100,00%

3,76	0	100,00%
3,78	0	100,00%
3,80	0	100,00%
3,83	0	100,00%
3,85	0	100,00%
3,87	0	100,00%
3,90	0	100,00%
3,92	0	100,00%
3,94	0	100,00%
3,97	0	100,00%
3,99	0	100,00%
4,01	0	100,00%
and bigger...	1	100,00%

4.1.5 CUMULATIVE PROBABILITY OF THE DURATION OF PRACTICE 5

Interval	*Frequency*	*% accumulated*
0,08	1	0,00%
0,10	2	0,01%
0,12	0	0,01%
0,15	0	0,01%
0,17	1	0,02%
0,19	2	0,03%
0,22	0	0,03%
0,24	2	0,03%
0,26	0	0,03%
0,29	4	0,05%
0,31	3	0,06%
0,33	1	0,07%
0,36	0	0,07%
0,38	5	0,09%
0,40	5	0,11%
0,43	3	0,12%
0,45	7	0,15%
0,47	8	0,19%
0,50	6	0,21%
0,52	9	0,25%
0,54	14	0,31%
0,57	18	0,38%
0,59	19	0,46%
0,61	15	0,53%
0,64	20	0,61%
0,66	20	0,70%
0,68	32	0,83%

0,71	34	0,97%
0,73	36	1,13%
0,75	31	1,26%
0,78	37	1,41%
0,80	55	1,64%
0,82	44	1,83%
0,85	53	2,05%
0,87	67	2,33%
0,89	64	2,60%
0,92	95	3,00%
0,94	100	3,43%
0,96	98	3,84%
0,99	120	4,34%
1,01	128	4,88%
1,03	144	5,49%
1,06	135	6,06%
1,08	138	6,64%
1,10	180	7,40%
1,13	194	8,22%
1,15	186	9,00%
1,17	184	9,78%
1,20	237	10,78%
1,22	259	11,87%
1,24	236	12,86%
1,27	260	13,96%
1,29	301	15,23%
1,31	294	16,47%
1,34	315	17,79%
1,36	371	19,36%
1,38	360	20,87%
1,41	335	22,28%
1,43	423	24,07%
1,45	405	25,77%
1,48	423	27,56%
1,50	410	29,28%
1,52	430	31,10%
1,55	422	32,88%
1,57	469	34,85%
1,59	499	36,95%
1,62	476	38,96%
1,64	512	41,12%
1,66	475	43,12%
1,69	480	45,14%
1,71	505	47,27%
1,73	502	49,39%

1,76	493	51,46%
1,78	516	53,64%
1,80	508	55,78%
1,83	477	57,79%
1,85	481	59,82%
1,87	494	61,90%
1,90	470	63,88%
1,92	478	65,89%
1,94	423	67,68%
1,97	449	69,57%
1,99	434	71,40%
2,01	404	73,10%
2,04	399	74,78%
2,06	390	76,43%
2,08	375	78,01%
2,11	380	79,61%
2,13	350	81,08%
2,15	340	82,52%
2,18	333	83,92%
2,20	328	85,30%
2,22	257	86,38%
2,25	273	87,53%
2,27	205	88,40%
2,29	221	89,33%
2,32	222	90,27%
2,34	196	91,09%
2,36	198	91,93%
2,39	197	92,76%
2,41	166	93,46%
2,43	140	94,05%
2,46	132	94,60%
2,48	118	95,10%
2,50	120	95,60%
2,53	110	96,07%
2,55	107	96,52%
2,57	91	96,90%
2,60	78	97,23%
2,62	72	97,53%
2,64	60	97,79%
2,67	51	98,00%
2,69	53	98,23%
2,71	48	98,43%
2,74	36	98,58%
2,76	39	98,74%
2,78	45	98,93%

2,81	25	99,04%
2,83	30	99,17%
2,85	27	99,28%
2,88	18	99,36%
2,90	21	99,44%
2,92	15	99,51%
2,95	16	99,57%
2,97	16	99,64%
2,99	13	99,70%
3,02	9	99,73%
3,04	5	99,76%
3,06	6	99,78%
3,09	8	99,81%
3,11	6	99,84%
3,13	4	99,86%
3,16	7	99,89%
3,18	4	99,90%
3,21	4	99,92%
3,23	2	99,93%
3,25	1	99,93%
3,28	1	99,94%
3,30	3	99,95%
3,32	1	99,95%
3,35	2	99,96%
3,37	2	99,97%
3,39	2	99,98%
3,42	0	99,98%
3,44	0	99,98%
3,46	1	99,98%
3,49	0	99,98%
3,51	0	99,98%
3,53	2	99,99%
3,56	0	99,99%
3,58	0	99,99%
3,60	0	99,99%
3,63	0	99,99%
3,65	1	100,00%
and bigger...	1	100,00%

4.2 SIMAN CODE OF THE MODEL CREATED IN ARENA.

```
;     Model statements for Part:  BasicProcess.Create 1 (Students)
;

158$          CREATE,
disc(0.333,2,0.666,3,1,4),SecondstoBaseTime(0.0),student:SecondstoBaseTime(0.3),
                            disc(0.005,1,0.02, 2,0.04,3,0.1,4,1,5):NEXT(159$);

159$          ASSIGN:       Students.NumberOut=Students.NumberOut + 1:NEXT(1$);


;
;
;     Model statements for Part:  AdvancedProcess.Delay 1 (Delay 1)
;
1$            DELAY:        0.000027777777778,,Other:NEXT(0$);


;
;
;     Model statements for Part:  BasicProcess.Batch 1 (Batch 1)
;
0$            QUEUE,        Batch 1.Queue;
162$          GROUP,        ,Temporary:students.numberout,Sum:NEXT(163$);

163$          ASSIGN:       Batch 1.NumberOut=Batch 1.NumberOut + 1:NEXT(8$);


;
;
;     Model statements for Part:  BasicProcess.Assign 10 (Contador)
;
8$            ASSIGN:       Students.numberout=0:
                            counter1=counter1+1:
                            classduration=2:
                            numberofpractices=counter1*5:
                            Englishlevel=unif(0,100):
                            Accesstovideos=unif(0,100):
                            wayofworking=unif(0,100):
                            attendancerate=unif(0,100):NEXT(9$);


;
;
;     Model statements for Part:  BasicProcess.Separate 1 (Separate 1)
;
9$            SPLIT::NEXT(164$);

164$          ASSIGN:       Separate 1.NumberOut Orig=Separate 1.NumberOut Orig +
1:NEXT(10$);


;
;
;     Model statements for Part:  AdvancedProcess.Delay 2 (Delay 2)
;
10$           DELAY:        0.000027777777778,,Other:NEXT(2$);


;
;
;     Model statements for Part:  BasicProcess.Decide 1 (Decide 1)
;
2$            BRANCH,       1:
                            If,counter1==1,3$,Yes:
                            If,counter1==2,4$,Yes:
                            If,counter1==3,5$,Yes:
                            If,counter1==4,6$,Yes:
                            Else,7$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Assign 9 (Team5)
```

```
;
7$              ASSIGN:         members(week+1,5)=separate 1.numberout orig:
                                team=5:
                                Picture=Picture.student5:NEXT(11$);


;
;
;     Model statements for Part:  AdvancedProcess.Delay 3 (Delay 3)
;
11$             DELAY:          0.000027777777778,,Other:NEXT(13$);


;
;
;     Model statements for Part:  BasicProcess.Decide 5 (English Level)
;
13$             BRANCH,         1:
                                With,(englishlevel)/100,169$,Yes:
                                Else,170$,Yes;
169$            ASSIGN:         English Level.NumberOut True=English Level.NumberOut True +
1:NEXT(14$);

170$            ASSIGN:         English Level.NumberOut False=English Level.NumberOut False
+ 1:NEXT(15$);


;
;
;     Model statements for Part:  BasicProcess.Assign 14 (High)
;
14$             ASSIGN:         separate 1.numberout orig=0:
                                English=5:NEXT(18$);


;
;
;     Model statements for Part:  BasicProcess.Decide 6 (Acces to videos)
;
18$             BRANCH,         1:
                                With,(accesstovideos)/100,171$,Yes:
                                Else,172$,Yes;
171$            ASSIGN:         Acces to videos.NumberOut True=Acces to videos.NumberOut
True + 1:NEXT(16$);

172$            ASSIGN:         Acces to videos.NumberOut False=Acces to videos.NumberOut
False + 1:NEXT(17$);


;
;
;     Model statements for Part:  BasicProcess.Assign 16 (YES)
;
16$             ASSIGN:         separate 1.numberout orig=0:
                                videos=5:NEXT(20$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 1 (Route 1)
;
20$             ROUTE:          0.,Station 2;


;
;
;     Model statements for Part:  BasicProcess.Assign 17 (NO)
;
17$             ASSIGN:         separate 1.numberout orig=0:
                                videos=1:NEXT(20$);


;
;
;     Model statements for Part:  BasicProcess.Assign 15 (Medium)
```

```
;
15$             ASSIGN:         separate 1.numberout orig=0:
                                English=1:NEXT(18$);


;
;
;     Model statements for Part:  BasicProcess.Assign 2 (Team1)
;
3$              ASSIGN:         Picture=Picture.student1:
                                members(week+1,1)=separate 1.numberout orig:
                                team=1:NEXT(11$);


;
;
;     Model statements for Part:  BasicProcess.Assign 6 (Team2)
;
4$              ASSIGN:         Picture=Picture.student2:
                                members(week+1,2)=separate 1.numberout orig:
                                team=2:NEXT(11$);


;
;
;     Model statements for Part:  BasicProcess.Assign 7 (Team3)
;
5$              ASSIGN:         Picture=Picture.student3:
                                members(week+1,3)=separate 1.numberout orig:
                                team=3:NEXT(11$);


;
;
;     Model statements for Part:  BasicProcess.Assign 8 (Team4)
;
6$              ASSIGN:         members(week+1,4)=separate 1.numberout orig:
                                team=4:
                                Picture=Picture.student4:NEXT(11$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 2 (Station 2)
;

21$             STATION,        Station 2;
175$            DELAY:          0.0,,VA:NEXT(22$);


;
;
;     Model statements for Part:  BasicProcess.Decide 7 (Decide 7)
;
22$             BRANCH,         1:
                                If,Week<5,176$,Yes:
                                Else,177$,Yes;
176$            ASSIGN:         Decide 7.NumberOut True=Decide 7.NumberOut True +
1:NEXT(23$);

177$            ASSIGN:         Decide 7.NumberOut False=Decide 7.NumberOut False +
1:NEXT(29$);


;
;
;     Model statements for Part:  AdvancedProcess.Hold 1 (Hold 1)
;
23$             QUEUE,          Hold 1.Queue;
                WAIT:           1:NEXT(26$);


;
;
;     Model statements for Part:  BasicProcess.Decide 8 (Attendance)
```

```
;
26$             BRANCH,         1:
                                With,(attendancerate)/100,178$,Yes:
                                Else,179$,Yes;
178$            ASSIGN:         Attendance.NumberOut True=Attendance.NumberOut True +
1:NEXT(32$);

179$            ASSIGN:         Attendance.NumberOut False=Attendance.NumberOut False +
1:NEXT(28$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 8 (Route 8)
;
32$             ROUTE:          0.,Station 3;


;
;
;     Model statements for Part:  BasicProcess.Assign 19 (Assign 19)
;
28$             ASSIGN:         members(week+1,team)=members(week+1,team)-1:

missingpracticesperweek(week+1,team)=missingpracticesperweek(week+1,team)+1:
                                Missingpractices(1)=

missingpracticesperweek(1,1)+missingpracticesperweek(2,2)+missingpracticesperweek(3,3)+m
issingpracticesperweek(4,4)+missingpracticesperweek(5,5):
                                Missingpractices(2)=

missingpracticesperweek(1,2)+missingpracticesperweek(2,3)+missingpracticesperweek(3,4)+m
issingpracticesperweek(4,5)+missingpracticesperweek(5,1):
                                Missingpractices(3)=

missingpracticesperweek(1,3)+missingpracticesperweek(2,4)+missingpracticesperweek(3,5)+m
issingpracticesperweek(4,1)+missingpracticesperweek(5,2):
                                Missingpractices(4)=

missingpracticesperweek(1,4)+missingpracticesperweek(2,5)+missingpracticesperweek(3,1)+m
issingpracticesperweek(4,2)+missingpracticesperweek(5,3):
                                Missingpractices(5)=

missingpracticesperweek(1,5)+missingpracticesperweek(2,1)+missingpracticesperweek(3,2)+m
issingpracticesperweek(4,3)+missingpracticesperweek(5,4)
                                :NEXT(123$);


;
;
;     Model statements for Part:  BasicProcess.Decide 60 (Decide 60)
;
123$            BRANCH,         1:
                                If,members(week+1,team)==0,180$,Yes:
                                Else,181$,Yes;
180$            ASSIGN:         Decide 60.NumberOut True=Decide 60.NumberOut True +
1:NEXT(124$);

181$            ASSIGN:         Decide 60.NumberOut False=Decide 60.NumberOut False +
1:NEXT(31$);


;
;
;     Model statements for Part:  BasicProcess.Assign 111 (Assign 111)
;
124$            ASSIGN:         mppt1(week,team)=1:
                                mppt2(1,1)=mppt1(1,1):
                                mppt2(1,2)=mppt1(5,2):
                                mppt2(1,3)=mppt1(4,3):
                                mppt2(1,4)=mppt1(3,4):
                                mppt2(1,5)=mppt1(2,5):
                                mppt2(2,1)=mppt1(2,1):
                                mppt2(2,2)=mppt1(1,2):
                                mppt2(2,3)=mppt1(5,3):
```

```
                                mppt2(2,4)=mppt1(4,4):
                                mppt2(2,5)=mppt1(3,5):
                                mppt2(3,1)=mppt1(3,1):
                                mppt2(3,2)=mppt1(2,2):
                                mppt2(3,3)=mppt1(1,3):
                                mppt2(3,4)=mppt1(5,4):
                                mppt2(3,5)=mppt1(4,5):
                                mppt2(4,1)=mppt1(4,1):
                                mppt2(4,2)=mppt1(3,2):
                                mppt2(4,3)=mppt1(2,3):
                                mppt2(4,4)=mppt1(1,4):
                                mppt2(4,5)=mppt1(5,5):
                                mppt2(5,1)=mppt1(5,1):
                                mppt2(5,2)=mppt1(4,2):
                                mppt2(5,3)=mppt1(3,3):
                                mppt2(5,4)=mppt1(2,4):
                                mppt2(5,5)=mppt1(1,5):

mppt2(6,1)=mppt2(1,1)+mppt2(2,1)+mppt2(3,1)+mppt2(4,1)+mppt2(5,1):

mppt2(6,2)=mppt2(1,2)+mppt2(2,2)+mppt2(3,2)+mppt2(4,2)+mppt2(5,2):

mppt2(6,3)=mppt2(1,3)+mppt2(2,3)+mppt2(3,3)+mppt2(4,3)+mppt2(5,3):

mppt2(6,4)=mppt2(1,4)+mppt2(2,4)+mppt2(3,4)+mppt2(4,4)+mppt2(5,4):

mppt2(6,5)=mppt2(1,5)+mppt2(2,5)+mppt2(3,5)+mppt2(4,5)+mppt2(5,5):

mppt2(1,6)=mppt2(1,1)+mppt2(1,2)+mppt2(1,3)+mppt2(1,4)+mppt2(1,5):

mppt2(2,6)=mppt2(2,1)+mppt2(2,2)+mppt2(2,3)+mppt2(2,4)+mppt2(2,5):

mppt2(3,6)=mppt2(3,1)+mppt2(3,2)+mppt2(3,3)+mppt2(3,4)+mppt2(3,5):

mppt2(4,6)=mppt2(4,1)+mppt2(4,2)+mppt2(4,3)+mppt2(4,4)+mppt2(4,5):

mppt2(5,6)=mppt2(5,1)+mppt2(5,2)+mppt2(5,3)+mppt2(5,4)+mppt2(5,5):

mppt2(6,6)=mppt2(6,1)+mppt2(6,2)+mppt2(6,3)+mppt2(6,4)+mppt2(6,5):NEXT(31$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 7 (Route 7)
;
31$           ROUTE:          0.,Station 2;


;
;
;     Model statements for Part:  AdvancedTransfer.Route 4 (Route 4)
;
29$           ROUTE:          0.,Station 1;


;
;
;     Model statements for Part:  BasicProcess.Create 2 (Weeks)
;

182$          CREATE,
1,MinutesToBaseTime(0.1),week_gone:MinutesToBaseTime(1440),5:NEXT(183$);

183$          ASSIGN:         Weeks.NumberOut=Weeks.NumberOut + 1:NEXT(27$);


;
;
;     Model statements for Part:  BasicProcess.Assign 18 (Assign 18)
;
27$           ASSIGN:         Week=week+1:
                              members(week+1,1)=members(1,1):
                              members(week+1,2)=members(1,2):
                              members(week+1,3)=members(1,3):
                              members(week+1,4)=members(1,4):
```

```
                              members(week+1,5)=members(1,5):
                              Attendance.NumberOut False=0:NEXT(25$);


;
;
;     Model statements for Part:  AdvancedProcess.Signal 1 (Signal 1)
;
25$           SIGNAL:         1:NEXT(19$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 1 (Station 1)
;
19$           STATION,        Station 1;
188$          DELAY:          0.0,,VA:NEXT(12$);


;
;
;     Model statements for Part:  BasicProcess.Dispose 3 (Dispose 3)
;
12$           ASSIGN:         Dispose 3.NumberOut=Dispose 3.NumberOut + 1;
189$          DISPOSE:        Yes;


;
;
;     Model statements for Part:  AdvancedTransfer.Station 5 (Station 3)
;
33$           STATION,        Station 3;
192$          DELAY:          0.0,,VA:NEXT(141$);


;
;
;     Model statements for Part:  AdvancedProcess.Delay 6 (Delay 6)
;
141$          DELAY:          0.000277777777778,,Other:NEXT(140$);


;
;
;     Model statements for Part:  BasicProcess.Batch 14 (Batch 14)
;
140$          QUEUE,          Batch 14.Queue;
193$          GROUP,          ,Temporary:

members(week+1,1)+members(week+1,2)+members(week+1,3)+members(week+1,4)+members(week+1,5
),Sum,
                              student:NEXT(194$);

194$          ASSIGN:         Batch 14.NumberOut=Batch 14.NumberOut + 1:NEXT(144$);


;
;
;     Model statements for Part:  BasicProcess.Assign 132 (Assign 132)
;
144$          ASSIGN:         teacherexplanation=tnow:NEXT(142$);


;
;
;     Model statements for Part:  BasicProcess.Process 46 (Initial Explanation)
;
142$          ASSIGN:         Initial Explanation.NumberIn=Initial Explanation.NumberIn +
1:
                              Initial Explanation.WIP=Initial Explanation.WIP+1;
198$          QUEUE,          Initial Explanation.Queue;
197$          SEIZE,          2,VA:
                              Teacher,1:NEXT(196$);
```

```
196$          DELAY:          MinutesToBaseTime(Normal(10,2)),,VA;
195$          RELEASE:        Teacher,1;
243$          ASSIGN:         Initial Explanation.NumberOut=Initial Explanation.NumberOut
+ 1:
                              Initial Explanation.WIP=Initial Explanation.WIP-
1:NEXT(145$);


;
;
;     Model statements for Part:  BasicProcess.Assign 133 (Assign 133)
;
145$          ASSIGN:         teacherexplanation=tnow-teacherexplanation:NEXT(143$);


;
;
;     Model statements for Part:  BasicProcess.Separate 22 (Separate 22)
;
143$          SPLIT::NEXT(246$);

246$          ASSIGN:         Separate 22.NumberOut Orig=Separate 22.NumberOut Orig +
1:NEXT(35$);


;
;
;     Model statements for Part:  BasicProcess.Assign 42 (Number of member)
;
35$           ASSIGN:         TeamDistribution=team:
                              weekly_members=members(week+1,team):
                              ArrivalTime=tnow:NEXT(30$);


;
;
;     Model statements for Part:  BasicProcess.Batch 7 (Batch 7)
;
30$           QUEUE,          Batch 7.Queue;
249$          GROUP,          team,Temporary:members(week+1,team),Sum:NEXT(250$);

250$          ASSIGN:         Batch 7.NumberOut=Batch 7.NumberOut + 1:NEXT(34$);


;
;
;     Model statements for Part:  BasicProcess.Decide 19 (Division of the team)
;
34$           BRANCH,         1:
                              If,divideteam(weekly_members),251$,Yes:
                              Else,252$,Yes;
251$          ASSIGN:         Division of the team.NumberOut True=Division of the
team.NumberOut True + 1:NEXT(36$);

252$          ASSIGN:         Division of the team.NumberOut False=Division of the
team.NumberOut False + 1:NEXT(43$);


;
;
;     Model statements for Part:  BasicProcess.Assign 43 (Reset counter)
;
36$           ASSIGN:         counter=0:NEXT(37$);


;
;
;     Model statements for Part:  BasicProcess.Separate 10 (Separate 10)
;
37$           SPLIT::NEXT(253$);

253$          ASSIGN:         Separate 10.NumberOut Orig=Separate 10.NumberOut Orig +
1:NEXT(38$);
```

```
;
;
;     Model statements for Part:  BasicProcess.Assign 44 (Relocation)
;
38$           ASSIGN:        counter=counter+1:NEXT(39$);


;
;
;     Model statements for Part:  BasicProcess.Decide 25 (subgroup creation)
;
39$           BRANCH,        1:
                             If,create_subgroup(weekly_members),256$,Yes:
                             Else,257$,Yes;
256$          ASSIGN:        subgroup creation.NumberOut True=subgroup
creation.NumberOut True + 1:NEXT(41$);

257$          ASSIGN:        subgroup creation.NumberOut False=subgroup
creation.NumberOut False + 1:NEXT(40$);


;
;
;     Model statements for Part:  BasicProcess.Assign 45 (Individualist)
;
41$           ASSIGN:        Way_of_working=counter:NEXT(44$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 17 (Route 17)
;
44$           ROUTE:         0.,Station 6;


;
;
;     Model statements for Part:  BasicProcess.Batch 10 (Batch 10)
;
40$           QUEUE,         Batch 10.Queue;
258$          GROUP,         Entity.Type,Temporary:2,Sum:NEXT(259$);

259$          ASSIGN:        Batch 10.NumberOut=Batch 10.NumberOut + 1:NEXT(42$);


;
;
;     Model statements for Part:  BasicProcess.Assign 46 (Semi_collaborative)
;
42$           ASSIGN:        Way_of_working=counter:NEXT(44$);


;
;
;     Model statements for Part:  BasicProcess.Assign 47 (Collaborative)
;
43$           ASSIGN:        Way_of_working=5:NEXT(44$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 11 (Station 6)
;

45$           STATION,       Station 6;
262$          DELAY:         0.0,,VA:NEXT(46$);


;
;
;     Model statements for Part:  BasicProcess.Decide 26 (Decide 26)
;
46$           BRANCH,        1:
                             If,practicenumber(week, teamdistribution)==1,47$,Yes:
```

```
                              If,practicenumber(week, teamdistribution)==2,48$,Yes:
                              If,practicenumber(week, teamdistribution)==3,49$,Yes:
                              If,practicenumber(week, teamdistribution)==4,50$,Yes:
                              Else,51$,Yes;

;
;
;     Model statements for Part:  AdvancedTransfer.Route 22 (Photonics Practice 5)
;
51$           ROUTE:          0.,Station 11;


;
;
;     Model statements for Part:  AdvancedTransfer.Route 18 (Photonics Practice 1)
;
47$           ROUTE:          0.,Station 7;


;
;
;     Model statements for Part:  AdvancedTransfer.Route 19 (Photonics Practice 2)
;
48$           ROUTE:          0.,Station 8;


;
;
;     Model statements for Part:  AdvancedTransfer.Route 20 (Photonics Practice 3)
;
49$           ROUTE:          0.,Station 9;


;
;
;     Model statements for Part:  AdvancedTransfer.Route 21 (Photonics Practice 4)
;
50$           ROUTE:          0.,Station 10;


;
;
;     Model statements for Part:  AdvancedTransfer.Station 13 (Station 7)
;

52$           STATION,        Station 7;
267$          DELAY:          0.0,,VA:NEXT(53$);


;
;
;     Model statements for Part:  BasicProcess.Decide 27 (Decide 27)
;
53$           BRANCH,         1:
                              If,Way_of_working==1,54$,Yes:
                              If,Way_of_working==5,54$,Yes:
                              If,Way_of_working==4,54$,Yes:
                              Else,56$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Decide 29 (Decide 29)
;
56$           BRANCH,         1:
                              If,Way_of_working==2,57$,Yes:
                              If,Way_of_working==3,57$,Yes:
                              If,Way_of_working==5,57$,Yes:
                              Else,59$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Separate 14 (Separate 14)
;
59$           SPLIT::NEXT(272$);
```

```
272$          ASSIGN:        Separate 14.NumberOut Orig=Separate 14.NumberOut Orig +
1:NEXT(60$);


;
;
;     Model statements for Part:  BasicProcess.Assign 49 (Duration 1)
;
60$           ASSIGN:        Scoreboard(team,1)=tnow-arrivaltime:NEXT(125$);


;
;
;     Model statements for Part:  BasicProcess.Decide 61 (Decide 61)
;
125$          BRANCH,        1:
                             If,Scoreboard(team,1)<=classduration-
teacherexplanation,275$,Yes:
                             Else,276$,Yes;
275$          ASSIGN:        Decide 61.NumberOut True=Decide 61.NumberOut True +
1:NEXT(126$);

276$          ASSIGN:        Decide 61.NumberOut False=Decide 61.NumberOut False +
1:NEXT(127$);


;
;
;     Model statements for Part:  BasicProcess.Assign 115 (Assign 115)
;
126$          ASSIGN:        p1finished(team)=1:NEXT(61$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 26 (Route 26)
;
61$           ROUTE:         0.,Station 12;


;
;
;     Model statements for Part:  BasicProcess.Assign 120 (Assign 120)
;
127$          ASSIGN:        p1finished(team)=0:NEXT(61$);


;
;
;     Model statements for Part:  BasicProcess.Decide 30 (Help 1B)
;
57$           BRANCH,        1:
                             If,help(English, videos),277$,Yes:
                             Else,278$,Yes;
277$          ASSIGN:        Help 1B.NumberOut True=Help 1B.NumberOut True +
1:NEXT(121$);

278$          ASSIGN:        Help 1B.NumberOut False=Help 1B.NumberOut False +
1:NEXT(58$);


;
;
;     Model statements for Part:  BasicProcess.Assign 109 (Assign 109)
;
121$          ASSIGN:        arrivaltime1B=tnow:NEXT(120$);


;
;
;     Model statements for Part:  BasicProcess.Process 45 (Teacher help 1B)
;
120$          ASSIGN:        Teacher help 1B.NumberIn=Teacher help 1B.NumberIn + 1:
                             Teacher help 1B.WIP=Teacher help 1B.WIP+1;
282$          QUEUE,         Teacher help 1B.Queue;
```

```
281$          SEIZE,          2,VA:
                              Teacher,1:NEXT(280$);

280$          DELAY:          MinutesToBaseTime(teacher1A(English,videos)),,VA;
279$          RELEASE:        Teacher,1;
327$          ASSIGN:         Teacher help 1B.NumberOut=Teacher help 1B.NumberOut + 1:
                              Teacher help 1B.WIP=Teacher help 1B.WIP-1:NEXT(122$);


;
;
;     Model statements for Part:  BasicProcess.Assign 110 (Assign 110)
;
122$          ASSIGN:         waitingtime1B=(help 1B.numberout true)*TAVG(Teacher help
1B.Queue.WaitingTime)-sumwaitingtimes1B:
                              sumwaitingtimes1B=sumwaitingtimes1B+waitingtime1B:
                              teacherhelpin1B=tnow-arrivaltime1B-waitingtime1B:
                              teacherin1B(week)=teacherhelpin1B:
                              teacherin1B(6)=teacherin1B(6)+teacherin1B(week):
                              queues1B(week)=waitingtime1B:
                              queues1B(6)=sumwaitingtimes1B:NEXT(58$);


;
;
;     Model statements for Part:  BasicProcess.Process 5 (Practice 1B)
;
58$           ASSIGN:         Practice 1B.NumberIn=Practice 1B.NumberIn + 1:
                              Practice 1B.WIP=Practice 1B.WIP+1;
331$          DELAY:          MinutesToBaseTime(Duration1B(English, videos)),,VA;
378$          ASSIGN:         Practice 1B.NumberOut=Practice 1B.NumberOut + 1:
                              Practice 1B.WIP=Practice 1B.WIP-1:NEXT(59$);


;
;
;     Model statements for Part:  BasicProcess.Decide 28 (Help 1A)
;
54$           BRANCH,         1:
                              If,help(English,videos),381$,Yes:
                              Else,382$,Yes;
381$          ASSIGN:         Help 1A.NumberOut True=Help 1A.NumberOut True +
1:NEXT(118$);

382$          ASSIGN:         Help 1A.NumberOut False=Help 1A.NumberOut False +
1:NEXT(55$);


;
;
;     Model statements for Part:  BasicProcess.Assign 105 (Assign 105)
;
118$          ASSIGN:         arrivaltime1A=tnow:NEXT(117$);


;
;
;     Model statements for Part:  BasicProcess.Process 43 (Teacher help 1A)
;
117$          ASSIGN:         Teacher help 1A.NumberIn=Teacher help 1A.NumberIn + 1:
                              Teacher help 1A.WIP=Teacher help 1A.WIP+1;
386$          QUEUE,          Teacher help 1A.Queue;
385$          SEIZE,          2,VA:
                              Teacher,1:NEXT(384$);

384$          DELAY:          MinutesToBaseTime(teacher1A(English,videos)),,VA;
383$          RELEASE:        Teacher,1;
431$          ASSIGN:         Teacher help 1A.NumberOut=Teacher help 1A.NumberOut + 1:
                              Teacher help 1A.WIP=Teacher help 1A.WIP-1:NEXT(119$);


;
;
;     Model statements for Part:  BasicProcess.Assign 106 (Assign 106)
;
```

```
119$          ASSIGN:        waitingtime1A=(help 1A.numberout true)*TAVG(Teacher help
1A.Queue.WaitingTime)-sumwaitingtimes1A:
                             sumwaitingtimes1A=sumwaitingtimes1A+waitingtime1A:
                             teacherhelpin1A=tnow-arrivaltime1A-waitingtime1A:
                             teacherin1A(week)=teacherhelpin1A:
                             teacherin1A(6)=teacherin1A(6)+teacherin1A(week):
                             queues1A(week)=waitingtime1A:
                             queues1A(6)=sumwaitingtimes1A:NEXT(55$);


;
;
;     Model statements for Part:  BasicProcess.Process 3 (practice 1A)
;
55$           ASSIGN:        practice 1A.NumberIn=practice 1A.NumberIn + 1:
                             practice 1A.WIP=practice 1A.WIP+1;
435$          DELAY:         MinutesToBaseTime(Duration1A(English,videos)),,VA;
482$          ASSIGN:        practice 1A.NumberOut=practice 1A.NumberOut + 1:
                             practice 1A.WIP=practice 1A.WIP-1:NEXT(56$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 14 (Station 8)
;

62$           STATION,       Station 8;
487$          DELAY:         0.0,,VA:NEXT(63$);


;
;
;     Model statements for Part:  BasicProcess.Decide 45 (Decide 45)
;
63$           BRANCH,        1:
                             If,Way_of_working==1,64$,Yes:
                             If,Way_of_working==5,64$,Yes:
                             If,Way_of_working==4,64$,Yes:
                             Else,66$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Decide 47 (Decide 47)
;
66$           BRANCH,        1:
                             If,Way_of_working==2,67$,Yes:
                             If,Way_of_working==3,67$,Yes:
                             If,Way_of_working==5,67$,Yes:
                             Else,69$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Separate 15 (Separate 15)
;
69$           SPLIT::NEXT(492$);

492$          ASSIGN:        Separate 15.NumberOut Orig=Separate 15.NumberOut Orig +
1:NEXT(70$);


;
;
;     Model statements for Part:  BasicProcess.Assign 50 (Duration 2)
;
70$           ASSIGN:        Scoreboard(team,2)=tnow-arrivaltime:NEXT(128$);


;
;
;     Model statements for Part:  BasicProcess.Decide 66 (Decide 66)
;
128$          BRANCH,        1:
                             If,Scoreboard(team,2)<=classduration-
teacherexplanation,495$,Yes:
                             Else,496$,Yes;
```

```
495$          ASSIGN:        Decide 66.NumberOut True=Decide 66.NumberOut True +
1:NEXT(129$);

496$          ASSIGN:        Decide 66.NumberOut False=Decide 66.NumberOut False +
1:NEXT(130$);


;
;
;     Model statements for Part:  BasicProcess.Assign 122 (Assign 122)
;
129$          ASSIGN:        p2finished(team)=1:NEXT(153$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 28 (Route 28)
;
153$          ROUTE:         0.,Station 12;


;
;
;     Model statements for Part:  BasicProcess.Assign 123 (Assign 123)
;
130$          ASSIGN:        p2finished(team)=0:NEXT(153$);


;
;
;     Model statements for Part:  BasicProcess.Decide 48 (Help 2B)
;
67$           BRANCH,        1:
                             If,help(English, videos),497$,Yes:
                             Else,498$,Yes;
497$          ASSIGN:        Help 2B.NumberOut True=Help 2B.NumberOut True +
1:NEXT(112$);

498$          ASSIGN:        Help 2B.NumberOut False=Help 2B.NumberOut False +
1:NEXT(68$);


;
;
;     Model statements for Part:  BasicProcess.Assign 101 (Assign 101)
;
112$          ASSIGN:        arrivaltime2B=tnow:NEXT(111$);


;
;
;     Model statements for Part:  BasicProcess.Process 41 (Teacher help 2B)
;
111$          ASSIGN:        Teacher help 2B.NumberIn=Teacher help 2B.NumberIn + 1:
                             Teacher help 2B.WIP=Teacher help 2B.WIP+1;
502$          QUEUE,         Teacher help 2B.Queue;
501$          SEIZE,         2,VA:
                             Teacher,1:NEXT(500$);

500$          DELAY:         MinutesToBaseTime(teacher1A(English,videos)),,VA;
499$          RELEASE:       Teacher,1;
547$          ASSIGN:        Teacher help 2B.NumberOut=Teacher help 2B.NumberOut + 1:
                             Teacher help 2B.WIP=Teacher help 2B.WIP-1:NEXT(113$);


;
;
;     Model statements for Part:  BasicProcess.Assign 102 (Assign 102)
;
113$          ASSIGN:        waitingtime2B=(help 2B.numberout true)*TAVG(Teacher help
2B.Queue.WaitingTime)-sumwaitingtimes2B:
                             sumwaitingtimes2B=sumwaitingtimes2B+waitingtime2B:
                             teacherhelpin2B=tnow-arrivaltime2B-waitingtime2B:
                             teacherin2B(week)=teacherhelpin2B:
                             teacherin2B(6)=teacherin2B(6)+teacherin2B(week):
```

```
                              queues2B(week)=waitingtime2B:
                              queues2B(6)=sumwaitingtimes2B:NEXT(68$);


;
;
;     Model statements for Part:  BasicProcess.Process 9 (Practice 2B)
;
68$           ASSIGN:         Practice 2B.NumberIn=Practice 2B.NumberIn + 1:
                              Practice 2B.WIP=Practice 2B.WIP+1;
551$          DELAY:          MinutesToBaseTime(Duration2B(English, videos)),,VA;
598$          ASSIGN:         Practice 2B.NumberOut=Practice 2B.NumberOut + 1:
                              Practice 2B.WIP=Practice 2B.WIP-1:NEXT(69$);


;
;
;     Model statements for Part:  BasicProcess.Decide 46 (Help 2A)
;
64$           BRANCH,         1:
                              If,help(English,videos),601$,Yes:
                              Else,602$,Yes;
601$          ASSIGN:         Help 2A.NumberOut True=Help 2A.NumberOut True +
1:NEXT(115$);

602$          ASSIGN:         Help 2A.NumberOut False=Help 2A.NumberOut False +
1:NEXT(65$);


;
;
;     Model statements for Part:  BasicProcess.Assign 103 (Assign 103)
;
115$          ASSIGN:         arrivaltime2A=tnow:NEXT(114$);


;
;
;     Model statements for Part:  BasicProcess.Process 42 (Teacher help 2A)
;
114$          ASSIGN:         Teacher help 2A.NumberIn=Teacher help 2A.NumberIn + 1:
                              Teacher help 2A.WIP=Teacher help 2A.WIP+1;
606$          QUEUE,          Teacher help 2A.Queue;
605$          SEIZE,          2,VA:
                              Teacher,1:NEXT(604$);

604$          DELAY:          MinutesToBaseTime(teacher1A(English,videos)),,VA;
603$          RELEASE:        Teacher,1;
651$          ASSIGN:         Teacher help 2A.NumberOut=Teacher help 2A.NumberOut + 1:
                              Teacher help 2A.WIP=Teacher help 2A.WIP-1:NEXT(116$);


;
;
;     Model statements for Part:  BasicProcess.Assign 104 (Assign 104)
;
116$          ASSIGN:         waitingtime2A=(help 2A.numberout true)*TAVG(Teacher help
2A.Queue.WaitingTime)-sumwaitingtimes2A:
                              sumwaitingtimes2A=sumwaitingtimes2A+waitingtime2A:
                              teacherhelpin2A=tnow-arrivaltime2A-waitingtime2A:
                              teacherin2A(week)=teacherhelpin2A:
                              teacherin2A(6)=teacherin2A(6)+teacherin2A(week):
                              queues2A(week)=waitingtime2A:
                              queues2A(6)=sumwaitingtimes2A:NEXT(65$);


;
;
;     Model statements for Part:  BasicProcess.Process 7 (practice 2A)
;
65$           ASSIGN:         practice 2A.NumberIn=practice 2A.NumberIn + 1:
                              practice 2A.WIP=practice 2A.WIP+1;
655$          DELAY:          MinutesToBaseTime(Duration2A(English,videos)),,VA;
702$          ASSIGN:         practice 2A.NumberOut=practice 2A.NumberOut + 1:
                              practice 2A.WIP=practice 2A.WIP-1:NEXT(66$);
```

```
;
;
;     Model statements for Part:  AdvancedTransfer.Station 15 (Station 9)
;

71$           STATION,       Station 9;
707$          DELAY:         0.0,,VA:NEXT(72$);


;
;
;     Model statements for Part:  BasicProcess.Decide 49 (Decide 49)
;
72$           BRANCH,        1:
                             If,Way_of_working==1,73$,Yes:
                             If,Way_of_working==5,73$,Yes:
                             If,Way_of_working==4,73$,Yes:
                             Else,75$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Decide 51 (Decide 51)
;
75$           BRANCH,        1:
                             If,Way_of_working==2,76$,Yes:
                             If,Way_of_working==3,76$,Yes:
                             If,Way_of_working==5,76$,Yes:
                             Else,78$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Separate 16 (Separate 16)
;
78$           SPLIT::NEXT(712$);

712$          ASSIGN:        Separate 16.NumberOut Orig=Separate 16.NumberOut Orig +
1:NEXT(79$);


;
;
;     Model statements for Part:  BasicProcess.Assign 51 (Duration 3)
;
79$           ASSIGN:        Scoreboard(team,3)=tnow-arrivaltime:NEXT(131$);


;
;
;     Model statements for Part:  BasicProcess.Decide 67 (Decide 67)
;
131$          BRANCH,        1:
                             If,Scoreboard(team,3)<=classduration-
teacherexplanation,715$,Yes:
                             Else,716$,Yes;
715$          ASSIGN:        Decide 67.NumberOut True=Decide 67.NumberOut True +
1:NEXT(132$);

716$          ASSIGN:        Decide 67.NumberOut False=Decide 67.NumberOut False +
1:NEXT(133$);


;
;
;     Model statements for Part:  BasicProcess.Assign 124 (Assign 124)
;
132$          ASSIGN:        p3finished(team)=1:NEXT(154$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 29 (Route 29)
;
154$          ROUTE:         0.,Station 12;
```

```
;
;
;     Model statements for Part:  BasicProcess.Assign 125 (Assign 125)
;
133$          ASSIGN:        p3finished(team)=0:NEXT(154$);


;
;
;     Model statements for Part:  BasicProcess.Decide 52 (Help 3B)
;
76$           BRANCH,        1:
                             If,help(English, videos),717$,Yes:
                             Else,718$,Yes;
717$          ASSIGN:        Help 3B.NumberOut True=Help 3B.NumberOut True +
1:NEXT(108$);

718$          ASSIGN:        Help 3B.NumberOut False=Help 3B.NumberOut False +
1:NEXT(77$);


;
;
;     Model statements for Part:  BasicProcess.Assign 97 (Assign 97)
;
108$          ASSIGN:        arrivaltime3B=tnow:NEXT(107$);


;
;
;     Model statements for Part:  BasicProcess.Process 40 (Teacher help 3B)
;
107$          ASSIGN:        Teacher help 3B.NumberIn=Teacher help 3B.NumberIn + 1:
                             Teacher help 3B.WIP=Teacher help 3B.WIP+1;
722$          QUEUE,         Teacher help 3B.Queue;
721$          SEIZE,         2,VA:
                             Teacher,1:NEXT(720$);

720$          DELAY:         MinutesToBaseTime(teacher1A(English,videos)),,VA;
719$          RELEASE:       Teacher,1;
767$          ASSIGN:        Teacher help 3B.NumberOut=Teacher help 3B.NumberOut + 1:
                             Teacher help 3B.WIP=Teacher help 3B.WIP-1:NEXT(110$);


;
;
;     Model statements for Part:  BasicProcess.Assign 100 (Assign 100)
;
110$          ASSIGN:        waitingtime3B=(help 3B.numberout true)*TAVG(Teacher help
3B.Queue.WaitingTime)-sumwaitingtimes3B:
                             sumwaitingtimes3B=sumwaitingtimes3B+waitingtime3B:
                             teacherhelpin3B=tnow-arrivaltime3B-waitingtime3B:
                             teacherin3B(week)=teacherhelpin3B:
                             teacherin3B(6)=teacherin3B(6)+teacherin3B(week):
                             queues3B(week)=waitingtime3B:
                             queues3B(6)=sumwaitingtimes3B:NEXT(77$);


;
;
;     Model statements for Part:  BasicProcess.Process 13 (Practice 3B)
;
77$           ASSIGN:        Practice 3B.NumberIn=Practice 3B.NumberIn + 1:
                             Practice 3B.WIP=Practice 3B.WIP+1;
771$          DELAY:         MinutesToBaseTime(Duration3B(English, videos)),,VA;
818$          ASSIGN:        Practice 3B.NumberOut=Practice 3B.NumberOut + 1:
                             Practice 3B.WIP=Practice 3B.WIP-1:NEXT(78$);


;
;
;     Model statements for Part:  BasicProcess.Decide 50 (Help 3A)
;
```

```
73$           BRANCH,         1:
                              If,help(English,videos),821$,Yes:
                              Else,822$,Yes;
821$          ASSIGN:         Help 3A.NumberOut True=Help 3A.NumberOut True +
1:NEXT(105$);

822$          ASSIGN:         Help 3A.NumberOut False=Help 3A.NumberOut False +
1:NEXT(74$);


;
;
;     Model statements for Part:  BasicProcess.Assign 95 (Assign 95)
;
105$          ASSIGN:         arrivaltime3A=tnow:NEXT(104$);


;
;
;     Model statements for Part:  BasicProcess.Process 39 (Teacher help 3A)
;
104$          ASSIGN:         Teacher help 3A.NumberIn=Teacher help 3A.NumberIn + 1:
                              Teacher help 3A.WIP=Teacher help 3A.WIP+1;
826$          QUEUE,          Teacher help 3A.Queue;
825$          SEIZE,          2,VA:
                              Teacher,1:NEXT(824$);

824$          DELAY:          MinutesToBaseTime(teacher1A(English,videos)),,VA;
823$          RELEASE:        Teacher,1;
871$          ASSIGN:         Teacher help 3A.NumberOut=Teacher help 3A.NumberOut + 1:
                              Teacher help 3A.WIP=Teacher help 3A.WIP-1:NEXT(106$);


;
;
;     Model statements for Part:  BasicProcess.Assign 96 (Assign 96)
;
106$          ASSIGN:         waitingtime3A=(help 3A.numberout true)*TAVG(Teacher help
3A.Queue.WaitingTime)-sumwaitingtimes3A:
                              sumwaitingtimes3A=sumwaitingtimes3A+waitingtime3A:
                              teacherhelpin3A=tnow-arrivaltime3A-waitingtime3A:
                              teacherin3A(week)=teacherhelpin3A:
                              teacherin3A(6)=teacherin3A(6)+teacherin3A(week):
                              queues3A(week)=waitingtime3A:
                              queues3A(6)=sumwaitingtimes3A:NEXT(74$);


;
;
;     Model statements for Part:  BasicProcess.Process 11 (practice 3A)
;
74$           ASSIGN:         practice 3A.NumberIn=practice 3A.NumberIn + 1:
                              practice 3A.WIP=practice 3A.WIP+1;
875$          DELAY:          MinutesToBaseTime(Duration3A(English,videos)),,VA;
922$          ASSIGN:         practice 3A.NumberOut=practice 3A.NumberOut + 1:
                              practice 3A.WIP=practice 3A.WIP-1:NEXT(75$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 16 (Station 10)
;

80$           STATION,        Station 10;
927$          DELAY:          0.0,,VA:NEXT(81$);


;
;
;     Model statements for Part:  BasicProcess.Decide 53 (Decide 53)
;
81$           BRANCH,         1:
                              If,Way_of_working==1,82$,Yes:
                              If,Way_of_working==5,82$,Yes:
                              If,Way_of_working==4,82$,Yes:
```

```
                              Else,84$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Decide 55 (Decide 55)
;
84$           BRANCH,         1:
                              If,Way_of_working==2,85$,Yes:
                              If,Way_of_working==3,85$,Yes:
                              If,Way_of_working==5,85$,Yes:
                              Else,87$,Yes;

;
;
;     Model statements for Part:  BasicProcess.Separate 17 (Separate 17)
;
87$           SPLIT::NEXT(932$);

932$          ASSIGN:         Separate 17.NumberOut Orig=Separate 17.NumberOut Orig +
1:NEXT(88$);


;
;
;     Model statements for Part:  BasicProcess.Assign 52 (Duration 4)
;
88$           ASSIGN:         Scoreboard(team,4)=tnow-arrivaltime:NEXT(134$);


;
;
;     Model statements for Part:  BasicProcess.Decide 68 (Decide 68)
;
134$          BRANCH,         1:
                              If,Scoreboard(team,4)<=classduration-
teacherexplanation,935$,Yes:
                              Else,936$,Yes;
935$          ASSIGN:         Decide 68.NumberOut True=Decide 68.NumberOut True +
1:NEXT(135$);

936$          ASSIGN:         Decide 68.NumberOut False=Decide 68.NumberOut False +
1:NEXT(136$);


;
;
;     Model statements for Part:  BasicProcess.Assign 126 (Assign 126)
;
135$          ASSIGN:         p4finished(team)=1:NEXT(155$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 30 (Route 30)
;
155$          ROUTE:          0.,Station 12;


;
;
;     Model statements for Part:  BasicProcess.Assign 127 (Assign 127)
;
136$          ASSIGN:         p4finished(team)=0:NEXT(155$);


;
;
;     Model statements for Part:  BasicProcess.Decide 56 (Help 4B)
;
85$           BRANCH,         1:
                              If,help(English, videos),937$,Yes:
                              Else,938$,Yes;
937$          ASSIGN:         Help 4B.NumberOut True=Help 4B.NumberOut True +
1:NEXT(97$);
```

```
938$          ASSIGN:        Help 4B.NumberOut False=Help 4B.NumberOut False +
1:NEXT(86$);


;
;
;     Model statements for Part:  BasicProcess.Assign 89 (Assign 89)
;
97$           ASSIGN:        arrivaltime4B=tnow:NEXT(96$);


;
;
;     Model statements for Part:  BasicProcess.Process 36 (Teacher help 4B)
;
96$           ASSIGN:        Teacher help 4B.NumberIn=Teacher help 4B.NumberIn + 1:
                             Teacher help 4B.WIP=Teacher help 4B.WIP+1;
942$          QUEUE,         Teacher help 4B.Queue;
941$          SEIZE,         2,VA:
                             Teacher,1:NEXT(940$);

940$          DELAY:         MinutesToBaseTime(teacher1A(English,videos)),,VA;
939$          RELEASE:       Teacher,1;
987$          ASSIGN:        Teacher help 4B.NumberOut=Teacher help 4B.NumberOut + 1:
                             Teacher help 4B.WIP=Teacher help 4B.WIP-1:NEXT(109$);


;
;
;     Model statements for Part:  BasicProcess.Assign 99 (Assign 99)
;
109$          ASSIGN:        waitingtime4B=(help 4B.numberout true)*TAVG(Teacher help
4B.Queue.WaitingTime)-sumwaitingtimes4B:
                             sumwaitingtimes4B=sumwaitingtimes4B+waitingtime4B:
                             teacherhelpin4B=tnow-arrivaltime4B-waitingtime4B:
                             teacherin4B(week)=teacherhelpin4B:
                             teacherin4B(6)=teacherin4B(6)+teacherin4B(week):
                             queues4B(week)=waitingtime4B:
                             queues4B(6)=sumwaitingtimes4B:NEXT(86$);


;
;
;     Model statements for Part:  BasicProcess.Process 17 (Practice 4B)
;
86$           ASSIGN:        Practice 4B.NumberIn=Practice 4B.NumberIn + 1:
                             Practice 4B.WIP=Practice 4B.WIP+1;
991$          DELAY:         MinutesToBaseTime(Duration4B(English, videos)),,VA;
1038$         ASSIGN:        Practice 4B.NumberOut=Practice 4B.NumberOut + 1:
                             Practice 4B.WIP=Practice 4B.WIP-1:NEXT(87$);


;
;
;     Model statements for Part:  BasicProcess.Decide 54 (Help 4A)
;
82$           BRANCH,        1:
                             If,help(English,videos),1041$,Yes:
                             Else,1042$,Yes;
1041$         ASSIGN:        Help 4A.NumberOut True=Help 4A.NumberOut True +
1:NEXT(102$);

1042$         ASSIGN:        Help 4A.NumberOut False=Help 4A.NumberOut False +
1:NEXT(83$);


;
;
;     Model statements for Part:  BasicProcess.Assign 93 (Assign 93)
;
102$          ASSIGN:        arrivaltime4A=tnow:NEXT(101$);


;
;
```

```
;     Model statements for Part:  BasicProcess.Process 38 (Teacher help 4A)
;
101$          ASSIGN:        Teacher help 4A.NumberIn=Teacher help 4A.NumberIn + 1:
                             Teacher help 4A.WIP=Teacher help 4A.WIP+1;
1046$         QUEUE,         Teacher help 4A.Queue;
1045$         SEIZE,         2,VA:
                             Teacher,1:NEXT(1044$);

1044$         DELAY:         MinutesToBaseTime(teacher1A(English,videos)),,VA;
1043$         RELEASE:       Teacher,1;
1091$         ASSIGN:        Teacher help 4A.NumberOut=Teacher help 4A.NumberOut + 1:
                             Teacher help 4A.WIP=Teacher help 4A.WIP-1:NEXT(103$);


;
;
;     Model statements for Part:  BasicProcess.Assign 94 (Assign 94)
;
103$          ASSIGN:        waitingtime4A=(help 4A.numberout true)*TAVG(Teacher help
4A.Queue.WaitingTime)-sumwaitingtimes4A:
                             sumwaitingtimes4A=sumwaitingtimes4A+waitingtime4A:
                             teacherhelpin4A=tnow-arrivaltime4A-waitingtime4A:
                             teacherin4A(week)=teacherhelpin4A:
                             teacherin4A(6)=teacherin4A(6)+teacherin4A(week):
                             queues4A(week)=waitingtime4A:
                             queues4A(6)=sumwaitingtimes4A:NEXT(83$);


;
;
;     Model statements for Part:  BasicProcess.Process 15 (practice 4A)
;
83$           ASSIGN:        practice 4A.NumberIn=practice 4A.NumberIn + 1:
                             practice 4A.WIP=practice 4A.WIP+1;
1095$         DELAY:         MinutesToBaseTime(Duration4A(English,videos)),,VA;
1142$         ASSIGN:        practice 4A.NumberOut=practice 4A.NumberOut + 1:
                             practice 4A.WIP=practice 4A.WIP-1:NEXT(84$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 17 (Station 11)
;

89$           STATION,       Station 11;
1147$         DELAY:         0.0,,VA:NEXT(92$);


;
;
;     Model statements for Part:  BasicProcess.Separate 18 (Separate 18)
;
92$           SPLIT::NEXT(1148$);

1148$         ASSIGN:        Separate 18.NumberOut Orig=Separate 18.NumberOut Orig +
1:NEXT(94$);


;
;
;     Model statements for Part:  BasicProcess.Batch 11 (Batch 11)
;
94$           QUEUE,         Batch 11.Queue;
1151$         GROUP,
team,Temporary:members(week+1,teamdistribution),Sum:NEXT(1152$);

1152$         ASSIGN:        Batch 11.NumberOut=Batch 11.NumberOut + 1:NEXT(90$);


;
;
;     Model statements for Part:  BasicProcess.Decide 58 (Help 5)
;
90$           BRANCH,        1:
                             If,help(English,videos),1153$,Yes:
```

```
                              Else,1154$,Yes;
1153$          ASSIGN:        Help 5.NumberOut True=Help 5.NumberOut True + 1:NEXT(99$);

1154$          ASSIGN:        Help 5.NumberOut False=Help 5.NumberOut False +
1:NEXT(91$);


;
;
;      Model statements for Part:  BasicProcess.Assign 91 (Assign 91)
;
99$            ASSIGN:        arrivaltime5=tnow:NEXT(98$);


;
;
;      Model statements for Part:  BasicProcess.Process 37 (Teacher help 5)
;
98$            ASSIGN:        Teacher help 5.NumberIn=Teacher help 5.NumberIn + 1:
                              Teacher help 5.WIP=Teacher help 5.WIP+1;
1158$          QUEUE,         Teacher help 5.Queue;
1157$          SEIZE,         2,VA:
                              Teacher,1:NEXT(1156$);

1156$          DELAY:         MinutesToBaseTime(teacher1A(English,videos)),,VA;
1155$          RELEASE:       Teacher,1;
1203$          ASSIGN:        Teacher help 5.NumberOut=Teacher help 5.NumberOut + 1:
                              Teacher help 5.WIP=Teacher help 5.WIP-1:NEXT(100$);


;
;
;      Model statements for Part:  BasicProcess.Assign 92 (Assign 92)
;
100$           ASSIGN:        waitingtime5=(help 5.numberout true)*TAVG(Teacher help
5.Queue.WaitingTime)-sumwaitingtimes5:
                              sumwaitingtimes5=sumwaitingtimes5+waitingtime5:
                              teacherhelpin5=tnow-arrivaltime5-waitingtime5:
                              teacherin5(week)=teacherhelpin5:
                              teacherin5(6)=teacherin5(6)+teacherin5(week):
                              queues5(week)=waitingtime5:
                              queues5(6)=sumwaitingtimes5:NEXT(91$);


;
;
;      Model statements for Part:  BasicProcess.Process 19 (practice 5)
;
91$            ASSIGN:        practice 5.NumberIn=practice 5.NumberIn + 1:
                              practice 5.WIP=practice 5.WIP+1;
1207$          DELAY:         MinutesToBaseTime(Duration5(English,videos)),,VA;
1254$          ASSIGN:        practice 5.NumberOut=practice 5.NumberOut + 1:
                              practice 5.WIP=practice 5.WIP-1:NEXT(95$);


;
;
;      Model statements for Part:  BasicProcess.Separate 20 (Separate 20)
;
95$            SPLIT::NEXT(1257$);

1257$          ASSIGN:        Separate 20.NumberOut Orig=Separate 20.NumberOut Orig +
1:NEXT(93$);


;
;
;      Model statements for Part:  BasicProcess.Assign 53 (Duration 5)
;
93$            ASSIGN:        Scoreboard(team,5)=tnow-arrivaltime:NEXT(137$);


;
;
;      Model statements for Part:  BasicProcess.Decide 69 (Decide 69)
```

```
;
137$          BRANCH,         1:
                              If,Scoreboard(team,5)<=classduration-
teacherexplanation,1260$,Yes:
                              Else,1261$,Yes;
1260$         ASSIGN:         Decide 69.NumberOut True=Decide 69.NumberOut True +
1:NEXT(138$);

1261$         ASSIGN:         Decide 69.NumberOut False=Decide 69.NumberOut False +
1:NEXT(139$);


;
;
;     Model statements for Part:  BasicProcess.Assign 128 (Assign 128)
;
138$          ASSIGN:         p5finished(team)=1:NEXT(156$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 31 (Route 31)
;
156$          ROUTE:          0.,Station 12;


;
;
;     Model statements for Part:  BasicProcess.Assign 129 (Assign 129)
;
139$          ASSIGN:         p5finished(team)=0:NEXT(156$);


;
;
;     Model statements for Part:  AdvancedTransfer.Station 18 (Station 12)
;

152$          STATION,        Station 12;
1264$         DELAY:          0.0,,VA:NEXT(147$);


;
;
;     Model statements for Part:  BasicProcess.Batch 15 (Batch 15)
;
147$          QUEUE,          Batch 15.Queue;
1265$         GROUP,          ,Temporary:

members(week+1,1)+members(week+1,2)+members(week+1,3)+members(week+1,4)+members(week+1,5
),Sum,
                              student:NEXT(1266$);

1266$         ASSIGN:         Batch 15.NumberOut=Batch 15.NumberOut + 1:NEXT(149$);


;
;
;     Model statements for Part:  BasicProcess.Assign 134 (Assign 134)
;
149$          ASSIGN:         teacherperweek(week)=

teacherin1A(week)+teacherin1B(week)+teacherin2A(week)+teacherin2B(week)+teacherin3A(week
)+teacherin3B(week)+teacherin4A(week)+teacherin4B(week)+teacherin5(week):
                              teacherperweek(6)=

teacherperweek(1)+teacherperweek(2)+teacherperweek(3)+teacherperweek(4)+teacherperweek(5
):
                              queuesperweek(week)=

queues1A(week)+queues1B(week)+queues2A(week)+queues2B(week)+queues3A(week)+queues3B(week
)+queues4A(week)+queues4B(week)+queues5(week):
                              queuesperweek(6)=

queuesperweek(1)+queuesperweek(2)+queuesperweek(3)+queuesperweek(4)+queuesperweek(5):
```

```
                              teacherperteam(1)=

teacherin1A(1)+teacherin1B(1)+teacherin2A(2)+teacherin2B(2)+teacherin3A(3)+teacherin3B(3
)+teacherin4A(4)+teacherin4B(4)+teacherin5(5):
                              teacherperteam(2)=

teacherin1A(5)+teacherin1B(5)+teacherin2A(1)+teacherin2B(1)+teacherin3A(2)+teacherin3B(2
)+teacherin4A(3)+teacherin4B(3)+teacherin5(4):
                              teacherperteam(3)=

teacherin1A(4)+teacherin1B(4)+teacherin2A(5)+teacherin2B(5)+teacherin3A(1)+teacherin3B(1
)+teacherin4A(2)+teacherin4B(2)+teacherin5(3):
                              teacherperteam(4)=

teacherin1A(3)+teacherin1B(3)+teacherin2A(4)+teacherin2B(4)+teacherin3A(5)+teacherin3B(5
)+teacherin4A(1)+teacherin4B(1)+teacherin5(2):
                              teacherperteam(5)=

teacherin1A(2)+teacherin1B(2)+teacherin2A(3)+teacherin2B(3)+teacherin3A(4)+teacherin3B(4
)+teacherin4A(5)+teacherin4B(5)+teacherin5(1):
                              queueperteam(1)=

queues1A(1)+queues1B(1)+queues2A(2)+queues2B(2)+queues3A(3)+queues3B(3)+queues4A(4)+queu
es4B(4)+queues5(5):
                              queueperteam(2)=

queues1A(5)+queues1B(5)+queues2A(1)+queues2B(1)+queues3A(2)+queues3B(2)+queues4A(3)+queu
es4B(3)+queues5(4):
                              queueperteam(3)=

queues1A(4)+queues1B(4)+queues2A(5)+queues2B(5)+queues3A(1)+queues3B(1)+queues4A(2)+queu
es4B(2)+queues5(3):
                              queueperteam(4)=

queues1A(3)+queues1B(3)+queues2A(4)+queues2B(4)+queues3A(5)+queues3B(5)+queues4A(1)+queu
es4B(1)+queues5(2):
                              queueperteam(5)=

queues1A(2)+queues1B(2)+queues2A(3)+queues2B(3)+queues3A(4)+queues3B(4)+queues4A(5)+queu
es4B(5)+queues5(1)
                              :NEXT(150$);


;
;
;     Model statements for Part:  BasicProcess.Decide 70 (Decide 70)
;
150$          BRANCH,         1:
                              If,Week<5,1267$,Yes:
                              Else,1268$,Yes;
1267$         ASSIGN:         Decide 70.NumberOut True=Decide 70.NumberOut True +
1:NEXT(148$);

1268$         ASSIGN:         Decide 70.NumberOut False=Decide 70.NumberOut False +
1:NEXT(151$);


;
;
;     Model statements for Part:  BasicProcess.Separate 23 (Separate 23)
;
148$          SPLIT::NEXT(1269$);

1269$         ASSIGN:         Separate 23.NumberOut Orig=Separate 23.NumberOut Orig +
1:NEXT(146$);


;
;
;     Model statements for Part:  AdvancedTransfer.Route 27 (Route 27)
;
146$          ROUTE:          0.,Station 2;


;
```

```
;
;     Model statements for Part:  BasicProcess.Assign 135 (Assign 135)
;
151$          ASSIGN:        practices=

p1finished(1)+p2finished(1)+p3finished(1)+p4finished(1)+p5finished(1)+
p1finished(2)+p2finished(2)+p3finished(2)+p4finished(2)+p5finished(2)+
p1finished(3)+p2finished(3)+p3finished(3)+p4finished(3)+p5finished(3)+
p1finished(4)+p2finished(4)+p3finished(4)+p4finished(4)+p5finished(4)+
p1finished(5)+p2finished(5)+p3finished(5)+p4finished(5)+p5finished(5):
                              activitiestime=

scoreboard(1,1)+scoreboard(1,2)+scoreboard(1,3)+scoreboard(1,4)+scoreboard(1,5)+
scoreboard(2,1)+scoreboard(2,2)+scoreboard(2,3)+scoreboard(2,4)+scoreboard(2,5)+
scoreboard(3,1)+scoreboard(3,2)+scoreboard(3,3)+scoreboard(3,4)+scoreboard(3,5)+
scoreboard(4,1)+scoreboard(4,2)+scoreboard(4,3)+scoreboard(4,4)+scoreboard(4,5)+
scoreboard(5,1)+scoreboard(5,2)+scoreboard(5,3)+scoreboard(5,4)+scoreboard(5,5)
                              :NEXT(157$);


;
;
;     Model statements for Part:  AdvancedProcess.ReadWrite 4 (ReadWrite 4)
;
157$          WRITE,         File 1:
                             attendancerate,
                             wayofworking,
                             Accesstovideos,
                             Englishlevel,
                             teacherperweek(6),
                             queuesperweek(6),
                             activitiestime,
                             practices,
                             numberofpractices:NEXT(148$);
```