

The Practice of Scheduling

A comparison between the methods used in
Spain and Hungary

*Diploma Project submitted
in fulfilment of the requirements
for the Degree
of
“Arquitectura Técnica”
Under the supervision
of
Miklós Hajdu Ph.D.
Department of Construction Management*

By
Carlos González Pérez

June - 2013



ESCUELA TÉCNICA SUPERIOR
INGENIERÍA DE
EDIFICACIÓN

Escuela Técnica Superior de Ingeniería
de Edificación
Universidad Politécnica de Valencia
Valencia (España)



SZENT ISTVÁN
EGYETEM



YBL MIKLÓS ÉPÍTÉSTUDOMÁNYI KAR, BUDAPEST

YBL Miklós Építéstudományi Kar
Szent István Egyetem
Budapest (Hungary)

TABLE OF CONTENTS

1. INTRODUCTION	4
2. THE ANCIENT SCHEDULING METHODS	5
3. HISTORICAL SCHEDULING METHODS	8
3.1. Priestley's Bar Chart	8
3.2. Playfair's Chart	10
4. TRADITIONAL SCHEDULING METHODS	12
4.1. Adamiciecki's Harmonygraph	12
4.1.1. Harmonogram	13
4.1.2. How does the Adamiciecki's Harmonogramn work?	14
4.2. Gantt Chart	14
4.2.1. Gantt Charts	15
4.2.2. Description about Gant Chart	16
4.3. Linear Scheduling Method	17
4.3.1. Characteristics of LOB	17
4.4. Gantt versus LOB	18
5. NETWORK TECHNIQUES	19
5.1. CPM	21
5.1.1. Construction of the arrow network	21
5.1.1.1. Elements:	21
5.1.1.2. Classification of the activities	21
5.1.1.3. Rules for drawing an arrow network	23
5.1.2. CPM durations	24
5.1.2.1. Times	25
5.1.3. CPM floats	27

5.1.4. The critical path	30
5.1.5 Cost Optimization	30
5.2. Program Evaluation Review Technique (PERT)	35
5.2.1. Probability of carrying out a project in a determined time.	36
5.2.2. The probability factor and the Gaussian distribution	38
5.2.3. Deductions of the factor of probability equation.	38
5.3. Metro Potential Method	40
5.3.1. Drawing of the activity	40
5.3.2. Relationships, times and restrictions.	40
5.3.3. Floats	43
5.3.4. Drawing of the network	45
5.4 Precedence Diagraming Method (PDM)	45
5.4.1. Drawing of the activity	46
5.4.2. Minimal precedence relationships and times	49
5.4.3. Maximal precedence relationships and times	52
6. THE PRACTICE OF SCHEDULING IN THE CONSTRUCTION MANAGEMENT EDUCATION.	54
6.1. Scheduling software	54
6.2. Assignment	56
6.3. Exam	59
7. COMPARISON	61
8. BRIEF OVERVIEW OF FUTURE PROSPECTING AND NEW METHODS	66
9. CONCLUSIONS	69
BIBLIOGRAPHY	72

Nomenclature and abbreviations

<i>A, B, C, (...)</i>	-	Name of the activity
<i>i, j, k, (...)</i>	-	Node number
<i>d [A,B,C (...)]</i>	-	Activity duration
<i>Es</i>	-	Earliest start time
<i>Ef</i>	-	Earliest finish time
<i>Ls</i>	-	Latest start time
<i>Lf</i>	-	Latest finish time
<i>Tf</i>	-	Total float
<i>Ff</i>	-	Free float
<i>If</i>	-	Independent float
<i>Cf</i>	-	Conditional float
<i>IC</i>	-	Indirect costs
<i>K</i>	-	Konstant
<i>Te</i>	-	Time
<i>α</i>	-	Slop
<i>Ac</i>	-	Maximal cost
<i>Nc</i>	-	Normal cost
<i>Ad</i>	-	Crash duration
<i>Nd</i>	-	Normal duration
<i>Us</i>	-	Unitary slop straight line cost
<i>Ot</i>	-	Optimistic time
<i>Pt</i>	-	pessimistic time
<i>Nt</i>	-	Normal time
<i>Ri</i>	-	Rang of uncertainly
<i>Et</i>	-	Estimated time
σ^2	-	Variance
σ	-	Estandard desviation
<i>Z</i>	-	Factor probability of success
<i>g</i>	-	gap or restriction
<i>FS</i>	-	Minimum Finish to Start
<i>SF</i>	-	Minimum Start to finish
<i>FF</i>	-	Minimum Finish to finish
<i>SS</i>	-	Minimum Start to start
<i>Cr</i>	-	Minimum Critical
<i>MaxFS</i>	-	Maximum Finish to Start
<i>MaxSf</i>	-	Maximum Start to finish
<i>MaxFF</i>	-	Maximum Finish to Finish
<i>MaxSS</i>	-	Maximum Start to Start
<i>MaxCr</i>	-	Maximum Critical

1. INTRODUCTION:

The definition of scheduling is the process of deciding how to commit resources between varieties of possible tasks.

More specifically we can say that the scheduling has two main tasks:

The first one is assigning an appropriate number of workers to the job during each day, shift, workday or simply work. The other one would be determining when an activity should start or end, depending on its duration, predecessor activity, predecessor relationship, resources availability and target completion date of the project.

I would add a condition more to the definition. The scheduling is sometimes conditioned by the cost of the project and the how much money the constructor wants to earn. This quote of Henry Gantt developer of Gantt Chart explains it quite good:

“The aim of our efficiency has not been to produce goods, but to harvest dollars... The production of goods was always secondary to the securing of dollars.”

H.L. Gantt cited in: Walter N. Polakov (1922) "The measurement of human work" in: Wallace Clark (1922) The Gantt chart, a working tool of management. New York, Ronald Press. Preface.p.152

Along the history the construction scheduling has been very important in the construction field. A lot of important engineers, architects and managers among others have tried to improve the practice of scheduling. As we will see the scheduling methods are a constant evolution through the years. The most of times, the new methods incorporate the best aspects of another one and improve it with little but important modifications.

The aim of this thesis is studying all the methods developed in the history of the construction from the ancient times to the methods of the twenty century, applicable nowadays.

Due the methods are global and they are over the world, they have variations depending on the place where they are practiced. In this case, taking advantage of my residence for five months and my studies in the University of Budapest, this thesis will be focused on the appreciable differences between the Hungarian and Spanish way of construction management education regarding to scheduling methodologies.

What will be studied are the different methods in the history, classified in four chronologic big groups:

- The ancient scheduling methods: This will be the starting point. Although there isn't a lot of information about this period, obviously the practice of scheduling was present in the building construction. We will see some examples about scheduling carried out in the ancient civilizations. I will be exposed the ancient Egyptians or the ancient Chinese Empire.
- Historical scheduling methods (Between 18th and 19th centuries). In this period Joseph Priestly and William Playfair started to use chars for organize the events in a scale of time. During this centuries were the real beginnings of the practices of scheduling.
- Traditional scheduling methods (Lasts years of 19th century and first half of the 20th century): At this time the practice of scheduling is consolidated. This is the period of the Industrial Revolution and the society demanded efficient ways to carry out the process. The Gantt chart developed by Henry Gant, ciklogram or Adamiecki's harmonogramn will be studied.
- Network techniques (Second half of 20th century to the present): We would call this one as the emergence of the modern techniques. In this period was developed the methods used in the actuality. It was the time of the first computers which helps to develop methods like CPM, PDM, PERT and ROY. These methods are used nowadays in the most of the companies.

As we said before, this methods have quite similitudes but also some differences regarding of the country. We will see that some methods have more importance in one system education or other cases it isn't even studied.

During the thesis, it will be compared the different methods: advantages and disadvantages between its history predecessor and the important of them in the Hungarian and Spanish education.

2. THE ANCIENT SCHEDULING METHODS.

The concept of scheduling is not new. Since the beginning of the construction, people have needed to organize the different activities. Of course the construction's field has always been an important restlessness in the human life. Since the ancient times the people has tried to build the biggest, nicest or the most useful constructions. This process had been impossible without the help of a good scheduling.

The best example is the Egypt pyramids. These were built 3000 years ago. Constructing a pyramid is the major civil engineering project. Pyramids are built on rock formations, conglomerate, gravel, or sand surfaces which are artificially leveled or unlevelled. While it will be relatively easy to level the sand surface, it would be more difficult to level gravel and very difficult to level conglomerate and rock surfaces.

The ancient Egyptians were the first recorded project managers. They had to organize a lot of resource, material and equipment. The way to build it is a mystery and archaeologists don't agree about it, there are a lot of theories. Which is sure is that they needed a good scheduling for carry out these huge constructions. Archeological research demonstrates that a significant effort was spent, including the creation of camp-towns, to supply the bread and beer needed to pay the workers.

About the supplies, the building material was usually brought from sources close to the site. All pyramids were built of stone from the nearest quarries, thus: granite at layer step pyramid of Elephantine, sand stone at layer step pyramid of El Ghenimiya and limestone for all the other pyramids. When fine stone was needed: for the lowest course of the outer facing, the other facing itself and the pyramidion in the superstructure and for the sarcophagus, portcullis and some inner chambers in the substructure. Their quarries and sources were deep in the desert or far upstream. In all cases transportation was needed. Preparing pyramidions and sarcophagi required higher skills.

The transportation was a hard job sure too. Quarrying is a skill which has existed during all phases of human civilizations. In Egypt the quarries are numerous and their output had to be transported - we are talking about solid blocks weighing from less than one ton to hundreds of tons. In Ancient Egypt the preferred quarries of limestone were in Middle Egypt, sand stone in Upper Egypt and granite from Aswan. Most preferable were those closest to the banks of the river. As for diorite, quartzite, shiest, breccia and rare stones, they were quarried from far locations. These also had to be brought to the river for transportation. Mining copper and other metals for tools came from remote locations in Sinai. The quarried blocks and mined metal had to be brought to the river, loaded on barges which sailed downstream. On arrival to the river banks closest to the destination, unloading takes place.

This picture shows how it could be the building site during the construction. A good management was on charge for sure.



Another special mention for one of the first people that wrote about the scheduling's importance. He was Sun Tzu. He lived between the 5th and 6th centuries Before Christ although historians are not sure about the exactly date.

Tzu was born in the Old Chine and was a famous general and philosophe. He wrote the famous book "the art of the war" where he talks about the warfare and the strategy. In spite of it is a military book is also an interest document about how to organize the process.



The book is not only popular among military theorists, but has also become increasingly popular among political leaders and those in business management. Despite its title, The Art of War addresses strategy in a broad fashion, touching upon public administration and planning. The text outlines theories of battle, but also advocates diplomacy and cultivating relationships with other nations as essential to the health of a state.

The picture shows us s Chinese bamboo book, open to display the binding and contents. This copy of The Art of War (on the cover, "孫子兵法" by Sun Tzu is part of a collection at the University of California, Riverside. The cover also reads "乾隆御書", meaning it was either commissioned or transcribed by the Qianlong Emperor.



3. HISTORICAL SCHEDULING METHODS:

3.1. PRIESTLEY'S BAR CHART:

Joseph Priestley was born in England in the 18th century, He was a scientific and philosopher. During his life he wrote over than 150 theories in different fields.

He was the originator of the “bar chart”. It's the first time that we can see the activities represented in a line. This way to write a chart bar was the inspiration to the next traditional methods



Priestley's philosophy was founded on the fervent belief that a thorough understanding of history was necessary not only to worldly success but also to spiritual growth. He wrote: "my view was, not merely to make history intelligible to persons who may choose to read it for amusement, but . . . to facilitate its subservience to the highest uses to which it can be applied: to contribute to its forming the able statesman and the intelligent and useful citizen." His abiding interest in history and particularly modern history, sets Priestley apart from his contemporaries. Priestley was the first person to advocate the serious study of modern history; no other British university was teaching the subject at the time and Oxford would not begin until 1841.

As a supplement to his lectures on history, Priestley also designed and published A Chart of Biography (1765) and a New Chart of History (1769) (which he dedicated to Benjamin Franklin). These charts and their accompanying Descriptions would allow students, Priestley said, to "trace out distinctly the dependence of events to distribute them into such periods and divisions as shall lay the whole claim of past transactions in a just and orderly manner.

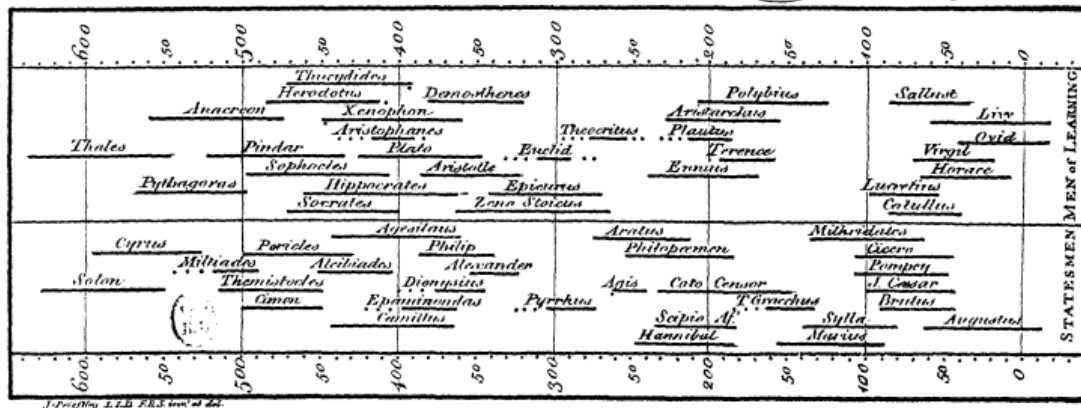
- Chart biography:

In 1765 he published “chart of biography” where he plotted some 2000 famous lifetimes on a time scaled chart. As he said: “...a longer or a shorter space of time may be most commodiously and advantageously represented by a longer or a shorter line.”

The Chart of Biography covers a vast timespan, from 1200 BC to 1800 AD, and includes two thousand names. Priestley organized his list into six categories: Statesman and Warriors; Divines and Metaphysicians; Mathematicians and Physicians (natural philosophers were placed here); Poets and Artists; Orators and Critics (prose fiction authors were placed here); and Historians and Antiquarians (lawyers were placed here).

As we can see in this example of Priestley's bar chart, in the horizontal axis there is written the data and the names are above each line.

A Specimen of a Chart of Biography.



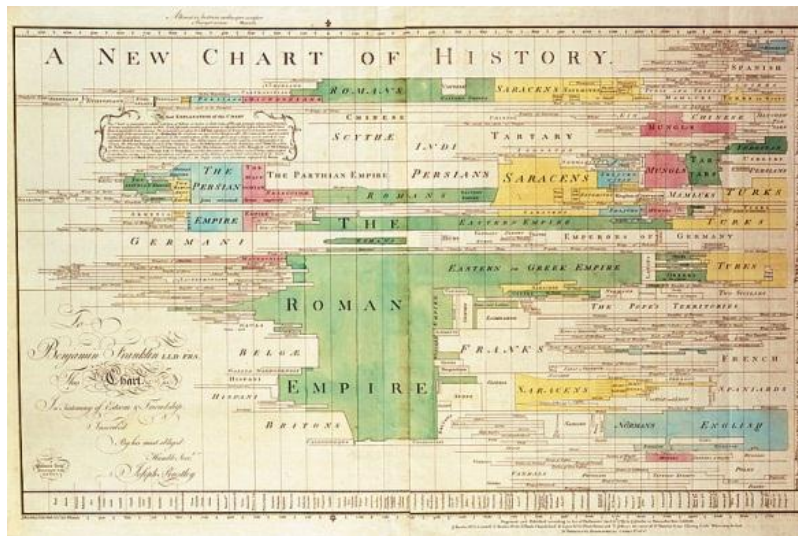
- Chart of History:

The Chart of History lists events in 106 separate locations; it illustrates Priestley's belief that the entire world's history was significant, a relatively new development in the eighteenth century, which had begun with Voltaire and William Robertson. The world's history is divided up into the following geographical categories: Scandinavia, Poland, Russia, Great Britain, Spain, France, Italy, and Turkey in Europe, Turkey in Asia, Germany, Persia, India, China, Africa and America. Priestley aimed to show the history of empires and the passing of power; the subtitle of the Description that accompanied the chart was "A View of the Principle Revolutions of Empire that have taken place in the World" and he wrote that:

"The capital use (of the Charts was as) a most excellent mechanical help to the knowledge of history, impressing the imagination indelibly with a just image of the rise, progress, extent, duration, and contemporary state of all the considerable empires that have ever existed in the world."

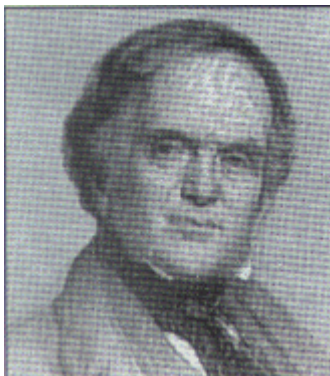
As Arthur Sheps writes in his article about the Charts, "the horizontal line conveys an idea of the duration of fame, influence, power and domination. A vertical reading conveys an impression of the contemporaneity of ideas, events and people. The number or density of entries...tells us about the vitality of any age." Voids in the chart indicated intellectual Dark Ages.

"A New Chart of History" went through fifteen editions by 1816



“A New Chart of History” 1769.

3.2. PLAYFAIR’S CHART:



William Playfair (22 September 1759 – 11 February 1823) was born in Scotland in the same period as Priestley. He was an important engineer and political economist. Playfair belonged to a notable family. His father was reverend and his brothers two important mathematics and architects. So he couldn't be less and worked in a lot of fields. Engineer, draftsman, accountant, inventor, silversmith, merchant and investment broker are only examples.

In 1786, 21 years after the Priestley's method, William Playfair published the “commercial and political atlas” where he picked up the ideas of Priestley and improved it. It has been described as the first major work to contain statistical graphs.

The innovation of this chart was included lines, bars and pie charts.

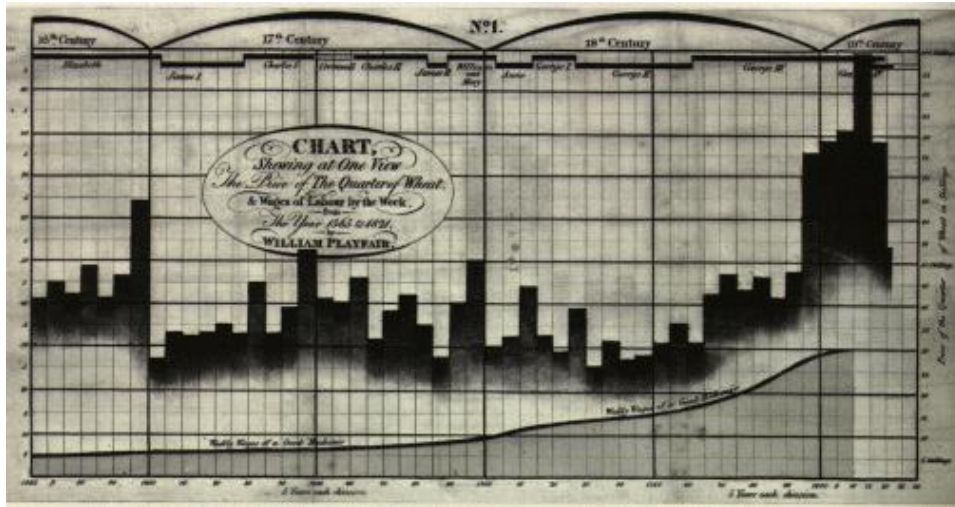
There are two main differences between this method and its predecessor:

- Each activity is in each line.
- The activity names are written in the axis and not above the bar.

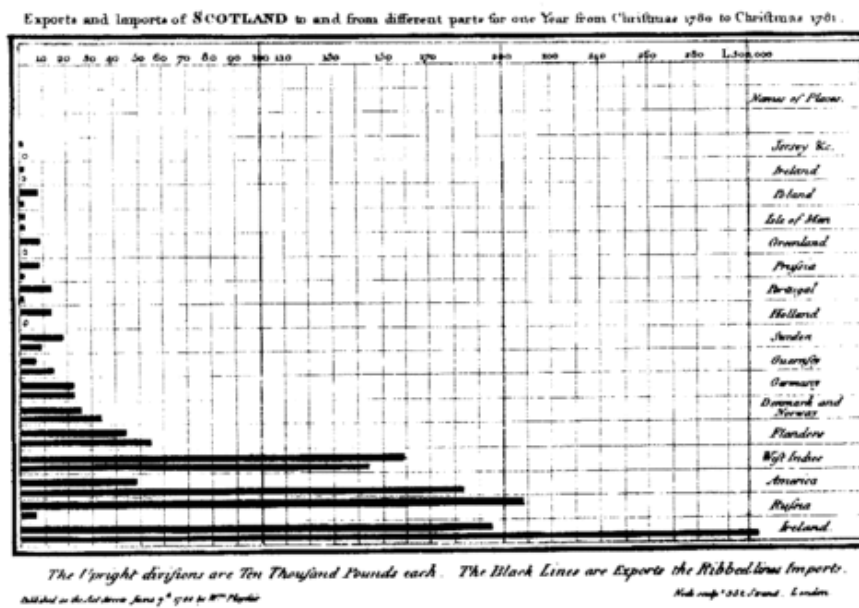
There are some examples of this chart:

The first one seems a chart evolution during several centuries. The information is represented in vertical and horizontal bars as well as in lines. In both vertical

axis and the horizontal below is written the numbers and dates. The centuries are in the upper axis



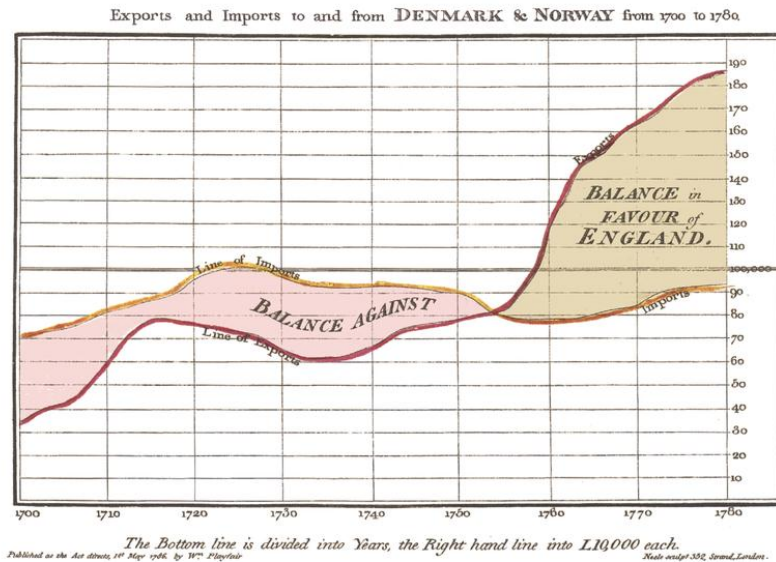
This second one represents the evolution of the Scottish exportation and importation. This is simpler. It's a horizontal bar representation. The numerical information is in the top and the name of the task is in the right side of the chart.



In this bar chart Scotland's imports and exports from and to 17 countries in 1781 are represented. "This bar chart was the first quantitative graphical form that did not locate data either in space, as had coordinates statistical breviary (1801), showing the proportions of the Turkish Empire located in Asia, Europe and Africa before 1789" Playfair, who argued that charts communicated better than tables of data, has been credited with inventing

the line, bar, and pie charts. His time-series plots are still presented as models of clarity.

Another Playfair's chart in which is analyze the commercial movements between Denmark and Norway in the 18th century.



4. TRADITIONAL SCHEDULING METHODS:

4.1. ADAMIECKI'S HARMONYGRAPH:

Karol Adamiecki (Dąbrowa Górnicza, 18 March 1866 – 16 May 1933, Warsaw, Poland) was a Polish economist, engineer and management researcher.

Adamiecki graduated in engineering from the university in St. Petersburg, Russia, in 1891. He returned to Dąbrowa Górnicza where he was in charge of a steel rolling mill. While working in the steel industry he developed his ideas on management. In 1919 he joined the Warsaw Polytechnic as a lecturer, becoming a professor in 1922. He was the founder and first director (1925–1933) of the Institute of Scientific Organization (Instytut Naukowej Organizacji) in Warsaw.



Karol Adamiecki was a prominent management researcher in Eastern and Central Europe. He began his research at the Institute of Technology in St. Petersburg, Russia (1884–90) and then moved to Poland.

In 1896, Adamiecki developed the Harmonogram. His theory caused a stir in the Russian technical circles.

The problem was that he didn't publish it until 1931 and it was in Polish and Russian, two languages that wasn't well known by the foreign people. For this reason, his theory is not well known in the rest of the world. As we will see, Henry Gantt took advantage of this problem.

Also, he is the author of the law of harmony in management: harmony should comprise three parts:

- Harmony of choice (all production tools should be mutually compatible, with special regard to their output production speed)
- Harmony of doing (the importance of time coordination — schedules and timetables)
- Harmony of spirit (the importance of creating a good team)

4.1.1. HARMONOGRAM:

It is more schematic than the others methods. For the first time, it adds the precedent and successor task not only drawing but numerical too.

Harmonogramn is a manual method. This is an advantage because it's possible to modify it if the project changes. This is an important thing because it allows keeping the logic of the project.

time	From	-	-	-	A-1	B-1	...
	To	A-2	B-2,C	D-2	A-3	E-1	..
	activity	A-1<4>	B-1<4>	D-1<2>	A-2<4>	B-2<3>	...
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							

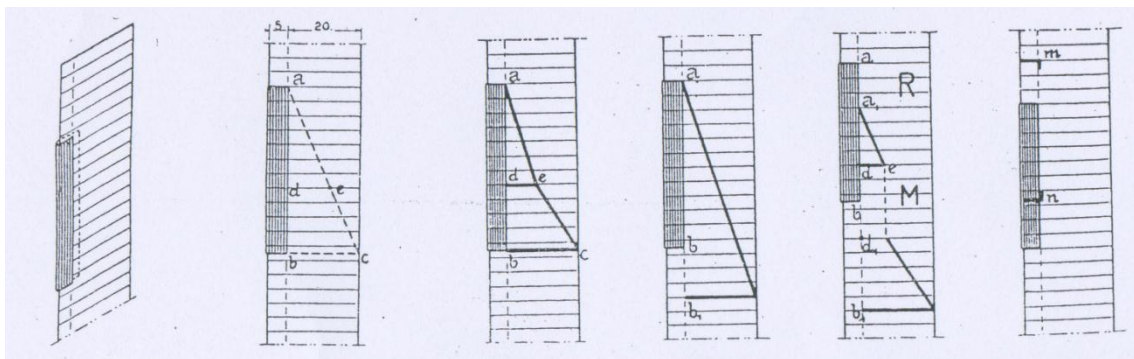
4.1.2. HOW DOES THE ADAMIECKI'S HARMONOGRAMN WORK?

In the vertical axis there is a number column (time). The time is usually written in days but it depends on the project. This column is the only one which it will never move.

Then we have the tasks. Each task is formed for a paper strip. In the top of the strip is written the predecessor activity, successor activity and itself name with the duration. There will be as many strips as activities in the project.

As each activity is in an own paper strip, you can move the activities as you want. The activities without predecessor or carry out before will be ordered from the left to right.

To show the duration of the activities, this method uses a black fold strip paper. This strip has the exact size of the activity duration. This strip allows showing the days that this activity will be carried out. If there would be a change in the scheduling for any reason it's possible to change it easy and fast due to its possibility to move the strip in the slide rail.



Graphical example about the use of harmonogram

4.2. GANTT CHART

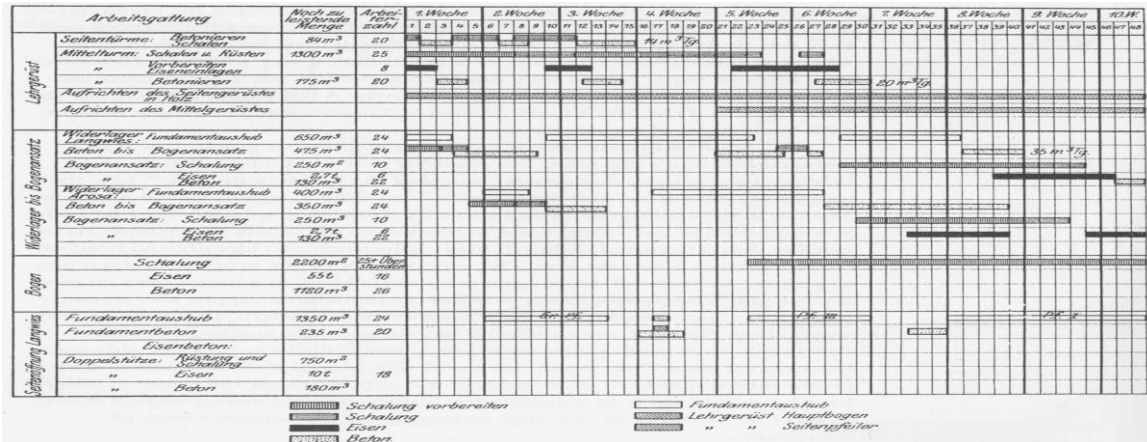
Henry Gantt (Maryland EEUU, May 20, 1861 – New Jersey, November 23, 1919) was an American mechanical engineer and management consultant.

Gantt's charts were employed on major infrastructure projects including the Hoover Dam and Interstate highway system and continue to be an important tool in project management.

He is as best known for developing the Gantt chart in 1910.



Henry Gantt improved the Adamiecki's Harmonogramn. He took advantage of the fact that it wasn't well known in the West.



A Bar Chart developed for a bridge constructed in 1912

This is the summary of Gantt's legacy about production management:

- The Gantt chart: Still accepted as an important management tool today, it provides a graphic schedule for the planning and controlling of work, and recording progress towards stages of a project. The chart has a modern variation, Program Evaluation and Review Technique (PERT).
- Industrial Efficiency: Industrial efficiency can only be produced by the application of scientific analysis to all aspects of the work in progress. The industrial management role is to improve the system by eliminating chance and accidents.[6]
- The Task and Bonus System: He linked the bonus paid to managers to how well they taught their employees to improve performance.
- The social responsibility of business: He believed that businesses have obligations to the welfare of the society in which they operate.

4.2.1. GANTT CHARTS:

Gantt created many different types of charts. He designed his charts so that foremen or other supervisors could quickly know whether production was on schedule, ahead of schedule, or behind schedule.

Gantt (1903) describes two types of balances:

- the "man's record", which shows what each worker should do and did do, and
- the "daily balance of work", which shows the amount of work to be done and the amount that is done

Henry Gantt wrote a lot about how to simplify the scheduling:

Also we can add the floats with another color and join with a line the critical activities.

4.3. Linear Scheduling Method:

Linear Scheduling Method (LSM) is a graphical scheduling method focusing on continuous resource utilization in repetitive activities. The manufacturing of parts and the assembly of units in the factory are two candidates for the use of LOB. Besides this, LSM is used in longitudinal construction projects as pipelines, rail, bridges, tunnels and roads.

LSM is a management control process for collecting, measuring and presenting facts relating to time, cost and accomplishment - all measured against a specific plan. It shows the process, status, background, timing and phasing of the project activities, thus providing management with measuring tools that help:

1. Comparing actual progress with a formal objective plan.
2. Examining only the deviations from established plans, and gauging their degree of severity with respect to the remainder of the project.
3. Receiving timely information concerning trouble areas and indicating areas where appropriate corrective action is required.
4. Forecasting future performance.

Also it's known as Cicklogram, time-distance diagram or line of balance (LOB).

History: LOB was devised by the members of a group headed by George E. Fouch. During 1941, the Goodyear Tire & Rubber Company monitored production with LOB. It was successfully applied to the production planning and scheduling of the huge Navy mobilization program of World War II. LOB proved to be a valuable tool for expediting production visibility during the Korean hostilities. During this period, defence suppliers used LOB.

4.3.1. CHARACTERISTICS OF LOB.

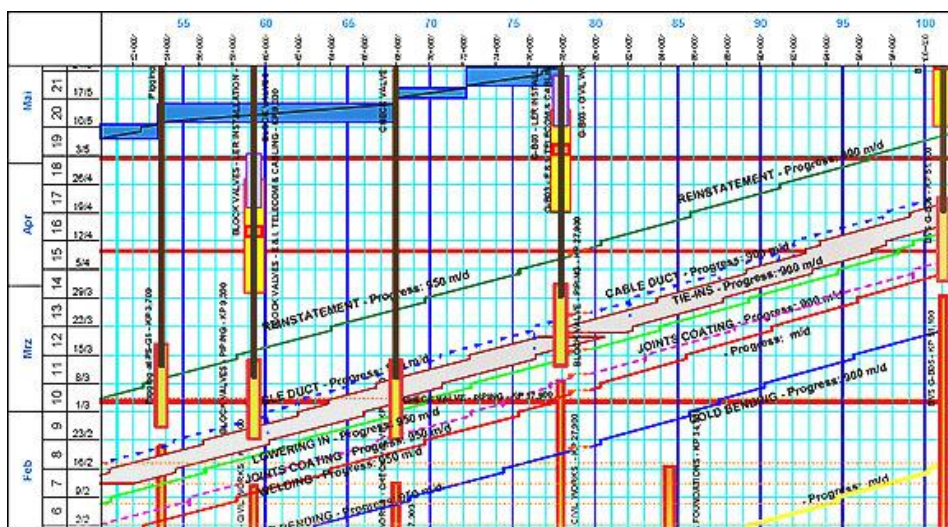
It has two axes, one vertical and the other one horizontal.

- Vertical axes: In this axe appears the time information. Normally, it's drawn up from top (start of the project) to bottom (end of the project). The units depend of the type of project, for large projects we will use years and for a short one minutes or hours.

- Horizontal axes: There is drawn the distant axis. The direction of this value is chosen regarding the geographical position of the project. Also the scale depends on the magnitude of the project.

These axes not only show the location of the activity but also the direction of the progress and the progress rate.

As to the activities can be presented as geometrical shapes showing the occupation of the work site over time such that conflicting access can be detected visually. Different types of activities are differentiated by color, fill pattern, line type or special symbols. A symbolic drawing along the distance axis is often used to improve the understanding of the time–distance diagram.



One example of line of balance.

4.4. GANTT VS LOB

The biggest advantage of ciklogram in contrary to the Gantt chart is that in the last one it's impossible to see the conflicts between the activities at a glance. Ciklogram or line of balance shows all those scheduling conflicts which are not shown in the Gantt chart.

This is because both methods have different ways to explain the scheduling:

Gantt chart is visually a good method for follow the scheduling but each activity is in each line of the chart so there is no overlap between them if there is a fail in the schedule.

In the other hand, in ciklogram the activities are shown as lines which go up in the chart. If there is any problem with timing, those lines will cross each other. It will be an overlap so if there is a mistake in the scheduling , it will fix it.

Regarding the similitudes, both of them are traditional techniques. That means they have some shortcomings related with this type of methods. Mention only three:

- **Planning and scheduling:** In the process of creation there isn't a division between both phases. It has to be carried out in one phase and it's not the best due you have to know the whole information.
- **Logic:** In the moment to create the plan, it has a logic relationship between the tasks. When the plan is changes this logic will not be kept.
- **Modifying:** This is a big problem in the traditional methods. The task to modify and track the project is tiresome and consumes even if using drawing software tools. It takes a lot of time.

5. NETWORK TECHNIQUES

The network techniques are very useful tools for the scheduling construction.

Basically, they are techniques based on a network drawing which allows us to visualize the different activities or tasks of the project and its precedence or succession relationships. Also, it shows the start time and the finish time of each activity and of the entire project. It allows checking which the critical points are and which could hinder the goal of the project.

We will see different kind of network techniques. We will begin by network arrow activities (AA). The Critical Path Method (CPM) and Program Evaluation and Review technique (PERT) are the systems to analyze. After that we will develop the network node activities (NA) exposing two methods: Precedence Diagramming Method (PDM) and Metra Potential Method (MPM) of Bernard Roy.

- **Historic review:**

In 1956, Morgan Walker (Du Pont de Nemours & Company) and James E. Kelley Jr. (Remington Rand Corporation) showed their theory about Network Techniques, establishing the mathematical foundations of the **CPM**.

In parallel, the USA Navy was trying to find some new techniques to carry out his most important projects. They created a new department of program evaluation (Special Projects Office, Bureau of Naval Weapons). On charge was Willar Fazard. The objective of this department was to evaluate the performance and advances realized in the Polaris submarine project.

At the end of 1957, the Navy decided to hire Booz Allen & Hamilton and Lockheed Missile and Space Division, who was one of the Polaris missile contractors, with the objective to create an evaluate program system to make it easier to take information about the Polaris project. The final result was the Program Evaluation Research Task.

Booz Allen & Hamilton and the doctor Charles E. Clark, established the concept of the network with three different estimations of time in each activity. Creating the Program Evaluation and Review technique, also known as **PERT**

Although the CPM and PERT were developed separately, both of them have two important aspects. One is the critical path and the other is the drawing model, arrows network.

In 1958 when Bernard Roy (Professor Emeritus of the Paris-Dauphine University) was working in the society of economy and mathematics found a lot of problems because the projects had a lot of activities and limitations. The magnitude of the projects made it necessary to find a specific scheduling method. For this, He created the Metra Potential Method (**MPM**) based on the network node activities (NA).

One year later, we can see the first texts about the Metra Potential Method and in 1960, Bernard Roy shows his whole thesis.

In 1961, the professor of the Stanford University, John W. Fondahl, presents his precedence diagram: Precedence Diagram Method (PDM). This method was the basis to IBM for development of the IBM System/360. This diagram is one of the most used nowadays in the construction companies.

MPM and PDM have the drawing of the activities in common. These are drawing in the nodes and the relationships are carried out with different types of segments which join the nodes.

We can see that the development of the Network techniques was born in the second half of the 20th century. It focuses on minimizing the project duration attends only on the relationship and duration of the activities assuming that the resources are unlimited.

As all people know, the resources are limited and because of this, **between 1962 and nowadays**, the investigations are focused in how to optimize the duration and costs with limited resources.

The methods mentioned before which are used nowadays, especially PDM, are the starting point of some investigation projects about production and resources optimization.

5.1. CPM

This method is very useful due its simplicity. It's based on the arrows network.

We can define an arrow network as a graphical representation of a project which shows us the relationships between success and tasks.

The main characteristics of this network are the graphics. Each activity is represented with a unidirectional segment, that is to say one arrow. This arrow has a beginning and an end determined for a node, usually drawing with a circle and also known as an event.

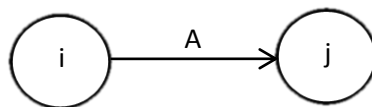
5.1.1. CONSTRUCTION OF THE ARROW NETWORK

5.1.1.1. ELEMENTS

An arrows network has two main elements: The task and the event.

The entire project is divided in tasks or activities. It has duration and resources. It will be drawing as arrows.

The event is the beginning and the end of one activity. This event doesn't have duration or resources, it's only a milestone. It will be with circle shapes. It's important to enumerate the events in a clear way.

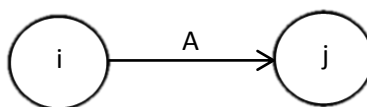


This is the way to represent the arrow network. "A" is writing upon the arrow and is the activity's name. On both sides of the arrow there are two nodes, the start success and the final success. So each activity is definite for its name or for the two successes (i and j).

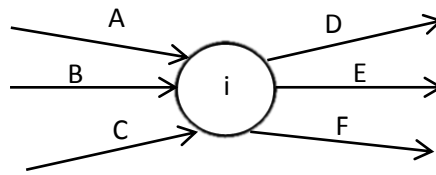
Also in the whole project there will be only one start success and only one final success but with different ways to join between them. We will call each one of these different ways as a path.

5.1.1.2. CLASSIFICATION OF THE ACTIVITIES

- In relation with the success:



The success “i” is the start success of activity A and the success “j” is the final success of activity A.

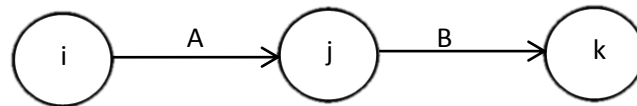


In the same event can start one or more activities and also finish one or more. In this case, the event i is the starting point of the activities D,E,F and the finishing point of A,B,C.

- In relation with themselves:

It can be two types, depends on the relationship between them:

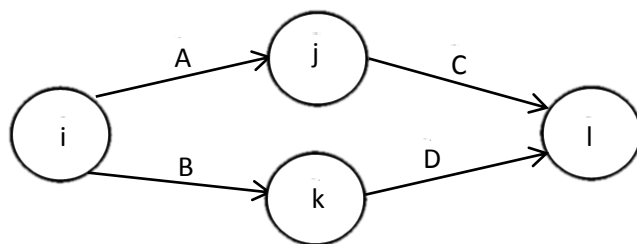
- Sequence’s activities:



In this case, there is a relationship between both activities. One of them depends on the other. One is the precedence activity and the other the successor activity. It means that it’s not allowed to carry out one activity before its predecessor finishes.

The activity B is successor of the activity A, so B has to wait until predecessor A is finished. Both activities share the same node, for A is the end node and for B the start node.

- Parallel activities:

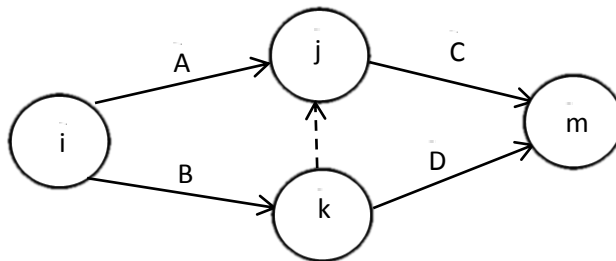


In this case it is allowed to carry out more than one activity at the same time. The activities A and B don’t have any relationship between them and they start in the same event so they are simultaneous activities. Activity C is successor of A but not of B and the predecessor of D is B but not depends on A. A and B have the same start event and C and D have the same final event.

- In relation with their durations:

There are three kind of activities depend of if their consuming time and resources.

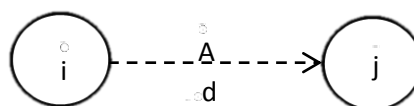
- Real activities: It's the biggest group. They are the activities which have a determined duration and consume resources. All of these activities seen previously were real activities.
- Dummies activities: They don't have duration and don't consume resources. They are useful in singular cases with singular situations of relationships between activities. It's drawn with a dashed line.



In this example, the activity C has two relationship of precedence, one with A and another with B but the activity D only depends on B. So it's necessary a dummy activity for make real this relationship.

- Expected activities: This type of activities consumes time but not resources. We will use it when we want to wait a determined duration for some reason. As we said before, this activity doesn't have an own cost, it only spends time. For example it could be useful in the case of the time that you should wait between to do the slab until remove the formwork.

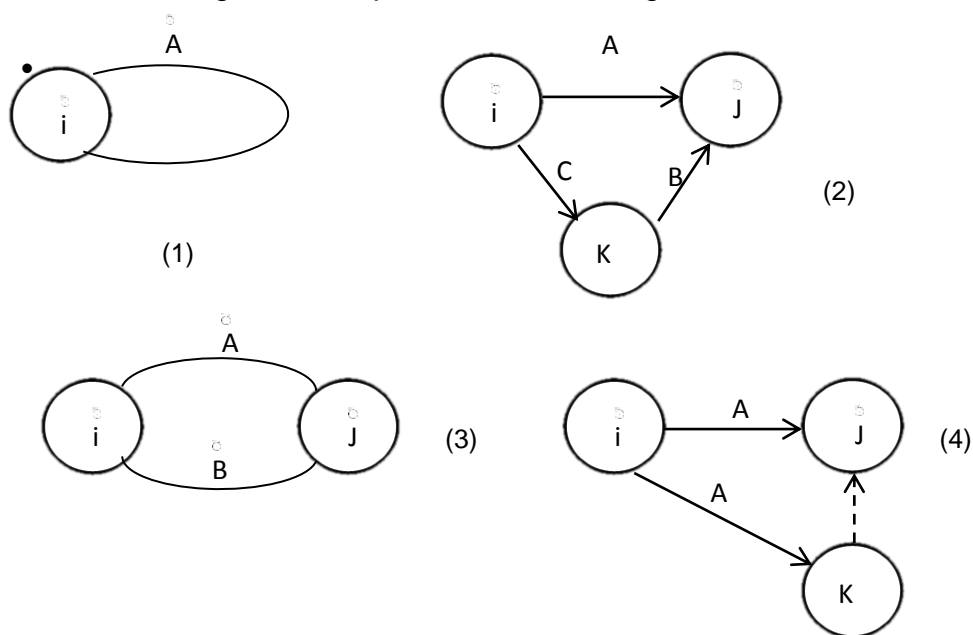
The drawing is a dashed line like the dummies activities but in this case with name and duration like the real activities.



5.1.1.3. RULES FOR DRAWING AN ARROW NETWORK

There are some important rules for drawing a correct network:

- One direction: The arrows should be only in one direction. It's necessary to make it clear.
- Start and Finish: An arrow network will be only with one start event and one finish event.
- Loop: It's not allowed that one activity starts and finishes in the same event. (1)
- Circuit: This rule is similar to the previous rule. It's impossible to make a relationship with one activity that finished before. (2)
- Parallel activities: Two activities can't start and finish in the same event. In this case maybe we will need a dummy activity. (3)
- Dummies activity: We will use only the strictly necessary dummy activities. If we use more than we need we will have no necessary events. (4)
- Also, for doing an understandable network it is necessary to have a good planning in the drawing. It's important to make straight arrows and with a similar length. At last prevent the crossing arrows in the network



5.1.2. CPM DURATIONS

In the previous chapter we saw how to realize arrow networks but always in a theory way. We named the activities with a capital letter or the events with lowercase letters. It was always without a specifically duration.

But in real life is necessary to assign duration to each activity. This duration will be an indicative value in base of our available resources and our own experience. Unfortunately, this value is difficult that will be the real value.

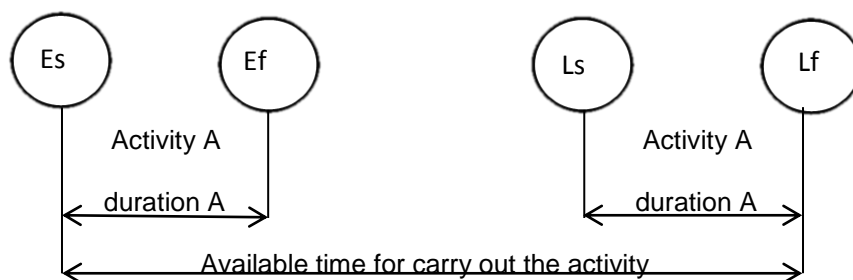
We can classify the methods of scheduling depending on their duration. In this case CPM is a deterministic method because we have to fix one value. Other methods like P.E.R.T. as we will see after proposing different durations for each activity, for this reason this is a stochastic method.

As we are going to see, we should calculate different times for each activity: The maximum time and minimum time that an activity can last.

5.1.2.1. TIMES

Each activity has four different times:

- Earliest Start (Es): Earliest time in which an activity can start.
- Earliest Finish (Ef): Earliest time in which an activity can finish.
- Latest Start (Ls): Latest time in which an activity can start
- Latest Finish (Lf): Latest time in which an activity can finish



As we can see in the previous scheme, the relationship between the times is:

- $Ef = Es + da$
- $Lf = Ls + da$

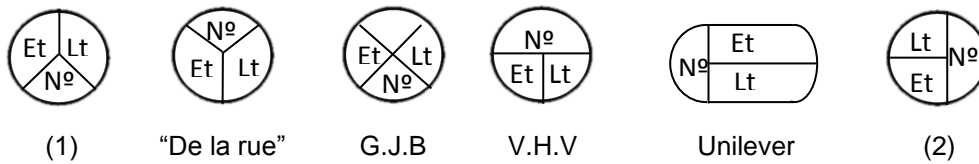
With these basic equations we will calculate all the time durations regarding of two things: Earliest start (Es) of the initial event is zero and latest finish (Lf) of the ending event is the same for all the ending activities and it never is zero.

Also each event has two times. As each activity has two events, the set of these four times will be the whole different times of the activity mentioned before. Therefore in each event we will write earliest time of the success (Et) and latest time of the success (Lt). The subtraction of these times will form the different float that we will see late. It should be noted that in the initial event and in the ending event there will be two immovable relationships:

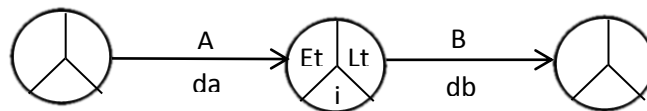
- The values in the initial event: $Et = Lt = 0$

- The values in the ending event: $Et = Lt \neq 0$

There are different ways for drawing the events. In Spanish education is usual to use the reverse “De la rue” Symbol (1). However as I could see, in Hungarian education it is more common to use a variant of the “V.H.V” symbol (2). Of course all symbols are valid and show us the same information with different shapes.



So independent of the type of symbol that we use, we will have a network like this:



We have a network with two activities and with three events; the event of the middle is shared for both activities. We are going to focus on this event.

The event i is the final event of A and the starting event of B . Consequently both activities share two relationships:

- Earliest time of the event: On the one hand regarding the activity A it will be the earlier finish and in the other hand regarding B it will be the earlier start. Consequently:

$$EfA = EsB = Et$$

In the hypothetical case of several activities finishing in the same event, for determinate the Et time, we will choose the highest value of earliest finish time of all the activities that finish in this node. The reason seems simple; the next activity can't start before all the previous activities finish.

- Latest time of the event: Li will be latest finish of activity A and at the same time latest start of activity B :

$$LfA = LsB = Lt$$

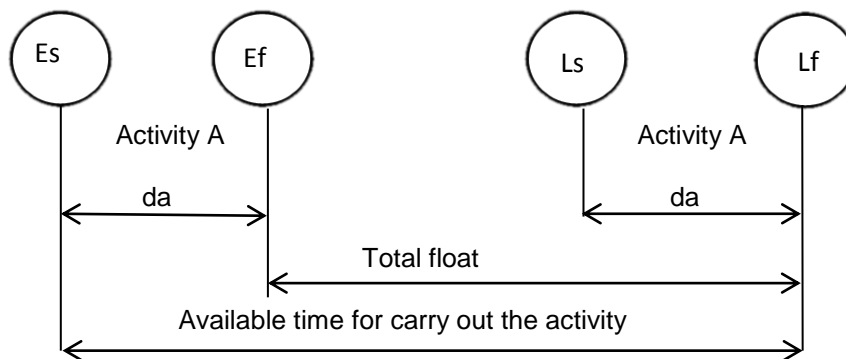
As in the previous case, if more than one activity starts in the same event, the right time of Lt will be the lowest value of latest start of all the activities that start in it.

5.1.3. CPM FLOATS

The float is the excess of time available for carrying out an activity. Said in another way, it's the time that we can delay one activity. The value of the float is regardless the duration of the activity. There are some different kinds of floats depending on applying this delay or not. If you apply this delay, the duration of the project or the timing of the successors activities will change or not: Total float, free float, independent float and conditional float.

All the different floats will be explained with the activities times and events times.

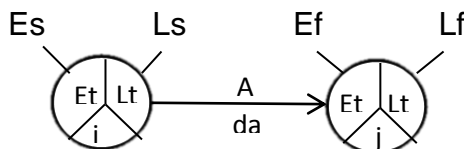
- Total float:
It's the time which we can delay one activity without delaying the duration of the project.



Attending to the activity time scheme, the Total Float (Tf) will be:

$$Tf = Lf - Ef$$

Let's see it with the time events:



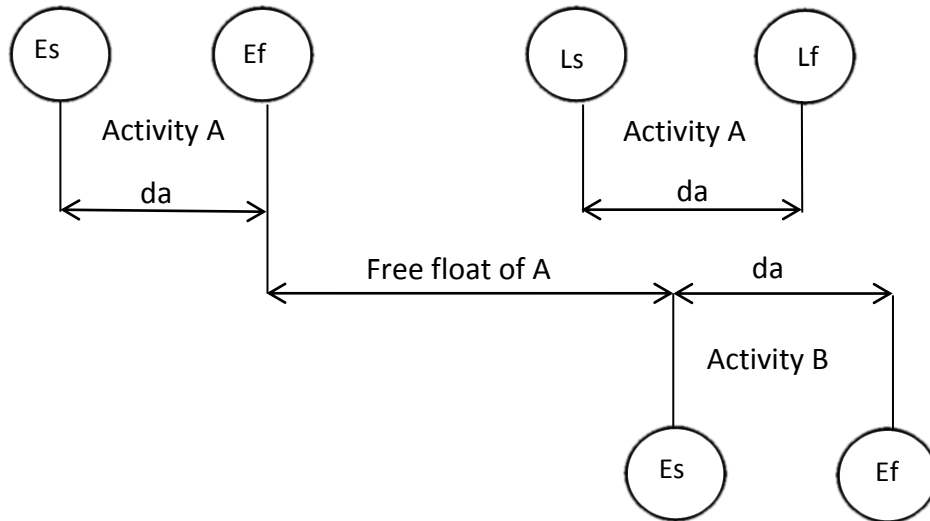
With the previous relationship $Tf = Lf - Ef$ and knowing that $Ef = Es + da$ we can determinate that $Ef = Et(i) + da$.

Moreover, $Lf = Lt(j)$. So replacing the activity times in the equation we can say that:

$$Tf = Lt(j) - (Et(i) + da) = Lt(j) - Et(i) - da$$

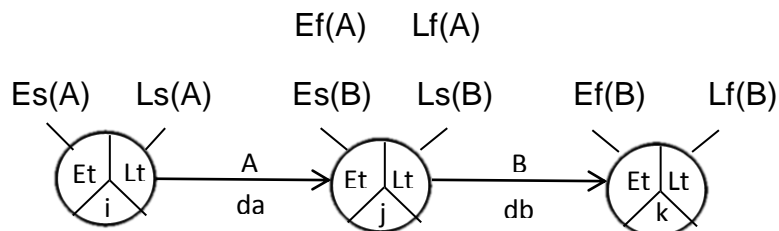
- Free float:

It's the time with which we can delay one activity without increasing the duration of the project and without delaying any successor activity.



The free float of the activity A will be: $Ff = Es(b) - Ef(a)$

Regarding to the time events we have the following network:



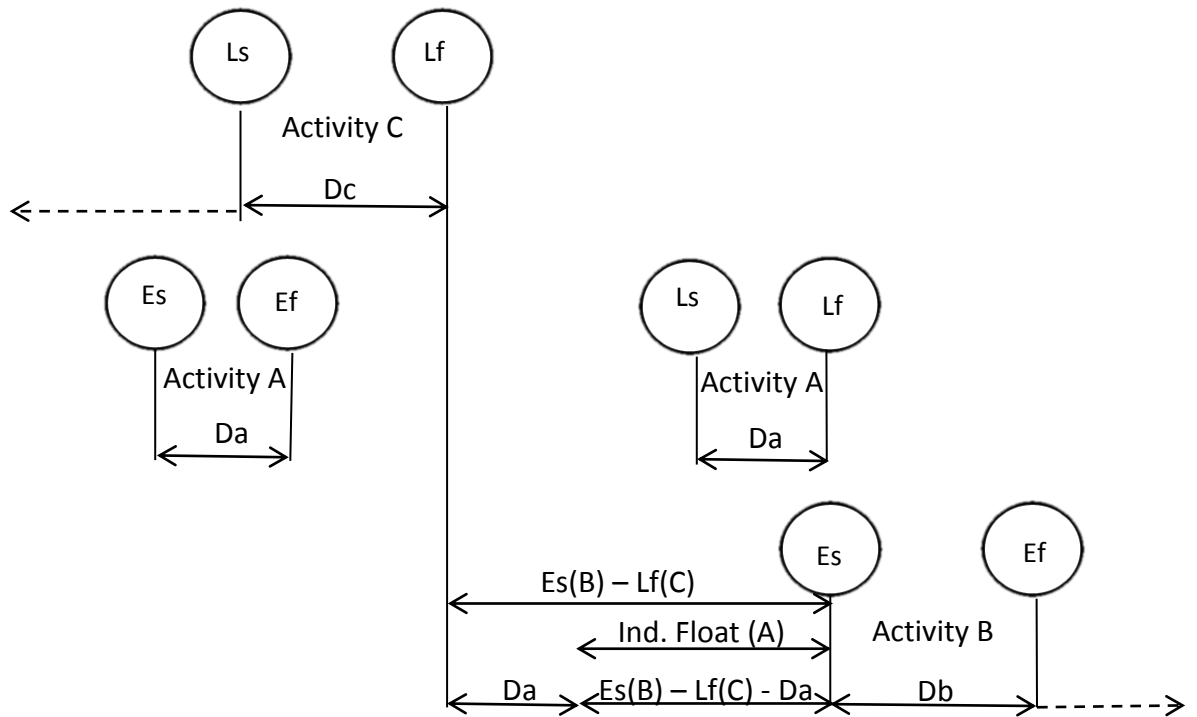
As we have seen before, $Ff = Es(b) - Ef(a)$ and we know that $Ef(a) = Es(a) + da$. Regarding to the equalities in the previous network and clearing the variable in the equation we can say that: $Ef(A) = Et(i) + da$.

Moreover, $Es(B) = Et(j)$.

Consequently, $Ff = Et(j) - (Et(i) + da) = Et(j) - Et(i) - da$

- Independent float.

It's the time which we can delay one activity without increasing the duration of the project if the precedent activity finishes as latest as possible and the successor activity starts as soon as possible.

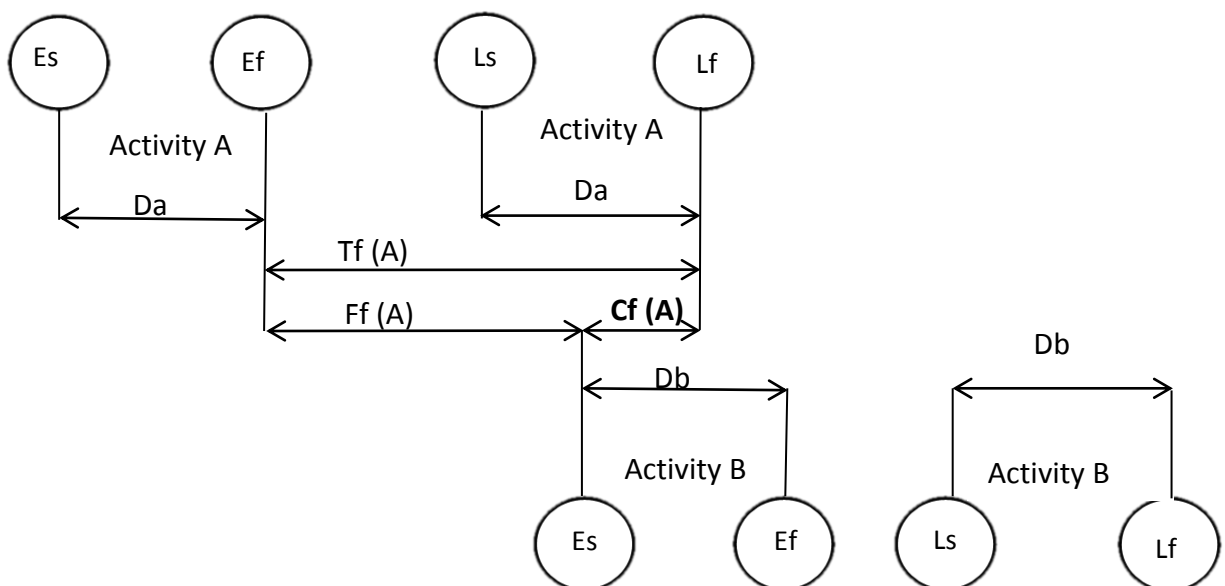


For drawing in the network of activities times, the independent float of the activity A is: $If = Es(B) - Lf(C) - Da$

Converting it into events times, we know that $Es(B) = Et(j)$ and $Lf(C) = Lt(i)$, so consequently the independent float is: $If = Et(j) - Lt(i) - Da$

- Conditional float

It's the time with which we can delay one activity without increasing the duration of the project but delaying some activities.



The conditional float would be the difference between the total float and the free float: **$Cf = Tf - Ff$**

In terms of activity time would be: $Cf = Tf - Ff = [Lf(A) - Ef(A)] - [Es(B) - Ef(A)] = Lf(A) - Ef(A) - Es(B) + Ef(A) = Lf(A) - Es(B)$; **$Cf = Lf(A) - Es(B)$**

Finally, converting it in event time: $Cf = (Lt(j) - Et(i) - da) - (Et(j) - Et(i) - da) = Lt(j) - Et(j)$

5.1.4. THE CRITICAL PATH

In a Critical path method one of the most important things is detecting which is the critical path. In each CMP there has to be at least one, although it can be several.

The critical path is the succession of activities that it's impossible to modify for reduce the time of the project or the cost. It's a fix duration and determinates the duration of the project. It has some singular characteristics:

- A critical path always has the longest duration.
- All its component activities are critical; it means that the different floats are null, it's not possible to delay them.
- The difference between the slack of each activity is zero. Et and Lt are always the same value

Also there are activities that are not critical but with a small float. We don't have to forget these activities because it's easy to make it critical.

The critical path will be painted by a different color with respect for the others activity paths.

5.1.5. COST OPTIMIZATION

Until this moment we have spoken about the duration of the project but not yet about the cost of this project. Not only the duration of the project is important, the costs are a fundamental side for taking decisions about the final duration.

In this point, we are going to see what types of costs we have to contemplate it in a schedule. Also we will discover that we can reduce the time of some activities but this fact will cause an increase for the cost of the project. It will be necessary to analyze which is the best choice for our purposes and objectives.

Let's start with the different kind of costs that we can find in a construction project. There are two: Direct cost and indirect cost.

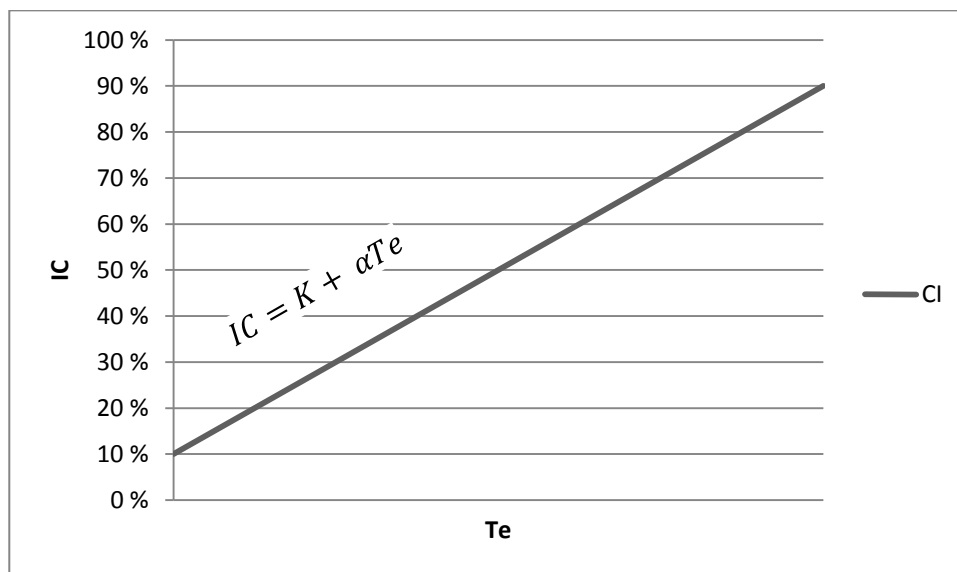
- Direct costs are costs consumed in the production. The direct cost would be; the equipment, laborers or material. These costs increase if the project duration decreases. This is due to decreasing the duration of one activity entails to use more resources.
- Indirect costs are costs which we don't consume in the production but we need it to carry out the project. The installations of the site, taxes, insurances and office expenses are examples of indirect costs.

The total of the indirect costs are the sum of the fix costs and variable costs. The first one doesn't depend on the project duration. However the second one is determined by the days that the project takes to finish.

Therefore we can define it as: Indirect costs = Fix costs + variable costs = $CI = K + \alpha Te$, where:

K is the constant of fix costs

αTe is the variable costs



As we can see in the indirect costs graph, we have fix costs even before the project starts (K) and the variable costs will depend on the slope of the straight line (αTe). In contrast to direct costs, indirect costs will decrease if the project duration decreases.

In the previous point we showed how to calculate the minimal and maximal duration of a project, also each duration has associated one different cost as is logical. Now the point is which is the best choice is; for this reason we have to

optimize the two concepts and choose the best one according as our necessities.

Most of the time the best solution will be the one with the lowest cost but sometimes due to the objectives of our company the best solution can be carry out the project as soon as possible. Two ways to think and both of them valid, we are only talking about preferences.

For this target we will move between two durations: the maximal duration of the project which we will call as crash duration and the minimal one known as normal duration.

Knowing these durations, it's the moment to decide which way following. Depending on the case, there are two methods for changing the project duration:

The first one is to take care of the duration of the project and try to reduce it. We will change the normal duration of some specific activities changing it for the crash one and obviously increasing the cost of the project. This method is known as Compression.

In the other hand we have the decompression which objectifies the opposite; If we made a project with the encouraging duration and we want to reduce the cost because we think that it's excessive or we don't have enough resources for carry it out it, we can do it.

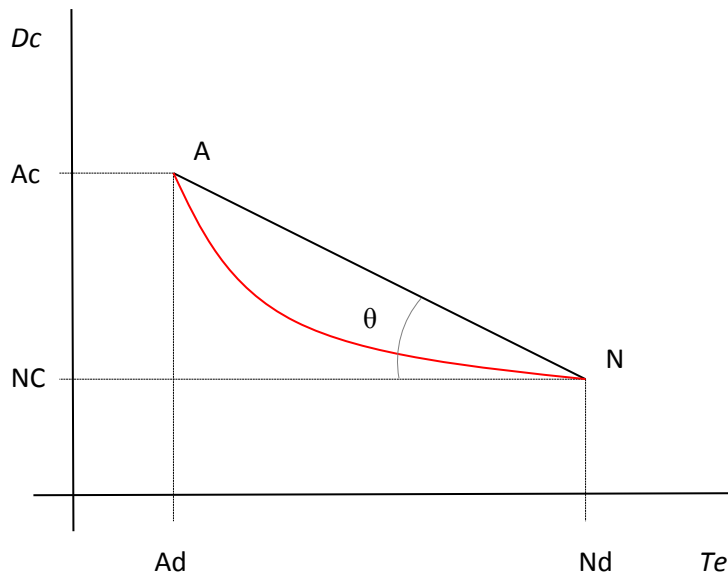
To make it more clear we can use the very useful the curve cost-time:

In this curve we will define both the duration mentioned before and their respective costs of one specific activity.

In the vertical axes we can see the direct costs and marked on it the two types of costs. In the other axe there is corresponds to the duration and on it is marked the crash duration and the normal duration. Linking these points we get:

- The cost of the normal duration (normal point) which means; the minimal cost with the maximal duration.
- The crash point: The minimal possible duration but with the maximal cost.

So regarding to our project we will have to find the best solution between these two limit points. Usually to make it easier we don't depict it like a curve but with a straight line.



Paying attention to the graphic we can deduce that we have to find the best solution between these two limit points. For example if we try to find a lower duration than the crash one we are not going to finish before the activity because this is the limit time. We have to think that all the activities need a certain time to carry out, so as more resources as you use the activity is not going to finish at instant. The same happens with the normal duration; trying to finish after this duration it will only lead to expending more days and therefore more money.

As we are going to see, to calculate the compression or decompression of the activities we need to know the “unitary slop of the straight line costs”. This value permits us to compare between two activities and choose which one the best is to reduce or increase.

$$Us = \text{Uni. slop straight line costs} = \text{tag } \theta = \frac{\text{costs difference}}{\text{duration difference}} = \frac{Ca - Cn}{Dn - Da}$$

- How to compress or decompress a CPM

The two cases have the same steps but with different objectives due to the fact that they are the opposite.

Decades ago maybe the target of the companies were producing as many as possible in the least amount of time, for this reason the compress way was so necessary without importing in some measure to the cost that it could be carry on. Nowadays the situation has changed and the economical politics are more important; Due to this some companies prefer to decrease the costs and increase the duration of the projects.

Said that we are going to opt to explain the decompress method. We can take as an example one of these companies. One Company that now can't sell their products as fast as years ago and they don't want to stop the production.

So we will start with the suppose of a project calculate with the crash durations and the maximal costs.

Let's Start: We will need a chart like this one.

Activities	Relationships	Durations (days)		Direct costs		Duration increase	Cost increase	Slop
		Normal	Crash	Minimal	Maximal			
A	-	5	3	120	150			
B	A	3	1	100	200			
C	A	4	3	156	250			
D	B	3	2	40	100			
					total			
IC = 1200 + Time increment.								

In this chart we have the name of the activities and the relationship between them. Also the duration and costs depend of the situation.

- 1- Calculate the number of days in which we can increase the project duration and the cost increase

$$D_i = \text{Normal duration} - \text{crash duration}$$

$$C_i = \text{Maximal cost} - \text{minimal cost}$$

- 2- Determinate which is the unitary slab of costs for all the activities:

$$U_s = \text{Uni.slop straight line costs} = \text{tag } \theta = \frac{\text{costs difference}}{\text{duration difference}}$$

$$= \frac{A_c - N_c}{N_d - A_d}$$

We have to use this value to determinate which is the activity that we should increase. Due to the fact we want to reduce the costs as many as possible we will choose the activity with the higher slab. That means that we are reducing the duration of the most expensive activity per day.

- 3- Choose the activity: We will increase the critical activities because they condition the project duration; it doesn't make sense to increase the non-critical activities because the duration of the project doesn't change.

In case of having more than one critical path we will choose one activity which belongs to either paths or one of each critical path.

- 4- Number of days: We can modify as many days as the activity allows. In the first step we have calculate this.

An important issue when you decompress one activity is that ,at the end of this process, none of the activities which were critical can't stop being it now. It's possible that appear new critical activities but not in the opposite way.

- 5- Finally we draw the new CPM with the increased durations. It's the moment to know if our decompress method made us reducing the cost or not. It will be necessary to calculate the decompress cost and we will rest it to the initial direct cost:

$$DecCost = SUM[Slop activity * days decompress]$$

We don't have to forget the indirect cost. As we are increasing the projects duration this will grow but the fix cost won't change.

The next chart can help us:

Network	Decompress Activities	Increment	Total duration	Direct Cost Increment	Total	Indirect Cost increment	Total	Total increment	Total cost
Initial	-	-	xxx	-		-		-	xxx
First Dec.									
Second									
Third...									
Finally	Total		xxx						xxx

- 6- Total decompress: We must reduce activities in rounds and draw again the CPM and when we see that it's impossible to reduce any day of any critical activity the job will be over.

It only remains to note that the longest solution maybe is not the cheapest. Sometimes we can do four or five compresses but we can check after that the best cost solution was the previous; undoubtedly this will be the longest solution but it isn't worth it. We would be talking about having exceeded the normal point in the curve cost-time.

5.2. PROGRAM EVALUATION AND REVIEW TECHNIQUE (P.E.R.T.)

This method was developed by the USA Navy at the end of 1957 with the objective to estimate the probabilities of carrying out the Polaris project.

As we studied in the previous chapter, CPM method is a deterministic method. That means that it's necessary to know the approximately duration of the activities based on the experience and the available resources. But what happens when we can't determine the duration of the activity? P.E.R.T helps us in these cases. By means of this method we will be able to estimate some times

for each activity for after calculating the probability of accomplishing it in the dates estimated. Therefore, a difference of CPM, P.E.R.T. is a stochastic method based on the probability.

The value of the different times that we will use in this method are based on the statistics information and the time estimation realized regarding to mathematics methods. The correct estimation of the times is very important to carry out the method in a right way.

This different times mentioned before will be three: Optimistic, pessimistic and more probable.

- Optimistic time (O_t): It's the lower duration of one activity. It's the optimal time and it is reached if we don't have any setbacks.
- Pessimistic time (P_t): It's the highest duration for one activity. We will reach this time in the worst case.
- More probable time or normal time (N_t): It will be the value that appears most often in a set of data with the same circumstances, the statistic mode.

All the possibilities of finishing the activity will be included in these three times. We will call the distance among the limit durations as range of uncertainly:
 $R_i = P_t - O_t$

Due to these times are random values that we will calculate it with statistics mathematics methods as are the law of variation, the average or standard deviation.

5.2.1. PROBABILITY OF CARRING OUT A PROJECT IN A DETERMINED TIME

The main objective of P.E.R.T is to determine the success probability of a project.

First it's necessary to make the CPM network as we have learnt in the previous chapter. We already know the different times of each activity but we have to take for the activity duration the estimated time which is a weighted average. Then, we will draw the network and will calculate the duration of the project according to the rules of CPM, marking the critical path too.

The next step is to calculate the estimated time regarding with the three times that we obtained. The estimated time is the weighted average of the three values. The definition of this time could be the time that we expect to finish the project. We will give more importance to the normal time so thereby the

equation will be thereby:

$$Et = \frac{Ot + 4Nt + Pt}{6}$$

Having calculated this variable we will calculate the variance. The variance is a measure of how far a set of numbers is spread out. It is one of several descriptors of a probability distribution, describing how far the numbers lie from the mean (expected value). It's exactly what we want to know, how far our project to the expected objective is. We will define the variance as σ^2 .

The variance is the squared of the difference between latest time and the earlier time, all divided in to 36. We will get for all the activities.

$$\sigma^2 = \frac{(Pt - Ot)^2}{36}$$

Previously in the CPM network we obtained the critical path or maybe paths. It's the moment to add up all the variances of these critical paths. After we will know which of them we have to use.

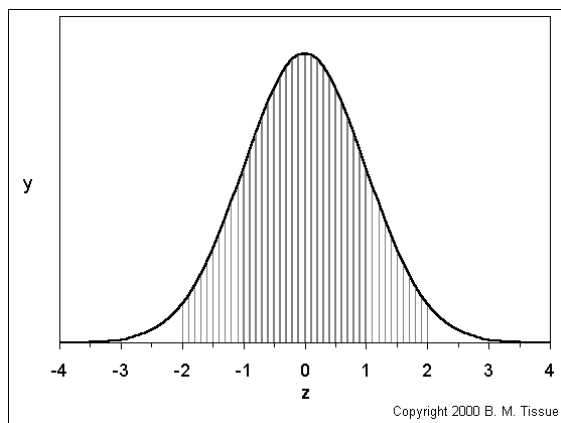
The next step is to make the square root of the valence critical path summation. With this we will obtain the standard deviation. With the finality to explain the standard deviation, we can say that it shows how much variation or dispersion there exists from the average (mean), or expected value. A low standard deviation indicates that the data points tend to be very close to the mean; high standard deviation indicates that the data points are spread out over a large range of values. It will be represented as.

$$\sigma = \sqrt{\text{Variance}} = \sqrt{\sigma^2}$$

Now we have all the tools to calculate the probability of success. There is only left to show the equation of probability factor (Z) with which we will obtain the percentage of it.

Note first at all that we take like stating point the hypothesis that the time of an event has a normal distribution. This distribution is more known as Gaussian distribution or bell curve for its shape. This curve in the horizontal axes has the values of the probability factor. The Zero value is marked in the middle of the curve indicating the statistic mode, where the probability of success is 50%

Then the probability factor follows this distribution. Z is defined as:



$$Z = \frac{Tt - Et}{\sigma}$$

Where Tt is the target time, Et is the estimated time mentioned before and σ is the standard deviation obtained previously.

5.2.2. THE PROBABILITY FACTOR AND THE GAUSSIAN DISTRIBUTION

This equation will give us a value of Z. We can represent this value in the Gaussian distribution .First of all we have to calculate the bell area and assign it the value of one (100% of probability). After that we can calculate the area of the Z value: this is the area between the starting negative point and the Z value. Done it only left to compare both results and obtain the probability of success of our target time.

Due to calculate the areas consume very time and could be tiresome we can use the following chart:

+ z	0	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09
0	0,5	0,50399	0,50798	0,51197	0,51595	0,51994	0,52392	0,5279	0,53188	0,53586
0,1	0,53983	0,5438	0,54776	0,55172	0,55567	0,55962	0,56356	0,56749	0,57142	0,57535
0,2	0,57926	0,58317	0,58706	0,59095	0,59483	0,59871	0,60257	0,60642	0,61026	0,61409
0,3	0,61791	0,62172	0,62552	0,6293	0,63307	0,63683	0,64058	0,64431	0,64803	0,65173
0,4	0,65542	0,6591	0,66276	0,6664	0,67003	0,67364	0,67724	0,68082	0,68439	0,68793
0,5	0,69146	0,69497	0,69847	0,70194	0,7054	0,70884	0,71226	0,71566	0,71904	0,7224
0,6	0,72575	0,72907	0,73237	0,73565	0,73891	0,74215	0,74537	0,74857	0,75175	0,7549
0,7	0,75804	0,76115	0,76424	0,7673	0,77035	0,77337	0,77637	0,77935	0,7823	0,78524
0,8	0,78814	0,79103	0,79389	0,79673	0,79955	0,80234	0,80511	0,80785	0,81057	0,81327
0,9	0,81594	0,81859	0,82121	0,82381	0,82639	0,82894	0,83147	0,83398	0,83646	0,83891
1	0,84134	0,84375	0,84614	0,84849	0,85083	0,85314	0,85543	0,85769	0,85993	0,86214
- z	0,09	0,08	0,07	0,06	0,05	0,04	0,03	0,02	0,01	0
0	0,46414	0,46812	0,4721	0,47608	0,48006	0,48405	0,48803	0,49202	0,49601	0,5
-0,1	0,42465	0,42858	0,43251	0,43644	0,44038	0,44433	0,44828	0,45224	0,4562	0,46017
-0,2	0,38591	0,38974	0,39358	0,39743	0,40129	0,40517	0,40905	0,41294	0,41683	0,42074
-0,3	0,34827	0,35197	0,35569	0,35942	0,36317	0,36693	0,3707	0,37448	0,37828	0,38209
-0,4	0,31207	0,31561	0,31918	0,32276	0,32636	0,32997	0,3336	0,33724	0,3409	0,34458
-0,5	0,2776	0,28096	0,28434	0,28774	0,29116	0,2946	0,29806	0,30153	0,30503	0,30854
-0,6	0,2451	0,24825	0,25143	0,25463	0,25785	0,26109	0,26435	0,26763	0,27093	0,27425
-0,7	0,21476	0,2177	0,22065	0,22363	0,22663	0,22965	0,2327	0,23576	0,23885	0,24196
-0,8	0,18673	0,18943	0,19215	0,19489	0,19766	0,20045	0,20327	0,20611	0,20897	0,21186
-0,9	0,16109	0,16354	0,16602	0,16853	0,17106	0,17361	0,17619	0,17879	0,18141	0,18406
-1	0,13786	0,14007	0,14231	0,14457	0,14686	0,14917	0,15151	0,15386	0,15625	0,15866

This is only an abstract of the “Table Z: Areas under the standard normal curve”; the complete table shows values until 3.9 positive and negative.

<http://people.richland.edu/james/spring07/m113/tables.pdf>

5.2.3. DEDUCTIONS OF THE FACTOR PROBABILITY EQUATION

- 1- Target time = Estimated time ; (Tt = Et)

Regarding to the equation it's easy to understand that if our target time has the same value as that the estimated time the Z value will be Zero, therefore the probability of success will be 50%. We can see it in the Gaussian distribution that Z=0 is in the middle of the bell and

due to the bell is symmetric the area of this value corresponds to half of the whole distribution. That means 50% of the area and 50 % of the probabilities.

2- Mathematical sign of Z in case of more than one critical path

• Z > 0 :

This will happen when our objective time (Tt) will be higher than the estimate time (Et). In this concrete case, we have to take as a standard deviation the most unfavorable, that means the higher of the standard deviations of all the critical paths. Using this option we obtain lower quotient possible and consequently a smaller area for Z and a smaller probability.

• Z < 0 :

This is the opposite case. It will be when we are checking the probability to finish the project before the estimated time. Then the value of the target time will be lower than the estimated one. We will choose the most unfavorable value of the standard deviation: the lowest. Obtaining the higher value of Z in absolute value and the smaller area with its consequent smaller probability.

3- Probability of an interval of time:

Until this moment we have calculate the probability of a specific success but also we can calculate the probability of success of an interval of time. In this case we only have to calculate the Z of the two successes and after compare it and make the subtraction.

$$.Probability (1 - 2) = P2 - P1 = Z2 - Z1$$

4- Project's viability:

Until now, the objective of the P.E.R.T was to check the probabilities that we have to accomplish one project in a determined time. But also we can do the reverse step: Find what the time for a viable project is. For this reason we have to define the limits of probability. Some construction managers' think that a 25% of probabilities of carry out a project mean that it is viable to do it in the considered time. Also with a 97% we could say that we have the statistical certainty to finish it. We will take these percentages as measurements of viability. Consequently if we want to know how many days the target time is for get a viable project we will take the value of Z= -0.6745 corresponding

to the 25%. On the other hand if we want to have the statistical certainty we will take the value of the 97% in the table; $Z= 1.8814$ Regarding to the Z equation and clearing the target time we obtain the duration.

$$Z = \frac{Tt - Et}{\sigma}; Tt = Z * \sigma + Et$$

5.3. METRA POTENTIAL METHOD (MPM)

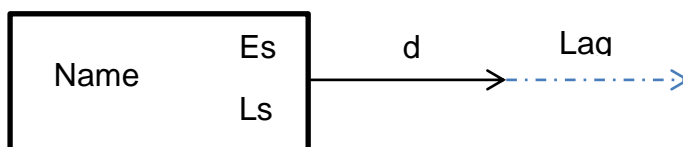
The Metra Potential Method was developed for the professor Bernard Roy in 1958 when he was working in the Economical and Mathematical society. He worked in a building's project in Paris. In his job he found a lot of troubles due to the magnitude of the project so he decided to create a new method based on the Nodes Activities.

This method is based on NA like PDM. The principal characteristics are that Roy's method only represents the starting times in the nodes and introduces a new concept: the restriction or lag. Also it shows the relationships with arrows but with duration upon them.

The method created by Bernard Roy has a lot of similitudes with the PDM, for this reason it is not studied thoroughly in some universities. I think that this is the case in the Hungarian education where the PDM has more importance.

5.3.1. DRAWING OF THE ACTIVITY

The representation of the activity is with a rectangle where it's indicated the name of the activity, earliest start time and latest start time. The duration is written upon the arrow. Also another arrow shows the restrictions, this arrow doesn't start necessarily at the end of the duration's arrow, it will depends on the relationship.



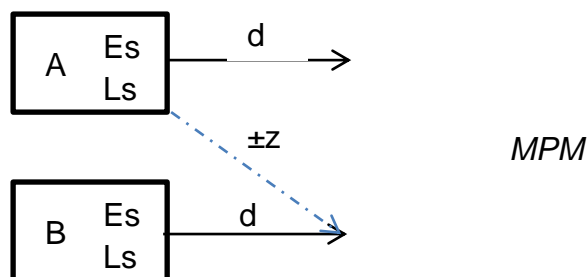
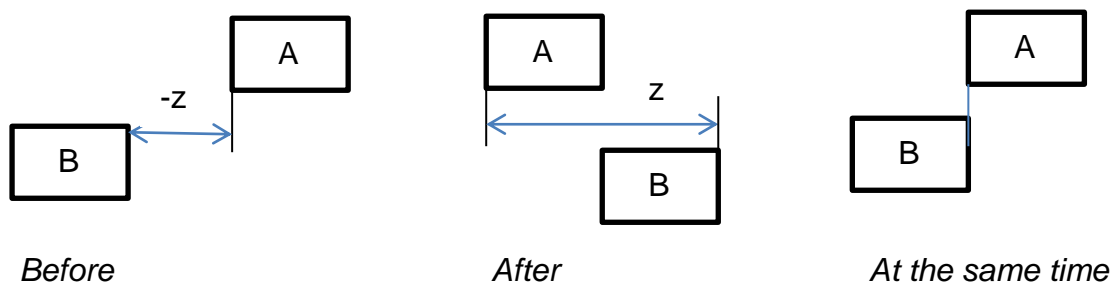
5.3.2. RELATIONSHIPS, TIMES AND RESTRICTIONS

The types of the relationships are start-start, finish-finish, start-finish and finish-start. In this method we will introduce the new concept introduced: the lag arrow.

The restriction or lag arrow is an activity conditioning. There are three different kinds of restrictions regarding to the time, overlap or resources. The first one, restriction time, also is divided in two types depending on if we want to restrict the activity according to a determinate date (localization time restriction) or if we want to do it for a specific value of time (succession time restriction). The second one, overlap restriction, forces two or more activities to not carry out at the same time, usually the reason is that it's necessary the same equipment for both of them. And the last one, resources restrictions, as its name indicate is when we have limited resources and we include some condition because it. MPM is able to show all these restrictions but the time one is the most usual, so we center on it.

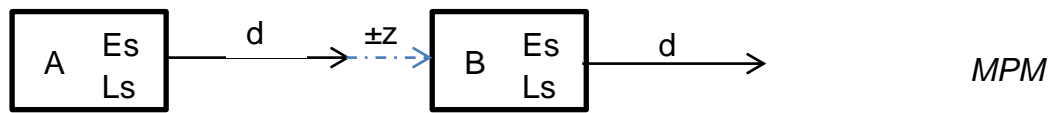
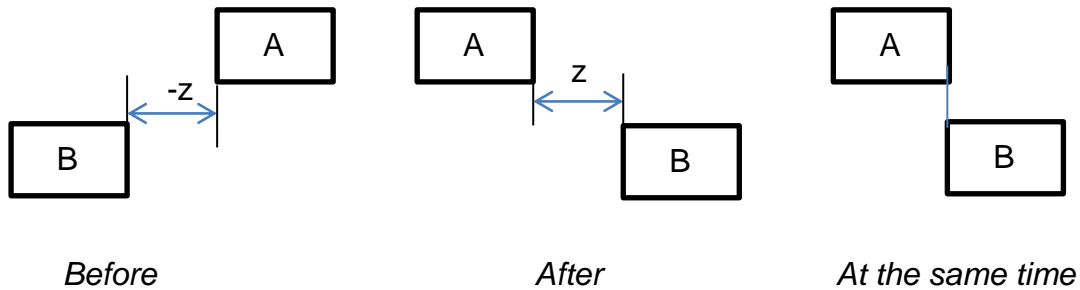
Depending on the start and finish point of this arrow it will be one kind of relationship or another. We will take as initial point the rectangle and the finish point as the end of the duration arrow. The lag or restriction can mark only the relationship with a null duration or also force the next activity with some duration. Below we are going to explain all the relationships possible with a time draw and with the MPM symbols.

- Start to finish: The next activity finishes after, before or at the same time that the starting of previous activity.



Times: $Es(B) = Es(A) \mp g - d(b)$
 $Ls(A) = Ls(B) + d(b) - (\mp g)$

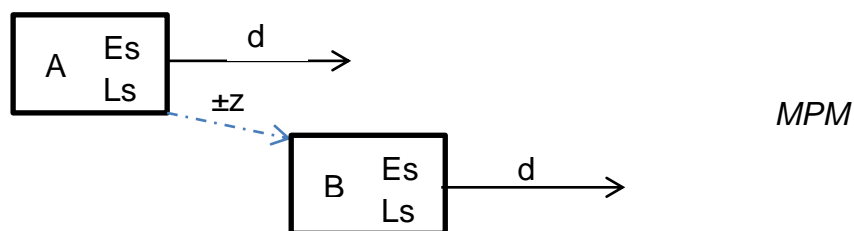
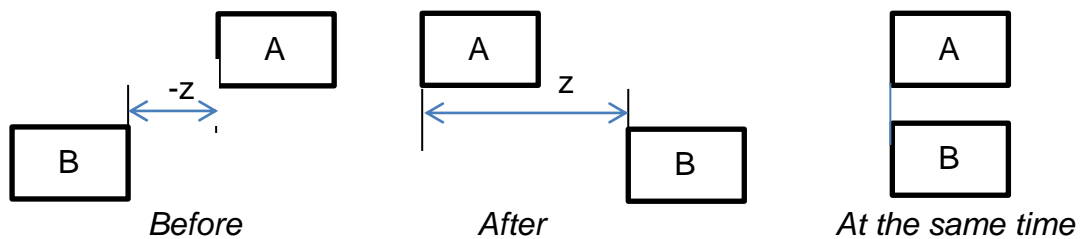
- Finish to start: The next activity starts after, before or at the same time that of the previous activity ends.



Times: $Es(B) = Es(A) + g + d(b)$

$Ls(A) = Ls(B) - d(a) - (±g)$

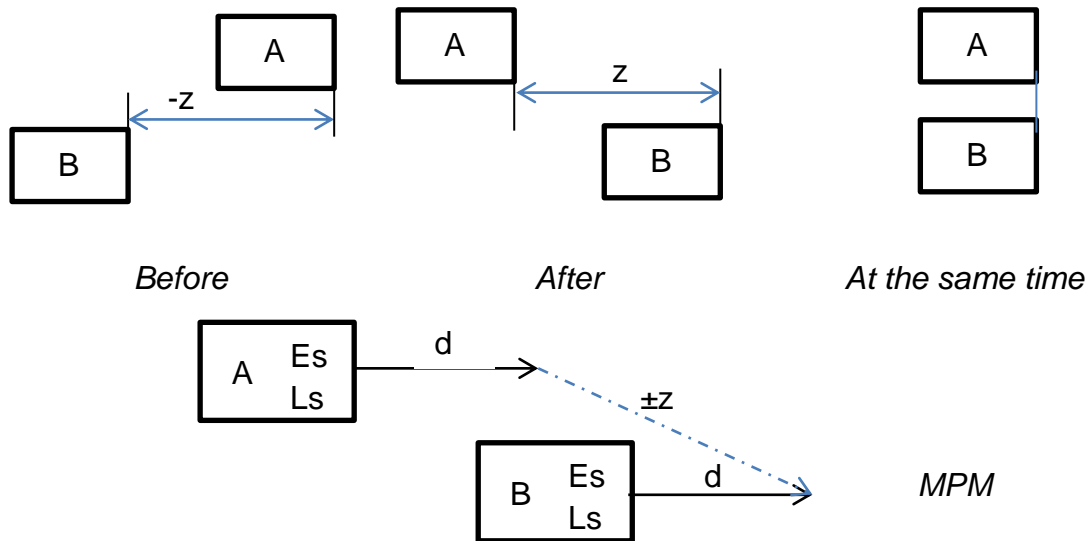
- Start to start: The next activity start after, before or at the same time of the start of previous activity



Times: $Es(B) = Es(A) + g$

$Ls(A) = Ls(B) - (±g)$

- Finish to finish: The next activity finishes after, before or at the same time that the end of previous activity.



Times: $Es(B) = Es(A) \mp g + d(a) - d(b)$
 $Ls(A) = Ls(B) - (\mp g) - d(a) + d(b)$

It only remains to note that, all these relationship previously exposed, can do it with a special arrow lag instead of the normal lag. We call this lag as rigid restriction or rigid lag. The characteristics of this one are that it forces both activities to keep the duration of the restriction in all cases. That means that any change in any of those activities will change the other one. We will represent the rigid lag as a two directions arrow.



5.3.3. FLOATS

We already know the different kinds of floats from CMP. We calculate the floats in the same way in previous methods studied but in MPM there is a little difference. Depending on the float we sometimes need the ending times of the activities, this point wasn't a trouble in the other methods because these times were explicitly written in the network. As much CPM as PDM, which we will explain later, have the ending times in the diagram. In this case, the Metra Potential Method only shows us the starting times as we can see points before. Therefore we will have to convert these times in ending times when we need it. The definition of each float and the representation of it was explained in the

other methods so we understand that it's not necessary to comment it again. The reasoning will be centered on the conversion to the MPM method.

- Total Float

As we know $Tf = Lf - Ef$ [1]; we are going to expose some equalities for clearing it out and express it on starting times. Due to the rule of the succession and predecessors activities $Lf(A) = Ls(B)$ and $Ef(A) = Es(B)$; as we indicated above in the finish-start times $Es(B) = Es(A) \mp g + d(b)$. Replacing the values in [1] we obtain: $Tf = Ls(B) - Es(A) - d(a) - g$ [2]. We already have the times in starting times values but we can convert it all in values of only one activity. Knowing that $Ls(B) = Ls(A) \mp g + d(b)$ and replacing in [1] finally we have.

$$Tf = Ls(A) - Es(A)$$

- Free float

The definition of it is $Ff(A) = Es(B) - Ef(A)$ [3] and using the relation $Ef(A) = Es(B) = Es(A) \mp g + d(b)$ we can replace in [3] and the resultant equation is:

$$Ff(A) = Es(B) - Es(A) - (\mp g) - d(A)$$

- Independent Float

In this float we have to consider the previous activity (C) and the successor activity (B). The expression is the following one:

$$If(A) = Es(B) - Lf(C) - d(A).$$

As we know that $Es(B) = Es(A) + d(A) \mp g$ and $Lf(C) = Ls(A)$ so we can replace it in the main equality and we obtain.

$$If(A) = Es(A) - Ls(A) - d(A).$$

- Conditional float

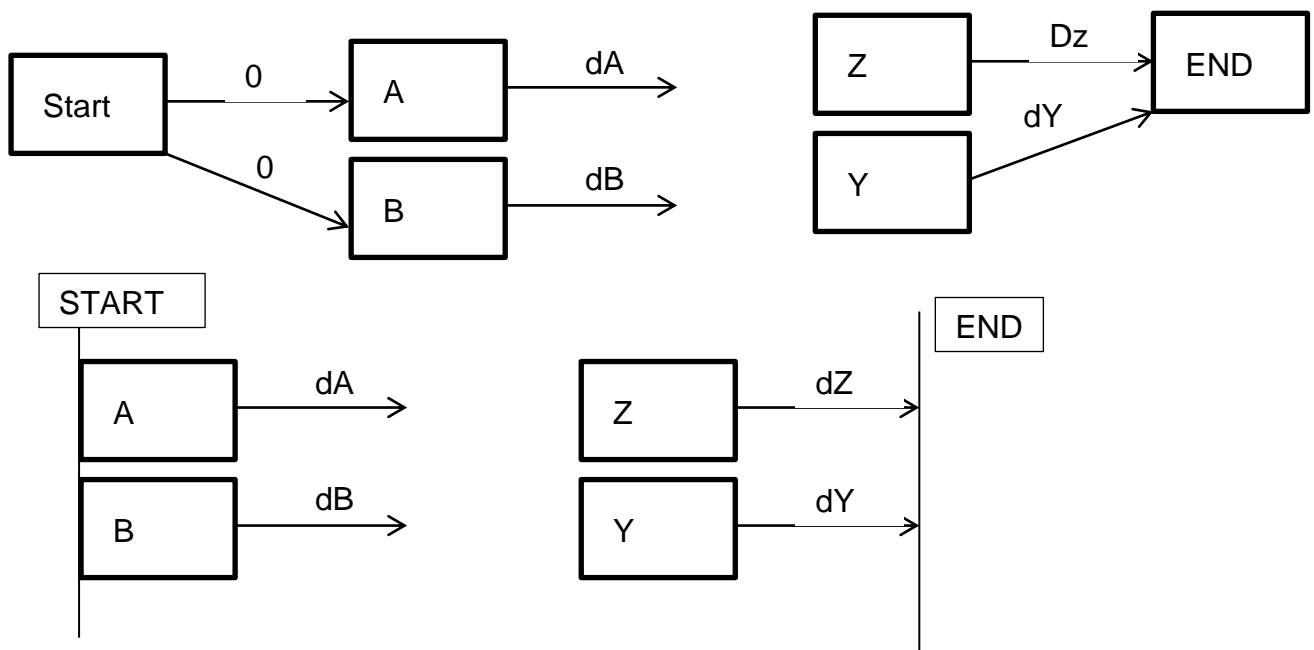
The Conditional float is determined by $Cf = Tf - fF$

Taking the equality of the floats converted in starting times which we obtained before, result:

$$\begin{aligned} Cf(A) &= Ls(A) - Es(A) - [Es(B) - Es(A) - (\mp g) - d(A)] \\ &= Ls(A) - Es(B) \mp g + d(A) \end{aligned}$$

5.3.4. DRAWING OF THE NETWORK

We have already seen the drawing of the different activities depending on their relationships. In that sense it only remains to explain the beginning and the end of the network. In the other arrow network, the PDM, we can choose if we want to start and finish the network with a specifically activity or do it with the first activity. In MPM we always start with an initial and end activity. This activity doesn't have duration and its task is only to mark the point. Also we can mark this point with a vertical line as much to the start as to the finish. In my opinion this last one is more useful and simply to draw, also it makes more sense because an activity null is theoretically impossible.



To finish say that the critical path can be drawn with a different color to difference it to the rest of the network as in all the networks but some experts in the field affirm that like in this method the activities doesn't have implicit ending times we have only to mark the activities not the path.

5.4. PRECEDENCE DIAGRAMING METHOD (PDM)

This method is the most important in the construction management field due to its characteristics. Nowadays it is used by the majority of construction companies.

The precedence Diagraming Method was created in 1961 by John W. Fondahl (Washington D.C 1924-(...) 2008). Fondahl was recognized worldwide as a major contributor to the development and use of the CPM for construction planning and



project management. He was faculty member at Stanford and he advanced construction research, practice and education by co-founding the graduate Construction Engineering and Management program and developing the precedence method of network scheduling. His long and distinguished career also included service in the Marines during World War II, bridge design, construction engineering for a major dam project, and an extended term as a Director of Caterpillar, Inc. John's quiet innovation and leadership resulted in significant contributions to each of his diverse fields of activity.

John conducted research on the "time-cost trade-off problem" to determine the performance rates for activities that would minimize the overall cost of a project, including indirect costs. He developed the precedence diagramming method for project planning and scheduling, which used flow charts that represented activities as the nodes of a graph, to replace the activity-on-arrow methods previously developed by DuPont and the U.S. Navy Special Project Office. The precedence method simplified the planning process and allowed the use of lag factors. John also investigated ways to increase the use of network-based planning techniques in construction. His publication "A Non-Computer Approach to the Critical Path Method for the Construction Industry" sold over 20,000 copies and was translated into over 20 languages. It provided an extremely valuable stepping stone between manual Gantt chart based procedures for analysis of construction plans and schedules and emerging computer based Critical Path planning methods and tools that are now routinely used for planning all kinds of projects.



PDM was the base of the development of IBM/system360. This was a mainframe computer system family announced by IBM on April 7, 1964, and delivered between 1965 and 1978. It was the first family of computers designed to cover the complete range of applications, from small to large, both commercial and scientific. The design made a clear distinction between architecture and implementation, allowing IBM to release a suite of compatible designs at different prices. All but the most expensive systems used microcode to implement the instruction set, which featured 8-bit byte addressing and binary, decimal and floating calculations.

About the characteristics of this method the most important thing is that changed the way to represent the activities. In the previous methods it was represented in the arrow, now they are in the node, for this reason this method is based in the node activity system (NA). The relationships are drawing in segments which join the nodes, this makes possible to add new kinds of relationships, not only start to finish.

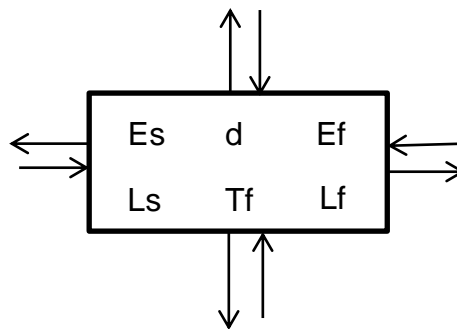
5.4.1. DRAWING OF THE ACTIVITY

The activity is a process that must be carried out with the same intensity without interruption. The activities are represented with a rectangle. Inside this one are written down the times: the earlier start time (Es) in the upper left corner, latest start time (Ls) in the lower left corner, the earlier finish time (Ef) in the upper right corner and latest finish time (Lf) in the lower right corner; also the duration (d) of those activities in the center of it. These are the similitudes of both country methods. Now we are going to see the differences.

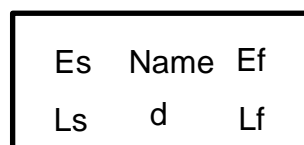


In this case in the rectangle there is space for the total float value (Tf), it's situated down in the center. The activity duration is above it, up in the center of the rectangle. The name of the activity is not written in it.

The relationship segment can start in any side of the rectangle and finish in any one of the next one. For this reason this segment became an arrow because this is the only way to show the direction of the diagram. Also it will be necessary to write down the kind of relationship above the arrow. This is only a brushstroke; we will see the types of relationships later.



About the values in the rectangle the principal difference is the addition of the activity name. It is situated in the place of the duration in Hungarian style and this one puts it above the place of the total float.



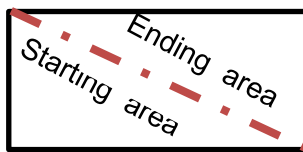
The main difference is about the relationship segment. In this version of the methods we assign a specific side of the rectangles depending on if the activity has a predecessor relationship with the next or it's the successor activity of the previous. Also, we will consider it depending on if it has a starting relationship or ending relationship. These rules are mandatory and we forget to write the type

of relationship above the segment. Now we are going to explain it graphically, it will be clearer:

- Area of arrivals/departures:



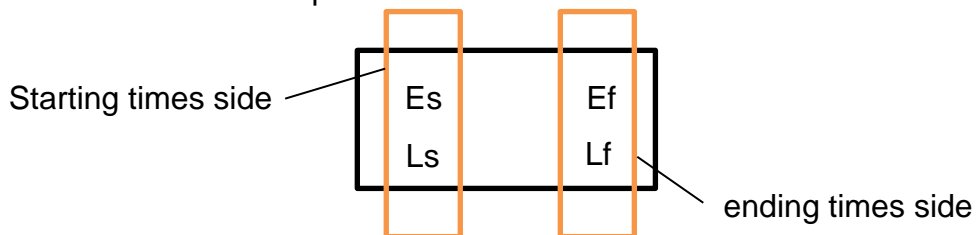
- Area of beginnings/endings:



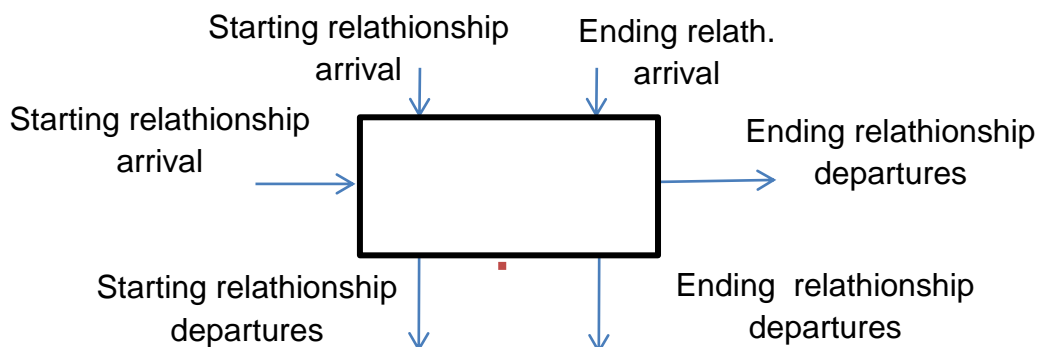
- Horizontal row: In this row we have the information about the times.



- Vertical row: Here the information about the starting or ending relationships.



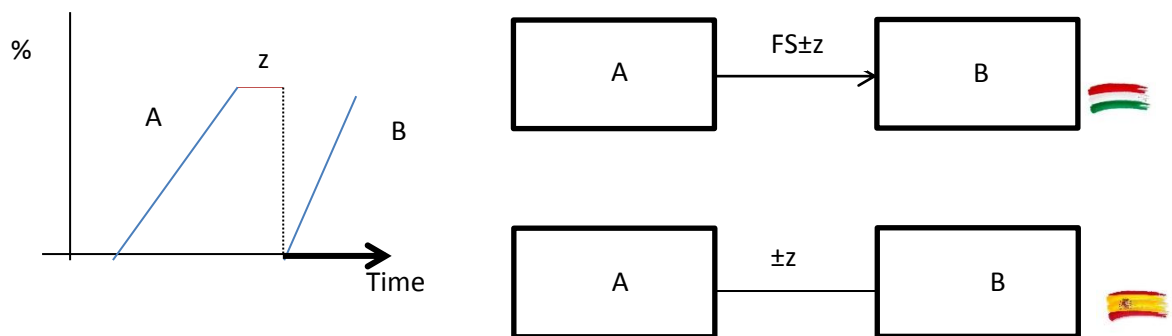
At the end, mixing the drawing and based on its rules we have the final one.



5.4.2. MINIMAL PRECEDENCE RELATIONSHIPS AND TIMES

In this method are four kinds of relationships as in MPM and another extra. As the duration is written inside of the rectangle, in the segment which joins the activities we only will draw the lag between these activities. Depending on the kind of relationship there will be different ways to represent it, regarding to the Hungarian or Spanish method. The lag can be positive or negative like in MPM depending if the lag of the relationship increases the distance between them or decrease it. These differences were explained in the previous method so we are going to center on the different way to draw the PDM activity node. After that we will determinate the times relations according to of each relationship, these ones are calculate to the same way in both educations.

- Finish to Start: The successor activity should begin at least when the predecessor ends, adding or deducting the lag.

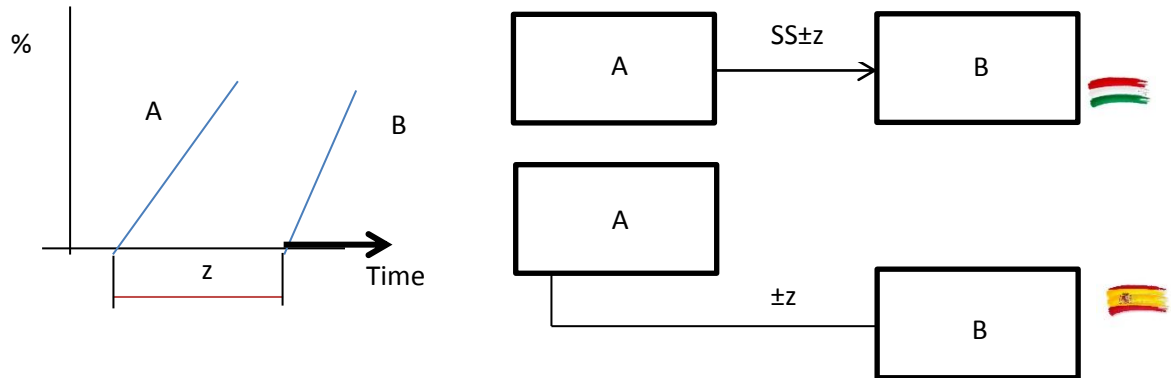


In the left side we can see the graphic with both activities and the lag which separates the finish of the first one and the start of the second one. In the other side the two kinds of drawing the node. In this case coincides the start and finish point but the in the Spanish time is not necessary to write the name of the relationship.

Times:

- Earliest times: $Ef(A) = Es(A) + d(A)$; $Es(B) = Ef(A) \mp g$; $Ef(B) = Es(B) + d(B)$
- Latest times: $Ls(B) = Lf(B) - d(B)$; $Lf(A) = Ls(B) \mp g$; $Ls(A) = Lf(A) - d(A)$

- Start to Start: The successor activity begin at least when the predecessor begins, adding or deducting the lag.

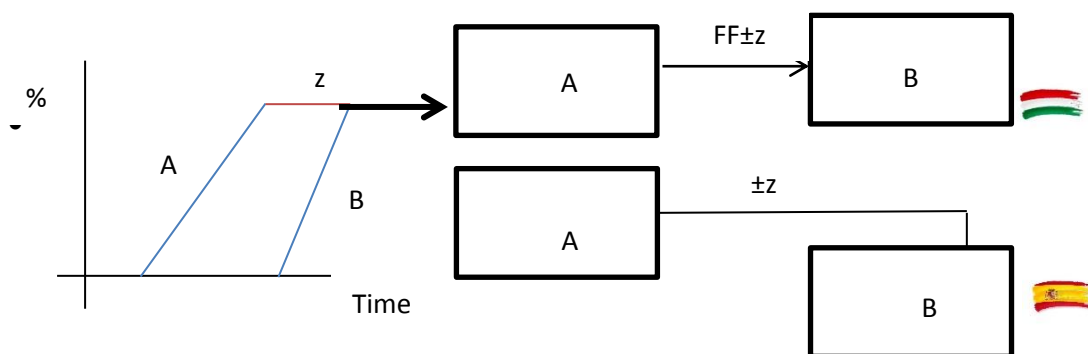


The specific lag separates both start times, it's important to say that of course if this lag is zero both activities will start at the same time. Regarding the Spanish node, the segment begins in the starting departures point and ends in the starting arrives point.

Times:

- The earlier times: $Ef(A) = Es(A) + d(A)$; $Es(B) = Es(A) \mp g$; $Ef(B) = Es(B) + d(B)$
- Latest times: $Ls(B) = Lf(B) - d(B)$; $Lf(A) = Ls(A) + d(A)$; $Ls(A) = Ls(B) \mp g$

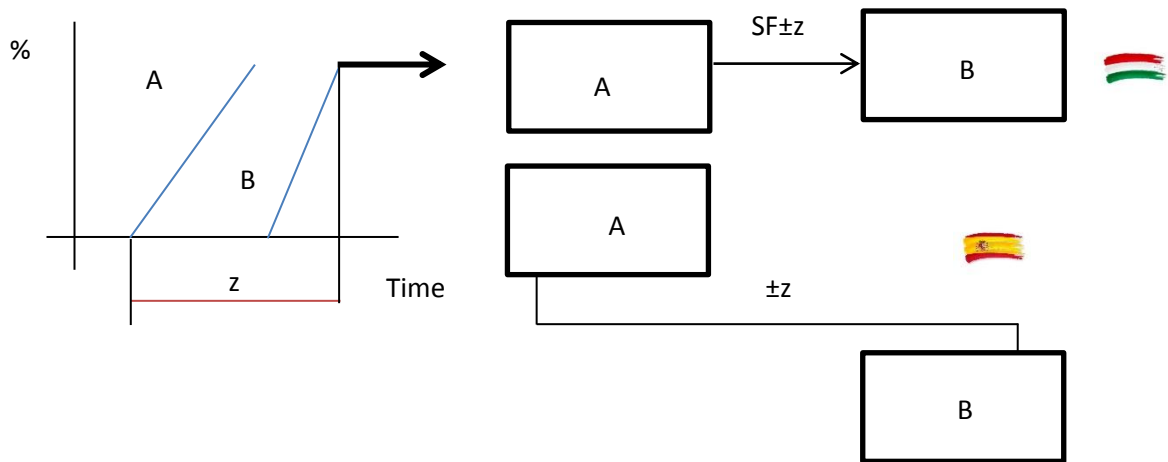
- Finish to finish: The successor activity ends at least when the predecessor ends, adding or deducting the lag.



Times:

- The earlier times: $Ef(A) = Es(A) + d(A)$; $Ef(B) = Ef(A) \mp g$; $Es(B) = Ef(B) - d(B)$
- Latest times: $Ls(B) = Lf(B) - d(B)$; $Lf(A) = Lf(b) \mp g$; $Lf(A) = Ls(A) - d(A)$

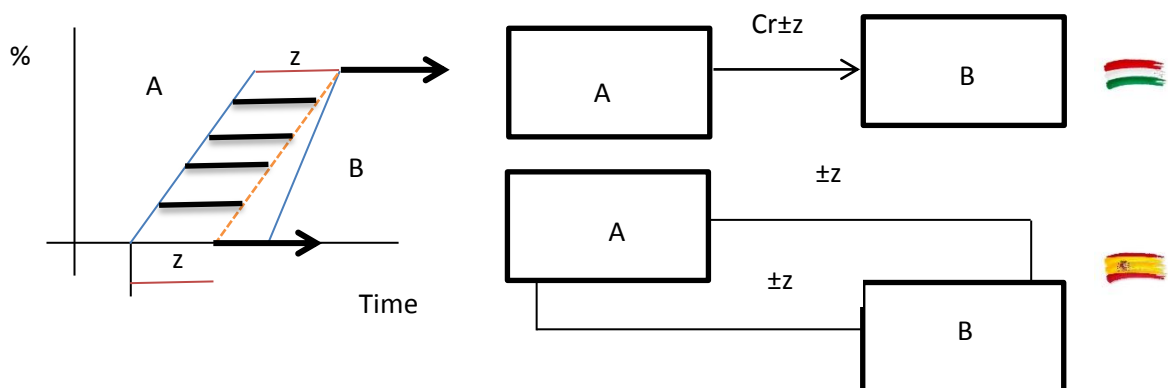
- Start to finish: The successor activity ends at least when the predecessor begins, adding or deducting the lag.



Times:

- The earlier times: $Ef(A) = Es(A) + d(A)$; $Ef(B) = Es(A) \mp g$; $Es(B) = Ef(B) - d(B)$
- Latest times: $Ls(B) = Lf(B) - d(B)$; $Ls(A) = Lf(B) \mp g$; $Lf(A) = Ls(A) + d(A)$

- Minimum Critical: The successor activity ends at least when the predecessor ends, adding or deducting the lag and also it begins at least when the other one begins regarding to the lag.



In this case, the successor activity shouldn't start in the black area. This is a special relationship because we have to fulfill with both conditions. Due to the lag it is the same but the difference between start-start and finish-finish doesn't have to be the same except on the case of activities with similar pendent, we will only take care of the smaller. But this is not a problem because we are talking about a minimum relationship so by looking at this example, the activity B should start before than the expected for keeping the relationship.

This kind is not usually used in Spanish education but it could be represented as the previous shape because is a mix between two relationships.

Times: It will be the smaller of both relationships.

- The earlier times: $Ef(A) = Es(A) + d(A)$;
 $Ef(B) = Ef(A) \mp g$ **or** $Ef(B) = Es(B) + d(B)$;
 $Es(B) = Ef(B) - d(B)$ **or** $Es(B) = Es(A) \mp g$;
- Latest times: $Ls(B) = Lf(B) - d(B)$;
 $Lf(A) = Lf(b) \mp g$ **or** $Lf(A) = Ls(A) + d(A)$
 $Lf(A) = Ls(A) - d(A)$ **or** $Ls(A) = Ls(B) \mp g$

5.4.3. MAXIMAL PRECEDENCE RELATIONSHIPS AND TIMES

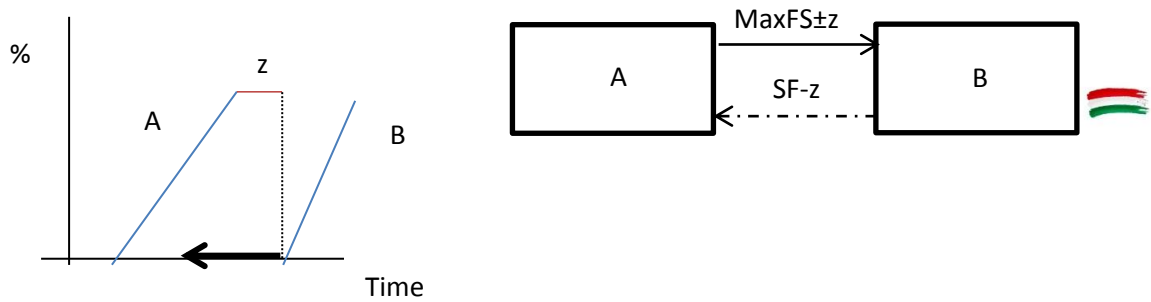
These types of relationships condition the successor activity to keep a distance always smaller than the lag. We could define it as the limit time that one activity has to be separated from another one. This kind of relationship is very useful in some construction works like excavation and shoring because the performance of both of them have to be synchronizing to not cause landslides. However, as far as I know, these relationships are not used in the Spanish education.

There are, like in the case of minimum one, the same five types of relationships but with the inverse purpose, conditioning the activities with a limited amount of time.

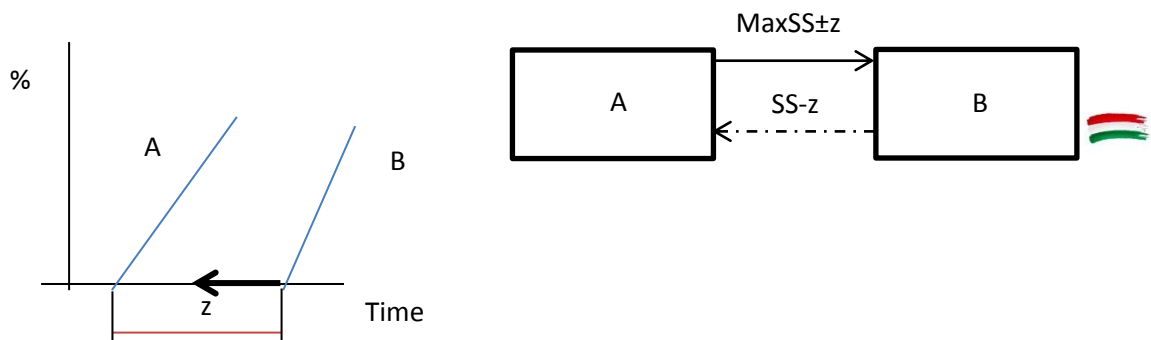
Regarding to the way to calculate the maximal relationship we will transform them in minimal. For that it will be necessary to change the direction of the relationship to the opposite, the arrow will show it. Also the sign of the lag should be changed. We will represent the new arrow with a dashed line. The resultant of this conversion will be:

$$\begin{aligned}
 \text{MaxFS} + g &= \text{SF} - g; & \text{MaxSF} + g &= \text{FS} - g; & \text{MaxSS} + g &= \text{SS} - g; \\
 \text{MaxFF} + g &= \text{FF} - g; & \text{MaxCr} + g &= \text{Cr} - g
 \end{aligned}$$

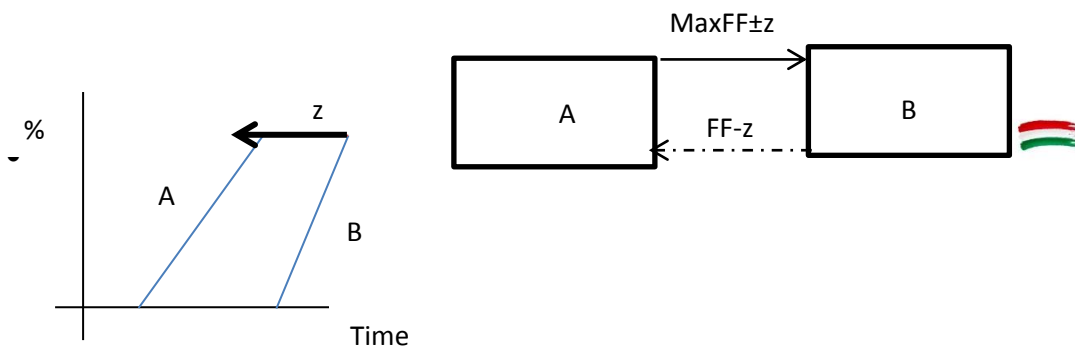
- Maximum Finish to Start: The successor activity should begin before the predecessor ends, adding or deducting the lag.



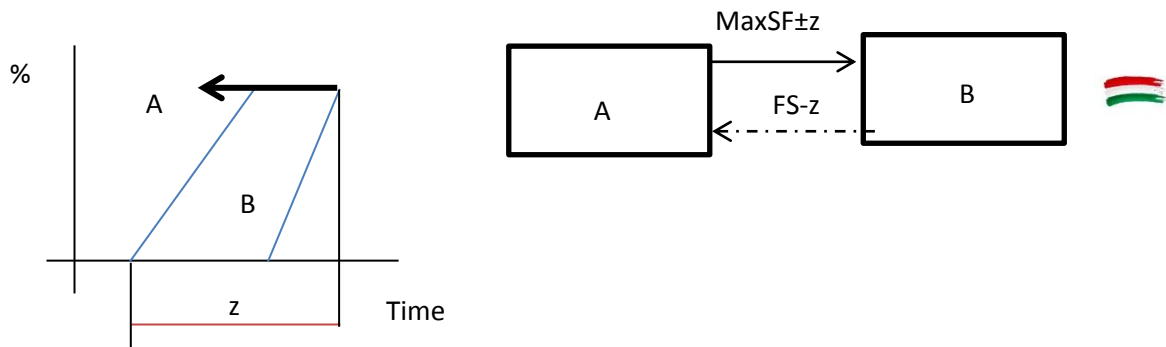
- Maximum Start to Start: The successor activity begin before the predecessor's begin, adding or deducting the lag.



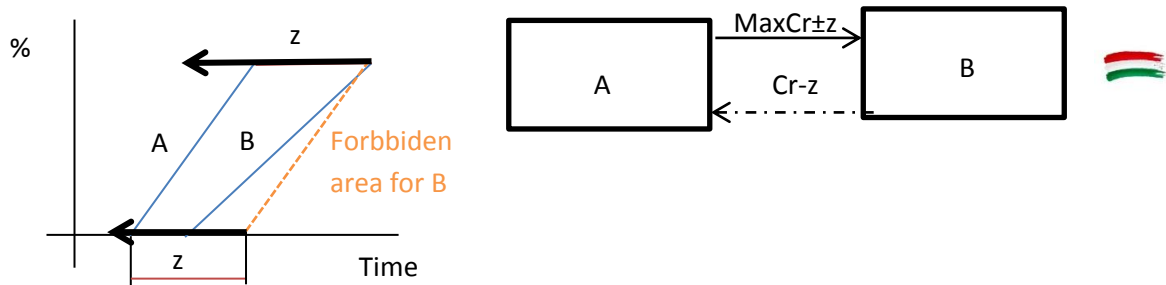
- Maximum Finish to finish: The successor activity ends before the predecessor ends, adding or deducting the lag.



- Maximum Start to finish: The successor activity ends before the predecessor begin, adding or deducting the lag.




- Maximum Critical: The successor activity ends before the predecessor ends, adding or deducting the lag and also it begins before the other one begins regarding to the lag.



6. THE PRACTICE OF SCHEDULING IN THE CONSTRUCTION MANAGEMENT EDUCATION

6.1. SCHEDULING SOFTWARE

 An important part of the construction management education system is the knowledge of the software which allows us the scheduling.

The subject of “Construction Management II” is divided in two parts; the first one dedicates to the basics and how to solve problems of CPM and PDM and the second one and not less important about the use of the software. Almost the forty percent of the lessons are dedicated to learn how to use the scheduling software. In my opinion this is very important because it is the future tool; it’s good to learn how to solve the diagrams by hand for understanding the logic of them but after it’s essential to apply it in the computer.

The computer software used is called “ProJack”. This program is a young program in the history of the construction scheduling. It was developed in September of 2010 but as the creators say: “I have nothing to be ashamed of”. The company of the software is PlanDoc Consulting Ltd, also relatively young company established in 2009. This company has Hungarian nationality and the headquarter is close to Budapest.

The creators tried to humanize the program creating a person (Projack) who talks to you in first person like a real person. I think it is interesting to write down his presentation: “My name is Jack... ProJack. Although I'm one of the youngest in the project planning software family (I was born in September 2010.), my parents keep telling me that I have nothing to be ashamed of. They're also saying that, regarding some topics, I know a lot more than my adult relatives. I would like to convince you about this and I hope that we'll be working together very soon. I can help you a lot in planning and tracking your projects.”

The software is very complete. At first it's necessary to create a calendar attending to our necessities. This calendar is completely modifiable. You can add national holidays, weekends, particulars no working days and the working hours, definitely a calendar for you.

Then, there is a data table. In this one we will put all the information and the program gives us a lot of them too. In this table you can add as many columns as you want; For example: the total cost, the person on charge of determinate activity (Organization), predecessors, successors, resources, WBS level, start, finish, etc...all the dates that you need. So in this table it will be necessary to add the activities, the duration of them and with the arrow you can choose the level of these activities.

In the right side of this table there is the Gant chart where you can follow the scheduling.

The next step is to go to the resources tab and add them in edit resources. There is possible to add some fields in each resource like the quantity, the kind of resource (laborer, material and equipment), the cost per use, standard rate and overtime rate. Also it's possible to fix a specific calendar for each resource and a determinate limit in some dates. This is not all because in the resources view tab we can see performance of each resource per day and per job; and check if we are within the limits and if not we can check in which dates we are consuming so many. Finally, Projack gives us the possibility of constraining the project regarding the time or the resources (or a determined resource) depending if our objective is the time or the cost.

It only remains to introduce the relationships between the activities and assign the resources to each one. We can do it in the budget view tab. It will appear in the bottom of the screen.

Also, before to end it, it's necessary to create a good hierarchy style. This is essential for an easy view of the project and not to create misunderstandings. We can change it in the Gant chart view tab, in the side of the Gant chart. Pressing the right bottom of the mouse we can find the Gant chart layout.

Now we have our project in the program. But this isn't all because the final and important target is obtaining the information in a determined point of the project. Projack allows us to know the cost of the project in a determinate date (weeks, days or months) or over a period. The same information we can check about the resources: how many laborers, equipment or materials we need. Also we can know the costs of the activities, the duration, the earliest start and the earliest finish.

As a result, Projack is useful software which allows you to create easily a scheduling and take it graphic information in a quick way.



The Spanish education is centered on solving the tasks by hand basically. In my opinion the software of scheduling is not that important. It's usual to use a Microsoft excel layout for making a Gantt Chart or Autocad for drawing the Precedence Diagramming Method.

Anyway, Microsoft Office Project is the most known software in Spain. It has almost the same characteristics of the Hungarian software but with the Microsoft brand.

6.2. ASSIGNMENT



The subject of Construction Management II in YBL Miklos School for Erasmus people is in my opinion based in the civil engineer constructions. The building construction is not so much kept in mind. Thinking about it, it is normal because all people who come to study there have been studying different branches of construction. I say that because the task of the subject was focused in a civil project.

There is a final task which can make it in couples and hand it at the end of the course. This task is about a sewer construction in progress in two parallels streets. The aim is to carry the domestic wastewater to the already existing main.

For realizing the task we have some dates about the magnitude of the street (length, depth and breadth) and about the characteristics of the pavement and pipes as well.

Then, a list of technological relations describes the constructive process and the machines which have to carry out each task; this entire equipment has a different performance in each task.

The main activities are: breaking the pavement, excavation of the earth, shoring work, undisturbed surface, gravel bed, laying of the pipes, removing the shoring, backfilled and pavement back.

At the end of the statement a chart shows how many resources we have for each activity and the unit price of them.

With all of this the question of the task is to find a solution that satisfies the technological requirements, doesn't exceed the resources and with the least cost.

The most difficult part of solving the task is the resources. The resources are limited and this conditions the entire project. Of course this is a problem in real life because the resources are not unlimited. Specifically the capacity of shoring is very important because it conditions the entire project. The streets have a length of 1000 and 800 meters and we only have 200 meters of shoring. Once excavated the trench we should carry out with the shoring immediately because there are risk of landslides. So until the trench is not shored we can't start with the next work inside it. For this reason we came to the conclusion that after the breaking of the pavement all the next tasks should take the same time. Also It's useless accelerate the process of breaking. All depends on the shoring.

Another important point is how to organize the work in both streets. We handle three possibilities: the first one is to start the two streets and the same time but it entails to divide the resources and lose time. The second one is start with one street and after finishing, start with the other. And the third one and the chosen option is share the resources but of the same activities; that is to say, when one resource finish one concrete task goes to the other street to carry out the same task which is left before.

At least the duration of the project is less than fifty days and the cost one hundred million.

The entire task is done it with the Projack software.



The subject of "Organización y programación en la edificación" studied in the "Universidad Politecnica de Valencia" specifically in the school of "Ingeniería de Edificación" is the similar subject of "Construction Management".

In this subject there is also a final task but shared in three parts.

The task consists in a concrete structure construction of a building focused only in the scheduling part. Starting in the basement and ending in the last slab.

A plain is given with the magnitudes of the building (ground plan and elevation with dimensions)

The cost of the construction is not contemplated. The only cost that we have to take care is the penalty costs for a latest delivery.

At first we have to describe the constructive process that we are going to carry out and explain the reasons of this choice. After that we should make a simple temporal diagramming with all the tasks needed. It's requested to make a chart with the resources necessities for each task pointing which are the most important and which one is going to be critical.

The next part is already more specifically, it is about CPM. It is requested an arrow network of the entire project. After this we have to specify more and analyze each main work: Beginning in the basements, then the excavation work and finally the structure construction. For each work we have to make a different CPM.

Once this is done, it's requested some time diagrams of the works about different periods of the building construction: the first one of the entire project, another each three months and the last one about each month.


Also, we have to realize diagrams based on the production, costs and resources. The production diagramming is about the basement, excavation and structure. About the cost we study the costs per week, per month and the cumulative cost of the entire project. Finally a diagram with the resources is needed. All the diagrams are based on earliest start and earliest finish.

We already have the scheduling of the project, now it's the time to optimize it. We apply the method of CPM optimization. It's necessary to determinate the slope of the activities and decompress the project until the cost are as less as possible. In this case this is the objective, reducing the project cost.

The last step is to analyze if our project is feasible. We use the Program Evaluation and Review Technique also known as PERT. We study if the original project without decompression and the optimize project are feasible. As we explained before, we take as a limit for a feasible project a 25% of probability of success. So if our project has a higher probability of success than 25%, it will be feasible.

Finally we should draw a perspective representation for making the whole project easier for understanding. It's important that in this representation we can see all the different works and it has to be easy enough for everyone, even for a person who doesn't have knowledge about construction.

6.3. EXAM

 The half part of the mark of the subject corresponds to the writing examination and the other part is about Projack. This exam is only one exam, one final exam. The first part includes only network techniques. CPM and PDM are these network techniques.

The most important difference between both education systems regarding the exam evaluation is the way that the students can prepare it. This way is more interactive in the Hungarian education. In the web of the school you can find a lot of practice exercises where the students can practice before the exam. These exercises have a limited time to do it and at the end you can check your mistakes. These practices are divided by issues and the last one is a resume about all the chapters of the subject. All the questions are with “quickly answers”, exposing the question the student has to choose and click between the proposed answers.

As we said before the questions are about Critical Path Method and Precedence Diagraming Method:

About the first one they are some common questions:

- A CPM is giving: create a list of predecessors
- Giving a list of predecessor or successor relationships create the CMP
- Giving a list of predecessor or successor determine how many dummies activities are the minimum necessities for make the CPM
- Giving a list of predecessor or successor determine how many events has the CPM.
- We have to lists: one of predecessor relationships and another of successor relationships. Are both list of the same CPM?
- Giving a relationship list: Which activity start first? This question can be with a list of successors or predecessors.
- Giving a list of successor or predecessor relationships: Find out if there are unnecessary information and if it is, click the unnecessary. In this case is considered unnecessary information the activities which appear in the list and they don't have an immediately relationship with the other one.
- Starting from a relationship list: Determined which the project duration is.
- Given a CPM: Determine which the longest total float is.
- Given a CPM: Determine which the sum of the total float and free float of one specific activity is.
- Given a CPM. Check the project duration if all the activities can be one day shorter; except the activities which take only one day.

The main questions about PDM are the following:

- Calculating the project duration giving a PDM network.
- Checking how many days can be longer the activities without affect the project duration. Check the floats.
- Calculating the total float
- Giving some different duration of one activity, determinate which is the best one for this activity
- Starting from a PDM with maximum relationships, calculate the duration of the project.
- Analyze the type of activity depending on the relationships. If it is normal neutral or reverse.

Until here the online practice. The evaluable exam is written. It is composed by two exercises. The first one is about CMP and the second one about PDM. It is given a network and the student has to solve it. The questions are about the project duration, total floats, project duration if we can short some activity...

The second part of the exam is about the construction management software, as we explained before, Projack. The exercise consists of a list of relationships with their durations and resources. The student has to create the scheduling and after answer some question about it. The way to create the scheduling in Projack was explained before in the chapter of software. The different kinds of questions are similar to the exercises explained in class: project duration, costs over a period, total cost, cost of a specific resource, what happens if we can spend more resources than we have, what happens if we want to save as much money as we can, which activities cost less than a determinate cost...definitely all the parameters that we can find in Projack software and we explained in the software chapter.



The exam in the Spanish education is only written. This is based on solve the different methods. This different methods studied are Gant Chart, CPM, PERT, PDM, MPM and Project Review.

The evaluation system is composed by thee exams with a similar value in the final mark.

The first one is about Gantt chart, Critical Path Method and PERT. The main exam exercise is about solving a CPM graph. Given the list of activities with their precedence activities and durations is asking to draw the CPM graph and after apply the cost optimization method with the objective of finding the best solution depending on the cost or the duration. After to optimize the CPM, we can determine the probability of success of this solution with PERT. All of this exercise can be do it separately too. For example, it is giving a list of activities

and relationships draw the Gant Chart and after the CMP; or exercises of CPM with or without optimization; or another one only about PERT.

The second exam is about PDM and MPM. As in the previous exam, this one consists in solving a network. Sometimes in Precedence Diagramming Method the handicap increases because in the statement there isn't a relationship between the activities, it's given a real case. So with the description of the activities works the student has to analyze which activity starts first and which one after, that's mean to find the relationships. Also it's asked some questions about the duration of some activity, about what happens if there is a delay in another activity or which date we can give back some equipment or material due that is not more necessary. In Metro Potential Method exercises is given a list of activities but in this case with relationships. It's usually to join temporal restrictions to this list in some activities. Of course in both methods the student has to find the critical path.

The third and last exam is about the project review. This kind of exercise corresponds to another part of the constructive process. It pretends analyze the process in a determined point of the construction and make sure if it is going on time or not. The point is that you get one day to the work site and you have to check if it's doing with the predicted scheduling. Like is probably that it isn't, it's necessary to make an analysis and create the new scheduling with the update situation. After this we can answer some questions like what is going to be the new final cost or the new project duration.

7. COMPARISON

In this point we are going to describe and resume the most important difference that we explained in the previous chapters.

The practice of scheduling is quite similar in the entire world. It's a globalized practice. These methods have been developed for over more than fifty years ago, it has been studied in a lot of universities and applied in most of the construction companies. For that reason the methods have small differences and a lot of similitudes regarding to the country where it is used.

I'm going to start with the methods which doesn't have difference in the practice in both countries:

- The Gantt chart

The Gantt chart is studied in the same way in both countries. Although in my opinion this method has more importance in the Spanish education. In Spain the method developed by Henry Gantt is used not only for specific exercises about itself, it's used for complementing another exercise about CMP for example. It's an easy way to see graphically the evolution of the project and even if done the CMP before, after it's good add a Gantt chart for extending the information. As far as I could know, the Gantt chart is important in the Hungarian education but in my case I didn't study it because the subject was center on the network techniques.

- Linear Scheduling Method and Adamecki's Harmonogram

I didn't know these methods before I came to Hungary. In Spanish's University the only one traditional method that is studied is Gant Chart.

In fact, the Adamecki's Harmonogram is not studied neither in the Hungarian university, in my opinion it's a pity that the teaching of this method is in disuse.

With the Gant Chart, the Linear Scheduling Method is the traditional method studied. There are focused in how in a glance the conflicts between activities are seen as easy.

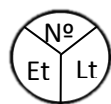
- Critical Path Method (CPM)

CPM is a much used method in both educations. The similitudes are bigger than the differences.

The most important one is the way to draw the event symbol. There are different ways for drawing the events. In Spanish education is usual to use the reverse "De la rue" Symbol (1). However as I could see, in Hungarian education it is more common to use a variant of the "V.H.V" symbol (2). Of course all symbols are valid and show us the same information with different shapes.



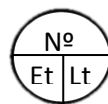
(1)



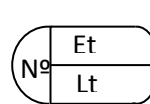
"De la rue"



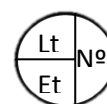
G.J.B



V.H.V



Unilever



(2)

About the cost optimization, in the subject of "Construction management" we study the optimization in a practice way. It's studied in the Cickogram chapter and without any particular method; I mean checking the

possibilities and choosing the best one. For sure, there will be a method used in the construction management education but I didn't study it.

- Program Evaluation Review Technique

I didn't study this one in Hungary.

- Metro Potential Method

The PDM method developed by Bernard Roy is used only in the Spanish education. Due to its similitudes is usually confused with PDM; this is the reason why in the Hungarian education sometimes both of them are called the same. The name Metro Potential Method is used for calling all the methods based in node activities (NA). When the literature refers to PMD is for describing the network of the MPM, ergo how to solve it.

In my opinion MPM is a totally different method. It's true that it works with the same shape as PDM, in rectangles where are represented the activities (node activities) but this is the unique similitude. In MPM the activities are represented only with the starting times in the contrast to PDM where all the times are in the node. Also the duration of the activity is on arrow and the end of it is points the ending; In PDM is also in the node. The way to represent the relationships is not the same too: MPM is based on the fact of the node is the beginning and the end of the arrow is the ending so the relationships will be governed with that standards.

- Precedence Diagramming Network

In PDM is where there are the most important differences between both educations systems.

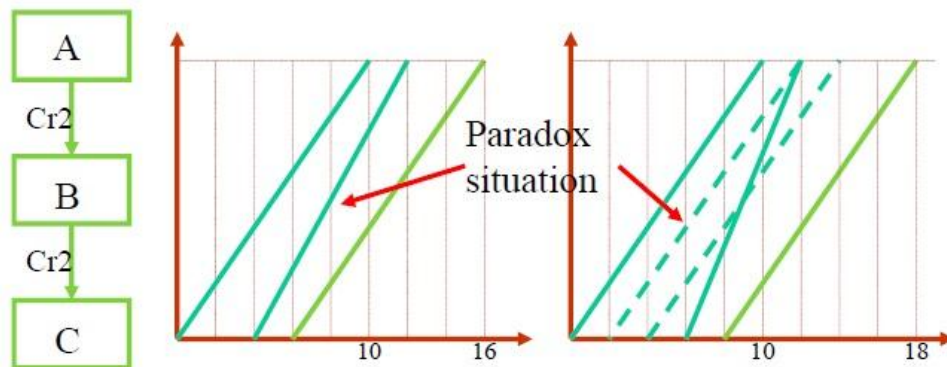
Starting in the way to write the nodes, the Hungarian education includes the total float of each activity in the rectangle while the Spanish one prefer to numerate the nodes and include them in this position.

The drawing of the relationships between the activities is a main point in the existing differences. In the Hungarian way the activities are joint with an arrow which pointing the direction of the relationship. This arrow begins always in the same point and ends also in the same of the successor activity; the representation of the type of relationship is achieved by writing the initials of the relationship. In the other case, each

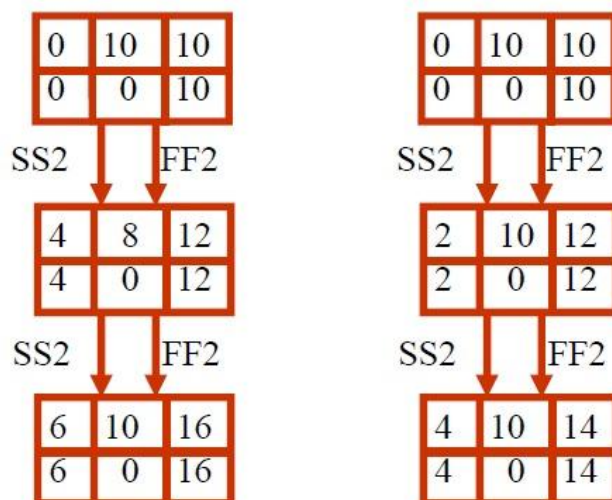
type of relationship has assigned a side in the node, as for arrive as for depart. This allow don't put the type of relationship. I think this time the Spanish method is better because in a glance you can check the kind of relationship, Also you have to know the rules of the game if you don't know them it's much better the Hungarian technique and not allow confusion.

The Hungarian way introduces a new kind of relationship: the critical one. The characteristic of it is that the activity is conditioned by two rules, start to start and finish to finish. In Spain this relationship is made with the sum of the two kinds and it doesn't have a specific name. Having a name for the join of more than one relationship is quite good for the cleaning of the network. All is clearer.

Continuing with the minimal critical relationships, the Hungarian education introduces a good question: The Splittable activities. Sometimes reduce the time of one activity can delay the project. This is at first unbelievable but due to this relationships is possible because this change in the activity keep one of the critical relationships but delay the other time of the activity forcing the successor to end after in the time.



This is one example of how reduce a one activity the project is delayed. We have three activities both of them connected by a critical relationship plus two days. The duration of B is 8 days and we want to change it for 10 days. After do that we can see that the relationship finish to finish existing between A and B is kept but the slope of B has

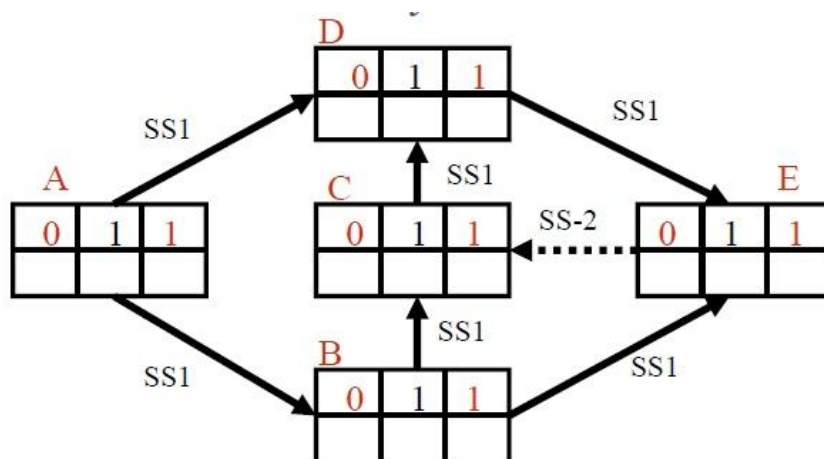


changed forced it to begin two days after. This will not be a problem if the successor activity wouldn't have a critical relationship with B. Now B begin in the day where C began before so regarding the critical+2 relationship is necessary to move the start of C two days later increasing the duration of the project in two days more.

Here we can see the previous explication in a PDM network. In the right side the initial network and in the left side the supposed network. Reducing the duration of the activity B in two days it won't start two days before because the relationship finish to finish with A conditions its ending. So the Activity B will start two days later and its successor activity will add two days in all of its times. As a result not for more reduce the activities the project will finish before.

Another new concept introducing in the Hungarian education is the maximal relationship. As we explained in its chapter, this one conditions the activities to not end after a determined date. As far as I could see in Spain, this type is not used there. The mechanic of the calculation is similar to the minimal one but converting previously the maximal in minimal. I would want to point a special case in the solving of PDM with maximal relationships:

Sometimes in the moment to convert the maximal relationships on minimal one we can find troubles. We can see that as a result of the conversion a loop has arisen, this mean that we can't start in any activity because all of them have a predecessor .In this case the algorithm cannot be continued and we have to use other method.



This would be the beginning point of the calculation.

During the analysis we can choose any activity order. Earliest start of each activity has to be zero like it is the starter activity. During the calculations the earliest start and finish of activities have to be calculated using the actual data of the preceding activities (In case of

more predecessors the greatest value calculate for earliest start/finish will be the determined one.)

After finishing the calculating of all the activities the result must be compared to the results of the previous iteration.

In case of any differences in results, the iteration must be repeated. In case of no differences the first phase is accomplished.

8. BRIEF OVERVIEW OF FUTURE PROSPECTING AND NEW METHODS

The practice of scheduling is a field constantly changing. During a lot of years the previously studied methods has been the main techniques used in the construction companies. These methods are so useful for the project management but the society evolving and the scheduling is not going to be less. In recent decades have emerged new methods for helping the task of the scheduling manager. These methods are incipient and their use is not common yet. However, year by year they are more known and their practice is extending over the world.

We are going to expose some of these methods. We have spoken about the existing methods, now it's the time to know the methods of the future; a brief outline about the new practice of scheduling.

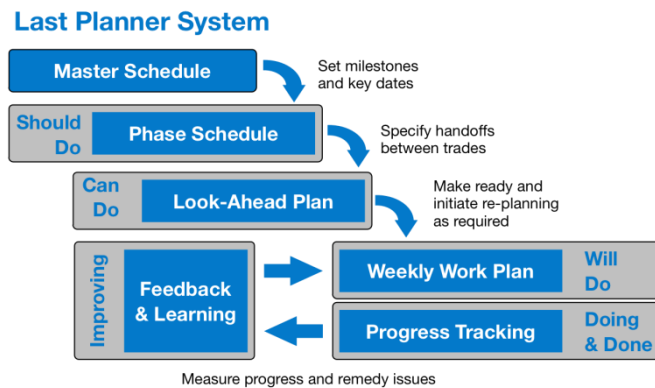
- Lean construction; the last planner system.

Lean Construction is a combination of original research and practical development in design and construction with an adaption of lean manufacturing principles and practices to the end-to-end design and construction process. Unlike manufacturing, construction is a project based-production process. Lean construction is concerned with the alignment and holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs .The term "Lean Construction" was coined by the International Group for Lean Construction in its first meeting in 1993. The Construction in "Lean Construction" refers to the entire industry and not the phase during which construction takes place. Thus, Lean Construction is for owners, architects, designers, engineering, constructors, and suppliers.

Specifically, the last planner (sometimes referred to as the Last Planner® System) is a production planning system designed to produce

predictable work flow and rapid learning in programming, design, construction and commissioning of projects. Last Planner® was developed by Glenn Ballard and Greg Howell. LCI licenses the use of these processes and related IP to various organizations, including most recently the Associated General Contractors of America.

Completing the definition we can say that Last Planner ® is a methodology for planning, monitoring and control of projects which improves the timeliness and costs, by increasing commitments among team members, optimizing coordination and increasing the ability to anticipate situations that might affect the proper development of the project.



- Building Information modeling (BIM)

The National Building Information Model Standard Project Committee has the following definition:

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.”

Traditional building design was largely reliant upon two-dimensional drawings (plans, elevations, sections, etc.). Building information modeling extends this beyond 3-D, augmenting the three primary spatial dimensions (width, height and depth) with time as the fourth dimension and cost as the fifth. BIM therefore covers more than just geometry. It also covers spatial relationships, light analysis, geographic information, and quantities and properties of building components (for example manufacturers' details).

We are going to focus on two kinds of BIM; The 4D BIM and the 5D BIM.

- 4D BIM, an acronym for 4D Building Information Modeling and a term widely used in the CAD industry, refers to the intelligent linking of individual 3D CAD components or assemblies with time- or schedule-related information. The use of the term 4D is intended to refer to the fourth dimension: time, i.e. 4D is 3D + schedule (time).

The construction of the 4D models enables the various participants (from architects, designers, contractors to owners) of a construction project, to visualize the entire duration of a series of events and display the progress of construction activities through the life time of the project. This BIM-centric approach towards project management technique has a very high potential to improve the project management and delivery of construction project, of any size or complexity.

- 5D BIM, an acronym for 5D Building Information Modeling and a term widely used in the CAD industry, which refers to the intelligent linking of individual 3D CAD components or assemblies with schedule (time) constraint and cost-related information. The use of the term 5D is intended to refer to the addition of fourth dimension: time and fifth dimension: cost to the 3D model, i.e. 5D is 3D + schedule (time) + cost.

The construction of the 5D models enables the various participants (from architects, designers, contractors to owners) of any construction project, to visualize the progress of construction activities and its related costs over time. This BIM-centric project management technique has a potential to vastly improve the project management and delivery of construction project of any size and complexity.



9. CONCLUSIONS

In the present project work we have studied the different methods used during the history of scheduling, from the beginnings of the construction to the most modern systems.

We could see the evolution of the techniques throughout almost more than three thousand years.

Studying all this years we can obtain a main conclusion: the importance of the scheduling.

Since the first constructions, people have tried to optimize the performance of the materials, equipment or laborers for carry out the construction task in the best way.

We don't have so much information about how were built the first big constructions. Civilizations like Chinese or Egyptian were brilliant constructors and a lot of their constructions are still in good conditions. This show the importance that this field represented to them.

However, the most important developments in the field of the scheduling construction were in the last three centuries.

In the 18th and 19th centuries, Priestley and Plairfair started to represent the information in charts. Both of them thought that this was the best way to show as much information as possible in the minimum space possible. They were not wrong. In the case of Priestley, he was fused on the history field; his charts allowed condensing determined events of the history or biographies of famous people and make the view of it easier. The labor of Playfair was more directed towards the engineering and statistic. The commercial movements and its evolution was his main concern.

Some decades later, during the last part of the 19th and the 20th century, we can see the really starting of the practice of scheduling. Adamiecki or Gantt were the first people who investigated about the scheduling in the construction. The Adamiecki's Harmonogramn developed by Karol Adamiecki provided the basis of the Gantt Chart. This method is known in the entire world and it's used nowadays.

In the second half of the 20th century with the development of the computers the practice of scheduling underwent a major change. The computer software allowed working easier and quick and the modern methods started to develop. As in the most of the new techniques, the most powerful governments and the most important companies started to research and use these methods on their own benefit. This is the case of the US Navy with PERT or IBM with PDM. After

that the network techniques extended in all the fields coming to the construction one.

About these network techniques, the Critical Path Method was the precursor of the rest of methods. This was the first method which use this aspect for show the schedule, the first which synthetize all the information in simple shapes. Although this is based in the system of arrow activities, in my opinion it was the inspiration of the next methods based on node activities.

Not less important it's the optimization that this method allows to make. I think it was the best side of it; compress or decompress the duration of the project and comparing it regarding on the cost it's a very important aspect.

One of the best systems that I have studied is the Program Evaluation and Review Technique (PERT). This is not a typical method of Scheduling; we could say that it's a complement of the scheduling. As we have seen it's a probabilistic method and statistic too. Its objective is not determinate the duration of the project or the cost; it's check if the project that we want to carry out is viable in the planned dates or not. It doesn't analyze only one time like the typical methods, it considers three different times. With these times we know the worst and the best possibilities and it allows us to know the real situation of our project.

The last network methods were MPM and PDM. Both of them similar but they are not the same. Precedence Diagraming Method took advantage against Metro Potential Method and nowadays is more known; especially in the Hungarian education where it's not study. Maybe this is due to the fact that the method developed by Bernard Roy doesn't work with all the activity times, it works only with the starting times and PDM reflects all the times of each activity node. In my opinion this difference raises PDM to a higher stair in the scheduling history.

I would like to emphasize in some aspects that I could see about PDM in the Hungarian education:

We have seen the difference of the relationships drawing in both education system, Spanish and Hungarian; in my opinion, in this case I have to choose the Spanish way to drawing. The main reason is the cleaning of the network. The Spanish way has a strict rules in the relationships drawing which allows don't write the kind of relationship, depending on the point of the segment in the node we determine the relationship. It requires a greater knowledge about the network but it make easier the reading of it.

In support of the Hungarian education system of PDM: the maximum relationships. In the practice of scheduling in the construction field is very important this kinds of relationships. Some tasks need to be connected with the

others with a maximum time; a time which never has to be exceeded due the conditions of the activity. In the Hungarian education, It is emphasized and used in a lot of exercises. A special mention to the method used for calculate the loop networks due to the existences of maximum relationships in it.

Finally, I think that the Hungarian construction education has some advantages regarding the Spanish one especially in terms of software education or online education. As we have seen, in the lessons a very important aspect is the learning of the scheduling software. This is the tool of the present and the tool of the future, for this reason it's very important that the students know how to use it; it's true that the best way to learn the basics it is with exercises by hand but it has to be space for the software too. The web of the subject is a good example too. There we can find exercises which the student has to do it in a limited time. This forces him to exercise the mind.

I would like to finish this Diploma Project with a quote of one of the pioneer in the practice of scheduling:

"Whatever we do must be in accord with human nature. We cannot drive people; we must direct their development... The general policy of the past has been to drive, but the era of force must give way to that of knowledge and the policy of the future will be to teach and to lead, to the advantage of all concerned"

Henry Gantt (1910) *Work, Wages, and Profits: Their Influence on the Cost of Living*, p.112

BIBLIOGRAPHY

- The pyramids of Egypt
http://www.bradshawfoundation.com/pyramids_of_egypt/construction.php
- Sun Tzu
http://es.wikipedia.org/wiki/Sun_Tzu
- What is scheduling?
<http://www.businessdictionary.com/definition/scheduling.html>
- CPM- 200: Principles of Schedule Management (Harry Sparrow)
<http://www.evmlibrary.org/library/CPM-200A%20Intro%20to%20Scheduling%20Techniques,%20Harry%20Sparrow.pdf>
- Karol Adamiecki
http://en.wikipedia.org/wiki/Karol_Adamiecki
- Harmonogram
<http://pl.wikipedia.org/wiki/Harmonogram>
- A new chart of history
http://en.wikipedia.org/wiki/A_New_Chart_of_History
- Charles Adamiecki vs Henry Gantt
<http://manageitup.wordpress.com/2009/12/04/adamiecki-vs-gantt/>
- William Playfair
http://en.wikipedia.org/wiki/William_Playfair
- History of Bar Charts and Graphs
<http://www.jpowered.com/graphs-and-charts/bar-chart-history.htm>
- Time-distance diagram
http://en.wikipedia.org/wiki/Time_distance_diagram
- Henry Gantt
http://en.wikipedia.org/wiki/Henry_Gantt
- Henry Gantt quotes
http://en.wikiquote.org/wiki/Henry_Gantt
- Gantt chart
http://en.wikipedia.org/wiki/Gantt_chart
- Gantt (1910) Work, Wages, and Profits: Their Influence on the Cost of Living
- The concept of linear scheduling
<http://www.datcc.pl/en/component/content/article/97-harmonogramowanie-liniowe>
- A brief history of scheduling (Patrick Weaver)
http://www.mosaicprojects.com.au/Resources_Papers_042.html
- Francisco Javier Medina Ramón. "Programación y Edificación". Editorial Universidad Politécnica de Valencia
- Construction Scheduling using Non-Traditional Optimization. (Samdani Saurabh Arun)
- Joseph Priestley and education

- http://en.wikipedia.org/wiki/Joseph_Priestley_and_education
- Critical Path
http://en.wikipedia.org/wiki/Critical_path_method
- Precedence Diagram Method
http://en.wikipedia.org/wiki/Precedence_diagram_method
- Técnica de Revisión y Evaluación de Programas (PERT)
http://es.wikipedia.org/wiki/T%C3%A9cnica_de_revisi%C3%B3n_y_evaluaci%C3%B3n_de_programas
- IBM system/360
https://en.wikipedia.org/wiki/IBM_System/360
- Metra Potential Method
http://en.wikipedia.org/wiki/Metra_potential_method
- John W. Fondahl
http://faculty.senate.stanford.edu/memorial_resolutions/Fondahl_John_SenD6213.pdf
- Projack Management
<http://www.projackmanager.com/pj>
- PowerPoint presentations of the subject Construction Management II in Szent Istvan Egyetem, YBL Miklos (Miklos Hajdu and Orsolya Bokor)
- The Last Planner (The Lean Construction Institute)
<http://www.leanconstruction.org/training/the-last-planner/>
- 4D BIM
<http://www.vicosoftware.com/what-is-4D-BIM/tabid/88206/Default.aspx>
- 5D BIM
<http://www.fgould.com/uk/articles/5d-bim-explained/>