PERT and CPM Techniques for Manufacturing Systems

Prashant Singh Nirban, Dr. Kailash Chaudhary

*Department of Mechanical Engineering, MBM engineering college Jodhpur (Rajasthan), India*

***Abstract—* In this paper we would see a brief view on various project scheduling techniques that might be helpful to software project managers to deliver the project on time and aiming to support the development of successful systems, the classification of scheduling techniques by how they are implemented is considered in detail through several aspects. Each kind of techniques is used to achieve a particular task and capture the structure and behavior of the system at various levels of detail, this study is aimed at finding trade-off between the cost and minimum expected time that will be required to complete the project. Both critical path method (CPM) and project evaluation and review technique (PERT) were used for the analysis. The activities underwent crashing of both the time and cost using linear programming, this paved way for the determination of critical path.**

***Key words:* Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)**

# INTRODUCTION

For project scheduling of manufacturing systems industrial engineers has been working since a long time from then project scheduling is a very tough job for industrial engineers.

Many evolutions had been done by industrial engineers to do the planning and control of production system’s project scheduling. In this chapter we would focus on basically to project scheduling techniques named as C.P.M. (Critical Path Method) and P.E.R.T. (Program Evaluation and Review Techniques).

When we do planning of simple jobs at home we call them house chores. On other hand when we do planning for big purposes like atomic power plant construction we call it by a specified name Project Scheduling.

For production control it is important to –

* + First plan your work;
  + Then work your plan.

Project scheduling of manufacturing system can be distinguished by number of activities or operations like small or big scale projects.

# VARIOUS PROJECTS SCHEDULING TECHNIQUES

In this era of computers industrial engineers had developed so many techniques for project scheduling of manufacturing systems. Using these various techniques we are now able to control the time of project completion up to a certain extent.

For example, An American Missile Company (POLARIS) construction project had completed before two years of forecasted time using these techniques so that’s why their importance had raised since then.

Some of the Manufacturing System Project Scheduling and Controlling techniques are as follows:

2

1. Critical path method(C.P.M)
2. Program Evaluation And Review Techniques(P.E.R.T)
3. Resource Allocation And Multi Project Scheduling(R.A.M.P.S)
4. Program Evaluation And Procedure(P.E.A.P)
5. Man Power Allocation Procedure(M.A.P)
6. Critical Operating Production Allocation Control(C.O.P.A.C)

All of these techniques based on a similar Net-work Analysis Principle. After doing slight changes and according to their different names they vary for different projects.

PERT/CPM techniques are used to do optimization of the time and cost of a project**.** By analyzing all these existing techniques, it is found that the primary objective is to deliver the project on time, effort distribution, managing human and technical difficulties. Each technique is designed on a particular principle to meet the end user requirements and to manage the projects.

# HISTORY

*CPM (Critical Path Method)*was the discovery of M.R. Walker of E.I. Du Pont de Nemours & Co. and J.E. Kelly of Remington Rand, circa 1957. The computation was designed for the UNIVAC-I computer. The first test was made in 1958, when CPM was applied to the construction of a new chemical plant. In March 1959, the method was applied to maintenance shut-down at the Du Pont works in Louisville, Kentucky. Unproductive time was reduced from 125 to 93 hours.

*PERT (Project Evaluation and Review Technique)*was devised in 1958 for the POLARIS missile program by the Program Evaluation Branch of the Special Projects office of the U.S. Navy, helped by the Lockheed Missile Systems division and the Consultant firm of Booz-Allen & Hamilton. The calculations were so arranged so that they could be carried out on the IBM Naval Ordinance Research Computer (NORC) at Dahlgren, Virginia.

# CRITICAL PATH METHOD or C.P.M.

## Definition

Consider all the paths in a project, beginning with the start event and stopping at the end event. For each path, calculate the time of execution, by adding the time for the individual activities in that path.

The path with the largest time is called the critical path and the activities along this path are called the critical activities or bottleneck activities.

The activities are called critical because they cannot be delayed. However, a non-critical activity may be delayed to a certain extent. Any delay in a critical activity will delay the completion of the whole project. However, a certain permissible delay in a non –critical activity will not delay the completion of the whole project. It shall be noted that delay in a non-critical activity beyond a limit would certainly delay the completion the whole project. Sometimes, there may be several critical paths for a project. A project manager shall pay special attention to critical activities.

## Major components of CPM

### Activity or Operation

Every project can be fragmented in small segments when they all sum up together forms completeproject and these segments termed as *activity or operation***.**

In how many parts a project can be broken depends on

* What is the aim of project?
* Extent of control.

3

* On complexness of counting of activities.

*Types of operations:-*

*a) Pre operation*

*b) Post operation*

*c) Concurrent operation*: **-** they are independent in nature they don’t have any pre or post operations therefore; they can take place concurrently with other operations.

Generally operations are represented by the help of circles and character or integer written in it represents it.

Excavation of foundation

Filling of foundation

Line

Excavation of foundation

Filling of foundation

Arrow

Fig. 1 Line and arrow representation

Arrow

### Line or Arrow

For the representation of sequence line and arrow used in CPM, Arrow usage is more popular than that of line because it differentiates post and pre operations.

### Critical Path

Critical an operation which takes maximum time to occur are setted in a particular sequence by ignoring other small operations to get the total manufacturing time of project is known as critical path. It is represented by a bold line in the net-work of operations.

### Network

All operations in a sequential order from initial operation to final operation are known as network. After making a network in a rough manner we can get the critical path by choosing most time consuming operations in a sequence that is critical path. Network formation depends on the principle of activity on node

### Various Time Estimates

1. Earliest start time or ES
2. Earliest finish time or EF
3. Latest start time or LS
4. Latest finish time or LF

For last operation LS = LF = calculated time = project time

LF of any operation = minimum LS of post operations

LS of any operation = LF of that operation - time taken to complete that operation

For determining ES and EF we need to move from first activity to last activity. However, for LS and LF we need to move from last to first.

*Check of time estimates*

ES and EF should be equal for first operation as well as for last when we move in forward direction and same should goes for LS and LF when we move from last operation to first operation.

* *Total float or TF*

TF of a operation = LS-ES

* *Free float or FF*

FF of a operation = EF of operation - minimum ES of post operation

* *Independent float or IF*

IF of operation = LS of operation – ES of post operation

* *Interfering float*

It is the negative difference of TF and FF.

# PROGRAM EVALUATION AND REVIEW TECHNIQUE OR P.E.R.T.

## Definition

*Programme Evaluation and Review Technique (PERT)* is a tool that would help a project manager in project planning and control. It would enable him in continuously monitoring a project and taking corrective measures wherever necessary. This technique involves statistical methods.

Note that in CPM, the assumption is that precise time estimate is available for each activity in a project. However, one finds most of the times that this is not practically possible.

In PERT, we assume that it is not possible to have precise time estimate for each activity and instead, probabilistic estimates of time alone are possible. A multiple time estimate approach is followed here.

## Major components of PERT

### Activity – Event network:-

Which curve or network used to represent the critical path is known as activity event network.

### Events

7

Nodes are also called events which represents starting and ending of an operation. Like for excavation of foundation there are two types of events for excavation of foundation that is, ‘initiation of excavation’ and ‘completion of excavation’.

In events there is no consumption of resources and time but they represent important points of a project in this technique operation also represented by circle

*Types of events*

1. *Predecessor event*
2. *Successor event*
3. *Concurrent event:* - those events which occur simultaneously are known as concurrent event.

*Fig.* 2 Events representation

Excavation initiation

Excavation finalization

Foundation filling initiation

Foundation filling finalization

Foundation excavation

Foundation filling

### Activity

In PERT technique activities are represented by the help of arrows and their average time is denoted above them. Sometimes we have to introduce some *Dummy Activities*for the balancing of network only. They are represented by the help of dotted lines in network diagram.

### Average Time

Consumption of time for the completion of an operation is known as Average Time. Mathematically it is represented as,

Average Time, te = (To+4Ti+Tp)/6

Here To = Optimistic time (this is the time in which we finishes our job faster than normal time)

Ti = Most likely time (normal time for completing any operation)

And Tp = pessimistic time (this time is more than that of normal time)

8

T0, Ti and Tp are the calculated imaginary times which we takes to complete our project including work offs.

### Estimation of various times

* *Earliest expected time or TE*
* *Latest allowable or TL*
* *Slack: -*

for any event slack is difference between Tl and Te, it is represented by‘s’ and it can be negative positive or zero.

# DIFFERENCES BETWEEN C.P.M. AND P.E.R.T.

Looping

Fig. 4 Looping error in a network drawing

TABLE 1

C.P.M AND P.E.R.T DIFFERENCES

|  |  |  |
| --- | --- | --- |
| *S.NO.* | *C.P.M.* | *P.E.R.T.* |
| 1 | It is based on activities. | It is based on events. |
| 2 | In C.P.M. circles denotes operations and arrow denotes their sequence. | In P.E.R.T. circles denotes events and arrow denotes activities and their sequence. |
| 3 | Dummy activities are not required here. | Dummy activities are required here for network balancing. |
| 4 | Only one time required for an activity. | More than one time i.e., three required here TO, TL, TP due to occurrence of uncertainties. |
| 5 | In C.P.M. critical activities segregated. | No segregation required. |
| 6 | It is useful in installation, plant maintenance, and construction. | It is useful basically in development and scheduling projects. |

# COMMON ERRORS IN DRAWING NETWORKS

The three types of errors are most commonly observed in drawing network diagrams:

## Dangling

To disconnect an activity before the completion of all activities in a network diagram is known as dangling. As shown in the figure activities (5 – 10) and (6 – 7) are not the last activities in the network. So the diagram is wrong and indicates the error of dangling.

Dangling

Dangling

Fig. 3 Dangling occurrence in a network diagram

## Looping or Cycling

Looping error is also known as cycling error in a network diagram. Drawing an endless loop in a network is known as error of looping as shown in the following figure.

## Redundancy

Unnecessarily inserting the dummy activity in network logic is known as the error of redundancy as shown in the following diagram

Redundancy

Fig. 5 Redundancy in a network drawing

# ANALYSIS AND CONTROL OF COST IN PROJECT

As known by the usage of PERT certain objectives are best achieved and cost and time are also minimum for achieving this whole project target management has to consider these points:

* What we need to do?
* Essential scheduling time.
* Estimated cost

Along with executing the program for controlling time and cost we need to these activities also:

* Preparation of budget as per definite time for project scheduling.
* Estimation of the boon or decrease in cost due to increasing or decreasing time.
* Assessment of optimum cost.
* Graphical representation of time and cost.
* Reviewing progress of time and cost.

## Cost

Costs incurred for completing a project are basically of two types but some others also included in a project those are written as follows:

### Direct Cost

When completion of a project done before estimated time then that cost which incurred in it is known as *direct cost.*

### Indirect Cost

Each and every type of overheads expenses comes under *indirect cost.* These expenses includes interest on capital, equipment rental, supervision expenditure, cost of inventory, etc. in order to reduce time of action indirect cost spend.

### Total Cost

This is the total of both direct and indirect cost.

Total Cost = Direct Cost + Indirect Cost

Y1

Y

Total Cost

Indirect Cost

Direct Cost

**Activity Time**

**Activity Cost**

Fig. 6 Graph representing Total Cost, Indirect cost and Direct cost

In above figure all three costs are represented on the graph. Project/work duration represented on abscissa and cost represented on ordinate and at the intersection of the curves, total cost Y1 = 2Y because for this time direct and indirect costs both are equal. From graph we can see that for decreasing time of project, direct cost boons and indirect cost decreases. Hence, total cost also decreases. Minimizing time from estimated time is known as *crash* process. It is clear from the graph that at a certain point even if we decrease time but there would be no decrement in the total cost rather it starts increasing then it doesn’t matter how many additional resources we would use further. This cost is known as *Crash Cost* and denoted by ‘CC’.

### Crash Duration

It is that minimum cost of an activity after which it is not possible to diminish it rather how many addition resources we would take in consideration.

### Crash Cost

This is the minimum cost used on crash time. In below diagram we have plotted a graph between direct cost and duration to represent relation in between them,

CC = Crash cost

CN = Normal cost

dN  = Nornmal duration

dC = Crash duration

Fig. 7 Relation between direct cost and duration

**Duration**

**Direct Cost**

CC

CN

dN

dC

Cost Slope = (CC - CN) / (dN - dC)

# PROBLEM ANALYSIS BASED ON COST CONTROL IN A PROJECT SCHEDULING

Q. Find critical path for the following production project described as in table below, and Find the duration of the project and the cost of the project, if the duration is reduced to 22 days.

TABLE 2

PROJECT VARIOUS ACTIVITIES COSTS

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Activities* | *Normal time Days* | *Crash time Days* | *Normal Cost (in Rs.)* | *Crash Cost (in Rs.)* | *Cost Slope (in Rs.)*  0  5  10  15  25  30  20  10(3)  19(8)))  19(4)  10(2)  10(6)  19(8)  9(5)  9(2)  10(2)  19(4)  7(10)  17(6)  5(1)  10(2)  15(0)  *(a)*  *(b)*  *(c)*  Fig. 9 Square network diagram for critical paths |
| *1-2* | 10 | 7 | 400 | 640 | 80 |
| *1-3* | 19 | 11 | 600 | 1160 | 70 |
| *2-3* | 10 | 8 | 500 | 600 | 50 |
| *2-4* | 19 | 15 | 700 | 1000 | 75 |
| *3-4* | 10 | 4 | 300 | 810 | 85 |
|  |  |  | *2500* | *4210* |  |

Answer:-

S = 0

TL = 10

TE = 10

S = 0

TL = 20

TE = 20

S = 0

TL = 30

TE = 30

19

S = 0

TL = 0

TE = 0

10

10

s

Fig. 8 Network diagram for our project

Therefore we can see that from above network diagram that Critical path for this project is 1-2-3-4 which required 30 Days for completion.

And activities for this critical path have cost slope as follows

TABLE 3

CRASH COST OF CRITICAL PATHS

|  |  |
| --- | --- |
| Critical Path Activities | Cost Slope (in Rs.) |
| 1-2 | 80 |
| 2-3 | 50 |
| 3-4 | 85 |

For Critical activities we had made a square network diagram according to Fig. 9 *(a)* part as follows

From the observation of moving gradient we got to know that on the critical path activity 2-3 have minimum gradient of Rs.50.

From diagram it also got cleared that for crashing activity 2-3 we need to crash one of the preceding 1-3 or succeeding 2-4 activity respectively. For crashing both of these the cost would be more than that of cost required to crash activity 1-2, and crash cost of 1-2 is also greater than that of 2-3.

Therefore,

Cost of crashing Activity 1-2 for one day = Rs.80

Hence 29 days crash cost will be,

= Total Normal Cost + 1day Crash Cost

= Rs. 2500+80 = Rs. 2580

Now it would be frugal to crash activity 3-4 because its cost gradient is more than that of 1-2 activity.

Therefore,

Cost of crashing Activity 3-4 for one day = Rs.15

Hence 28 days crash cost will be,

= 29 days Crash Cost + 1 day Crash Cost

= Rs. 2580+85 = Rs. 2665

Now again making network Fig. 9 *(b)* part for 28 days we got clear that for crashing critical path we need to crash here more than one activity simultaneously for more than one day. For further crashing possible ways are as follows:

## 1. Total cost to crash both 1-2 and 1-3 activities simultaneously for one day is,

= Rs. 80+70 = Rs. 150

## 2. Total cost to crash 1-3, 2-3 and 2-4 activities simultaneously for one day is,

= Rs. 70+50+75 = Rs. 195

3. Total cost to crash both 2-4 and 3-4 activities simultaneously for one day is,

= Rs. 75+85 = Rs. 160

In all of them (1) is the most frugal in all that’s why activities 1-2 and 1-3 can be crashed for two days.

Total cost to crash both 1-2 and 1-3 activities simultaneously for 2 days is,

=2\*150 = Rs. 300

Hence, crash cost for 26 days

= 28 days crash cost + crash cost of 2 days

= Rs. 2665+300 = Rs. 2965

Now, since, activity 1-2 can’t be crashed any more so, activities 1-2 and 1-3 can’t be crashed more, even simultaneously we can’t. Therefore, next crashing can be further done of activities 3-4 and 2-4 only for 4 days not more than that and their crash cost would be nearest more than that of activities 1-2 and 1-3 simultaneously.

Therefore, crash cost of activities 3-4 and 2-4 for 4 days simultaneously will be,

=4\*160=Rs. 640

Thus,

*Crash Cost for 22 days* will be,

= 26 days Crash Cost + 4 days Crash Cost

= Rs. 2965+640

= *Rs. 3605*

Now if we want to crash further more then we can’t do anything and for this project we don’t need any further crashing because project time can be minimized up to 22 days only.

# CONCLUSION

The PERT/CPM technique as part an information system transforms data on individual activities into information about the project as a whole.

Identification of the critical path, slack time of activities and potential trouble spots exist in the system are the most important information for management a project using this technique.

PERT/CPM is a valuable technique for projects planning and control, but not a substitute for a judgment, with attention to organizational and behavioral implications.

PERT/CPM helps manager to focus attention on the most significant decisions, and to identify the implication of a decision.

In this study, attention should be paid to the fact that the final cost of project

This change in the duration of the project represents a reduction of project conclusion time, with an increase in the total cost of the project.

The results show that the PERT/CPM technique can bring a great contribution to the optimization of the times and costs of project of the production process and that applied to other Industry projects, can lead to reduced costs and even increase the amount of projects undertaken, and consequently lead to an increase in its competitiveness.

# REFRENCES

[1] S.T.Marpaung, C.N.Rosyidi, and W.A. Jauhari, “Manufacturing planning in an engineer – to order company using CPM and PERT” AIP Conference Proceedings, Published Online: 23 April 2019, <https://doi.org/10.1063/1.5098233>

[2] G.Ramesh, G.Sudha, and K.Ganesan,” A study on interval PERT/CPM network Problems”, AIP Conference Proceedings, Published Online: 24 June 2019, <https://doi.org/10.1063/1.5112308>

[3] *Fernando Henrique Lermen, Márcia de Fátima Morais,and Camila Matos,”*Optimization of times and costs of the project of horizontal laminator production using PERT/CPM technical*”, Independent journal of management and production (IJM&P),* v. 7, n. 3, July - September 2016, *DOI: 10.14807/ijmp.v7i3.423*

[4] Zachary A.Collier, Daniel Hendrickson; Thomas L.Polmateer and James H.Lambert, F.ASCE,” Scenario Analysis and PERT/CPM applied to strategic investment at an automated container port”, ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng., 06/15/18, DOI: 10.1061/AJRUA6.0000976

[5] Amit Adate, Arpan Goel, Sundaramali G,”Anlyis of project planning using CPM and PERT”, *IJCSMC, Vol. 6,* Available Online at [www.ijcsmc.com](http://www.ijcsmc.com) *, pg.24 – 25, Issue. 10, October 2017*

[6] Salih O. Duffuaa, A. Raouf, Planning and control of maintenance systems modeling and analysis 2nd ed., Springer International Publishing Switzerland, *pg.223 – 226,* 2015

[7] Mete MAZLUMa , Ali Fuat GÜNERİb,” CPM, PERT and project management with Fuzzy logic technique and implementation on a business”, 4th International Conference on Leadership, Technology, Innovation and Business Management, ,pg. 348 – 357, <http://creativecommons.org/licenses/by-nc-nd/4.0/>, 2015

[8] Lucia Knapčíková, Michal Balog,” Industry 4.0: Trends in management of intelligent

manufacturing systems”, Springer Nature Switzerland AG,pg. 76- 84, 2019

[9] Dr Pratibha Pant,”

PERT and CPM Techniques: A Brief Review”,

*IJSRD - International journal for Scientific Research & Development| Vol. 5, Issue 05, 2017*

[10] Adebowale, and Oluboyede, Network analysis and building construction: Implications for timing and costing of activities, Journal of Civil Engineering and Construction Technology, vol. 2(5), pp. 90-100, 2011

[11] AJIBOYE Sule Adegoke,” Measuring Process Effectiveness Using Cpm/Pert”, International Journal of Business and Management Vol. 6, No. 6; June 2011, doi:10.5539/ijbm.v6n6p286

[12]Bradley J. Best, Jeremy R.T. Lewis,” Management: Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM)”, Encyclopedia of Public Administration and Public Policy, Third Edition Copyright © by Taylor & Francis., 2015,DOI: 10.1081/E-EPAP3-120010811,pg.2072-2077