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ABSTRACT

This is a workbook containing problems in PERT (program evaluation review technique). It is intended to be used in a workshop or classroom to train management personnel in the basic methodology and capability of PERT. This material is not adequate in depth to create an expert in these techniques, but it is felt that the material is adequate to provide a working understanding of the methodology as a management tool. It is assumed that this workbook is used under the guidance of an experienced instructor. (Author)

A MANAGEMENT SCIENCE SERIES PRESENTATION

PERT AND CPM: WORKSHOP MATERIAL

Burroughs Corporation

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Detroit, Michigan 48232

INTRODUCTION

This is a workbook containing problems in PERT techniques. It is intended to be used in a workshop or classroom to train management personnel in the basic methodology and capability of PERT techniques. This material is not adequate in depth to create an expert in these techniques but it is felt that the material is adequate to provide a working understanding of the methodology as a management tool. It is assumed that this workbook is used under the guidance of an experienced instructor. A computer is not essential in order to utilize this problem material for training purposes. A training course is, however, enhanced if a computer demonstration is integrated with this classroom work.

PREFACE

Management decision making, like invention, is no longer a matter of one's individual effort. Project accomplishment is made through organizations of professional experts in administration, finance, science, engineering and production, to list just a few. The complexity of directing and controlling programs has challenged conventional management techniques for years. In our complex and ever expanding world of science and industry more effective tools are required for planning, analyzing and controlling the development of products.

Courses in PERT (program evaluation review technique) are given regularly. Mountains of literature have been written and published describing its methodology and uses. Undoubtedly, more has been written on the subject of critical path method and PERT-like techniques than on any other scheduling and controlling tool in all of our industrial history. Computer manufacturers have spent hundreds of thousands of dollars developing software to fill the requests of computer hardware users. Our government has poured millions into proving PERT's validity.

One might say, PERT is industry's better mouse trap.

Let us go back in time to what we might call the birth of PERT and see how it has evolved through its use of network and critical path planning.

Work began in January 1957. The basic development was carried on by Messrs. M. E. Walker and J. E. Kelly, Jr., of DuPont and Remington Rand UNIVAC Division respectively.

While this technique was being developed, a parallel development was under way by a program evaluation research task force team at the special projects office of the U. S. Navy's Bureau of Ordinance. This project team was direc-

ted to research and develop improved methods of planning and controlling the far reaching complex programs for developing our nation's fleet ballistic missiles. Improvements in management methods are and have been continually sought. Therefore, this objective was laudable but certainly not new.

Phase 1 report, issued by the special projects office of the Bureau of Naval Weapons, U. S. Navy in July 1958, presented the basic principle and technical parameters of PERT and outlined the proposed installation pattern. While some modifications to the concept have been made since, the basic concept still remains the same, and so, what started out to be a program evaluation research task force became a program evaluation review technique (PERT).

In its basic format the PERT plan of controlling programs is similar in format to any other type of project control technique where a series of tasks are scheduled in a logical sequence, building events and activities up to achievement of a final objective. Generally, this was done through Gantt charting. Product performance is specified and resources are allocated; then, the achievement of each task and the final objective were presented. However, Gantt charting does not depict the dependencies of activities nor does it provide the manipulative capability necessary in analyzing alternatives and planning and controlling complex project programs. Present computer-based network analysis models whether known as PERT or CPM have added power to project management.

Grossly oversimplified, the network planning approach involves:

1. The selection of specific, identifiable events which must occur to successfully conclude a project.

2. The sequence of these events and the establishment of interdependencies of events so that a project network can be developed.

3. The establishment of time required in doing an activity to achieve an event together with a measurement of the uncertainty involved.

4. Design of an analysis or evaluation procedure to process and evaluate data.

5. The establishment of information and communication channels to bring actual achievement data and change data to the evaluation point.

6. The application of electronic data processing equipment to the analysis procedure.

7. The end product to be a periodic summary evaluation for each level of management "need to know" where problems appear and alternate courses of action will be presented for consideration.

The basic concepts of project costs as they are associated with PERT can only be achieved if Time, Resources and Performance, are managed and manipulated within a common framework of work elements.

Let's now look at these variables and define them. Since the duration of any project is dependent on the times to complete the various required activities it is obvious that a range of durations is possible for the project depending on the selected time allowed each job. This selection of time also incorporates a selection of costs. The range of project duration and costs may be plotted graphically. The starting point of the curve is found by taking the normal time and cost for each job; any shorter duration time for an activity will result in a higher cost due to premium payments for some or all of the operations necessary in allowing for early completion. Of course, this can only be done after the initial planning stages have been completed and the project has been optimized to remove slack time wherever possible. In any project there are hundreds of possibility combinations for time and cost durations. Through the use of a computer we can examine these ranges and the best duration can be selected.

The basic information generated in a PERT/COST system can be summarized in several ways for program management reporting. The format detail in which this information is presented will vary depending upon the planning and control requirements of different levels of management. Essentially, the reports provide managers with the following information in varying degrees of detail:

1. The current project activity plan, time schedule and project duration

2. Time and cost performance to date with relation to the plan

3. Time and cost projections of the project objectives.

Identification of the project objectives is the first step in the PERT/Cost process. These objectives should be specified in terms of the end item that is deliverable. The subsequent division of each of these items into its component parts creates a project work breakdown structure which then serves as the framework for planning and controlling the project. To be most effective a PERT/Cost installation should begin in the planning phase of a project at the time the request for proposal is made. The project work breakdown structure also serves as the basis for construction of the planning network. The configuration and content of the work breakdown structure and its specific work packages will vary from project to project and will depend on the following considerations:

1. The size and complexity of the project
2. The structure of the organization
3. Method for handling the work
4. The specific amount of detail desired

The work package formed at the lowest level of breakdown then constitutes the basic units in the PERT/Cost system by which actual costs are obtained and compared with estimates for purposes of cost control.

In summary, the work breakdown structure represents the following subdivisions of work:

1. Project end items
2. End items subdivision
3. The work packages
4. Activities.

The end item approach to planning and control ensures that the total project is fully planned and that all derivative plans contribute directly to the desired objective. The level of detail to which it is desirable to apply PERT/Cost is largely a matter of judgment. For this reason it is unrealistic to specify a predetermined level of detail.

Time and/or Cost overruns are a basic concern to all of industry. The PERT system attempts to provide a reasonable degree of pertinent project information which will serve as a planning and control vehicle, enabling efforts to be guided more economically, purposefully and expeditiously then in the past.

1A. PROJECT: Paint House

ACTIVITIES: Buy Paint
Mix Paint
Paint House
Paint Trim
Clean Brushes

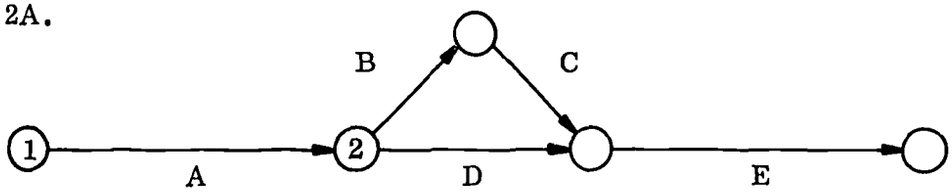
1B. PROJECT: Lay Pipe

ACTIVITIES: Dig Trench
Lay Pipe
Backfill

1C. PROJECT: Lay Pipe

ACTIVITIES: Start Trench
Finish Trench
Start Laying Pipe
Finish Laying Pipe
Start Backfill
Finish Backfill

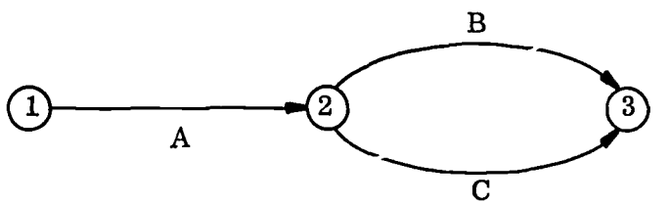
2A.



ACTIVITIES

A 1.2
B _____
C _____
D _____
E _____

2B.



ACTIVITIES

A _____
B _____
C _____

2C.

ACTIVITIES

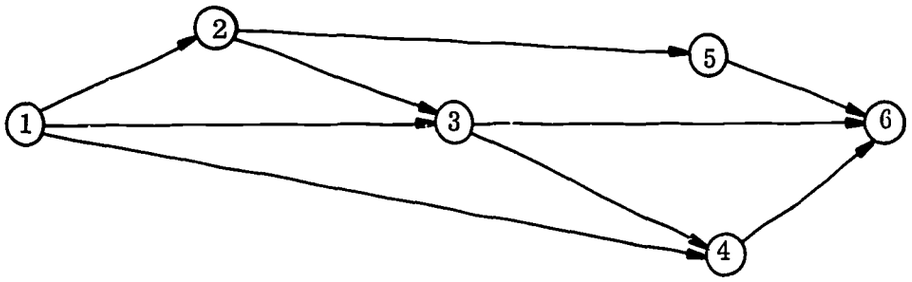
3A. ACTIVITIES: Plaster
Install Plumbing
Obtain Plumbing Fixtures
Erect Shell

3B. PROJECT: Build House

ACTIVITIES: Lay Foundation
Install Plumbing
Obtain Bricks and Lumber
Erect Shell
Acquire Lot
Obtain Concrete Blocks
Sign Closing Papers
Paint Interior
Obtain Plumbing Fixtures
Plaster
Excavate
Paint Exterior

4. Calculation of Expected Time (t_e), Earliest Expected Time (T_E), Latest Allowable Time (T_L) and Slack.

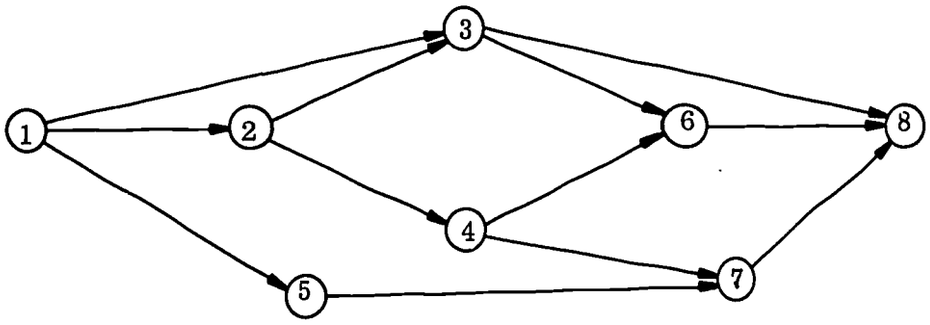
Activity From	To	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time (t_e)
1	2	1	2	3	———
1	3	2	2	4	———
2	3	2	4	6	———
3	4	1	3	8	———
1	4	3	4	6	———
2	5	2	4	8	———
3	6	1	3	7	———
4	6	2	4	9	———
5	6	1	1	2	———



Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack
1	———	———	———
2	———	———	———
3	———	———	———
4	———	———	———
5	———	———	———
6	———	———	———

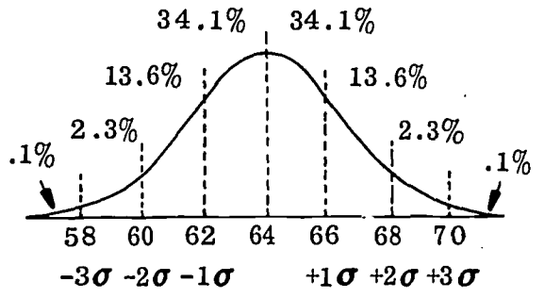
5. PROBLEM: Compute (1) t_e; (2) T_E; (3) T_L; (4) Slack

Activity From	Activity To	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time (t_e)
1	2	8	9	16	_____
1	3	15	20	25	_____
2	3	8	13	15	_____
2	4	5	6	7	_____
1	5	3	6	6	_____
3	6	8	8	8	_____
4	6	3	8	10	_____
4	7	1	5	6	_____
5	7	11	11	14	_____
3	8	4	6	8	_____
6	8	3	4	14	_____
7	8	1	9	14	_____



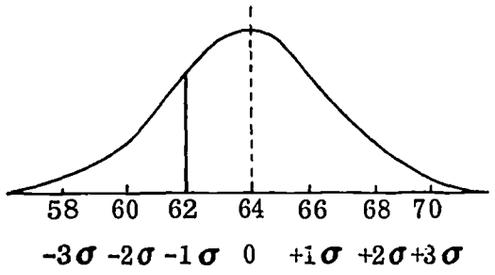
Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack
1	_____	_____	_____
2	_____	_____	_____
3	_____	_____	_____
4	_____	_____	_____
5	_____	_____	_____
6	_____	_____	_____
7	_____	_____	_____
8	_____	_____	_____

6A. Use of Normal Distribution to Estimate Probability of a Given Occurrence.



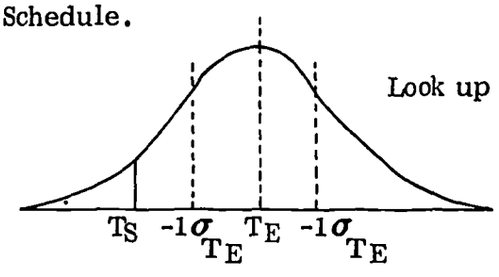
Expected Value

Assume: Heights of American females are normally distributed. Average height is 5' 4" or 64 inches. Variance in heights is 4 inches.



What percentage of females are less than 5' 2" tall?____%
What percentage are more than 5' 8" tall?____%
What height do 84 % of females exceed?

6B. Use of Normal Distribution to Estimate Probability of Meeting Schedule.



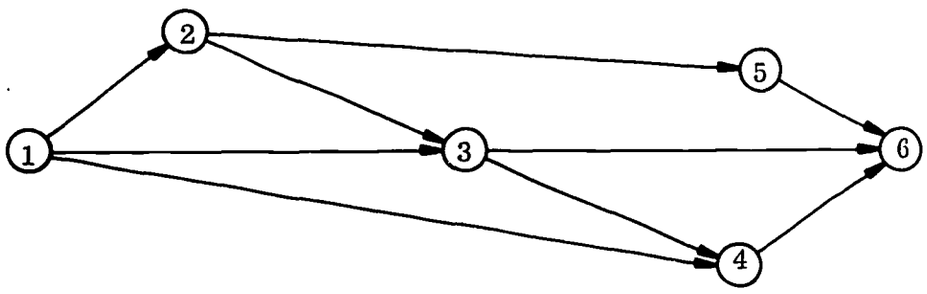
Look up $\frac{T_S - T_E}{\sigma_{T_E}}$ in table.

7. Table of Values of the Standard Normal Distribution Function

$\frac{T_S - T_E}{\sigma T_E}$	Probability	$\frac{T_S - T_E}{\sigma T_E}$	Probability
-3.0	.1 %	.1	54.0 %
-2.9	.2 %	.2	57.9 %
-2.8	.3 %	.3	61.8 %
-2.7	.4 %	.4	65.5 %
-2.6	.5 %	.5	69.2 %
-2.5	.6 %	.6	72.6 %
-2.4	.8 %	.7	75.8 %
-2.3	1.1 %	.8	78.8 %
-2.2	1.4 %	.9	81.6 %
-2.1	1.8 %	1.0	84.1 %
-2.0	2.3 %	1.1	86.4 %
-1.9	2.9 %	1.2	88.5 %
-1.8	3.6 %	1.3	90.3 %
-1.7	4.5 %	1.4	91.9 %
-1.6	5.5 %	1.5	93.3 %
-1.5	6.7 %	1.6	94.5 %
-1.4	8.1 %	1.7	95.5 %
-1.3	9.7 %	1.8	96.4 %
-1.2	11.5 %	1.9	97.1 %
-1.1	13.6 %	2.0	97.7 %
-1.0	15.9 %	2.1	98.2 %
- .9	18.4 %	2.2	98.6 %
- .8	21.2 %	2.3	98.9 %
- .7	24.2 %	2.4	99.2 %
- .6	27.4 %	2.5	99.4 %
- .5	30.9 %	2.6	99.5 %
- .4	34.5 %	2.7	99.6 %
- .3	38.2 %	2.8	99.7 %
- .2	42.1 %	2.9	99.8 %
- .1	46.0 %	3.0	99.9 %
.0	50.0 %		

8. Calculation of Variance (σ^2) and Probability

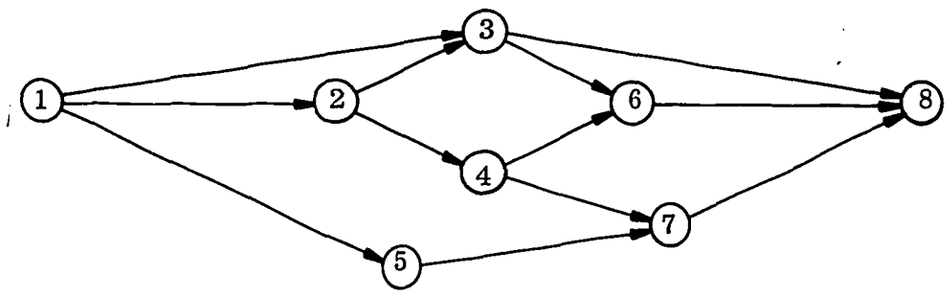
Activity From	To	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time (t_e)	Variance (σ^2)
1	2	1	2	3	_____	_____
1	3	2	2	4	_____	_____
2	3	2	4	6	_____	_____
3	4	1	3	8	_____	_____
1	4	3	4	6	_____	_____
2	5	2	4	8	_____	_____
3	6	1	3	7	_____	_____
4	6	2	4	9	_____	_____
5	6	1	1	2	_____	_____



Event	Earliest Expected Time (T_E)	Variance (σ^2)	Scheduled Time	Probability
1	_____	_____		
2	_____	_____		
3	_____	_____	7	____%
4	_____	_____		
5	_____	_____		
6	_____	_____	13	____%

9. PROBLEM: Compute (1) σ^2; (2) Probability

Activity From	To	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time (t_e)	Variance (σ^2)
1	2	8	9	16	____	____
1	3	15	20	25	____	____
2	3	8	13	15	____	____
2	4	5	6	7	____	____
1	5	3	6	6	____	____
3	6	8	8	8	____	____
4	6	3	8	10	____	____
4	7	1	5	6	____	____
5	7	11	11	14	____	____
3	8	4	6	8	____	____
6	8	3	4	14	____	____
7	8	1	9	14	____	____



Event	Earliest Expected Time (T_E)	Variance (σ^2)	Scheduled Time	Probability
1	____	____		
2	____	____	24	____%
3	____	____		
4	____	____		
5	____	____		
6	____	____	30	____%
7	____	____		
8	____	____	35	____%

10. Calculation of PERT Output without Network Diagram.

A. Sort activities into topological sequence.
B. To compute Earliest Expected Times:
   1. Enter 0 as T_E for first event(s).
   2. Take activities one by one in forward sequence.
   3. Add t_e for an activity to T_E for its beginning event. If the result is greater than the T_E for its ending event, enter it as the T_E for its ending event.
C. To compute Latest Allowable Times:
   1. Enter T_E (or T_D, if there is one) as T_L for last event(s).
   2. Take activities one by one in backward sequence.
   3. Subtract t_e for an activity from T_L for its ending event. If the result is less than the T_L for its beginning event, enter it as the T_L for its beginning event.

Activity From	To	Expected Time (t_e)	Activity From	To	Expected Time (t_e)
7	8	8.5	—	—	———
4	6	7.5	—	—	———
1	3	20.0	—	—	———
4	7	4.5	—	—	———
1	2	10.0	—	—	———
1	5	5.5	—	—	———
5	7	11.5	—	—	———
3	8	6.0	—	—	———
3	6	8.0	—	—	———
2	3	12.5	—	—	———
6	8	5.5	—	—	———
2	4	6.0	—	—	———

Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack
1	———	———	———
2	———	———	———
3	———	———	———
4	———	———	———
5	———	———	———
6	———	———	———
7	———	———	———
8	———	———	———

11. PROBLEM: Given standard PERT input, produce standard PERT output report.

STANDARD PERT INPUT					INTERMEDIATE CALCULATIONS	
Activity From	To	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time (t_e)	Variance (σ^2)
1	2	2.0	4.0	9.0	_____	_____
1	3	3.0	7.0	8.0	_____	_____
1	4	3.0	6.0	9.0	_____	_____
2	4	5.0	5.0	5.0	_____	_____
3	4	2.0	3.0	10.0	_____	_____
2	5	6.0	8.0	10.0	_____	_____
4	5	10.0	12.0	20.0	_____	_____
3	6	1.0	9.0	17.0	_____	_____
4	6	1.0	4.0	10.0	_____	_____
5	6	5.0	6.0	7.0	_____	_____
3	7	4.0	7.0	7.0	_____	_____
5	7	6.0	15.0	18.0	_____	_____
6	7	1.0	5.0	12.0	_____	_____

Directed Delivery Time (T_D) for Project = 39.0
Scheduled Time (T_S) = 39.0 for Event 7 and 10.0 for Event 4

STANDARD PERT OUTPUT

Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack	Scheduled Time	Variance (σ^2)	Probability
1	_____	_____	____		_____	
2	_____	_____	____		_____	
3	_____	_____	____		_____	
4	_____	_____	____	_____	_____	_____%
5	_____	_____	____		_____	
6	_____	_____	____		_____	
7	_____	_____	____	_____	_____	_____%

12. Calculation of CPM Activity-Oriented Output.

A. Earliest Start for an activity is equal to the T_E of its beginning event.
B. Latest Finish for an activity is equal to the T_L of its ending event.
C. Earliest Finish for an activity is equal to its Earliest Start plus its Expected Duration.
D. Latest Start for an activity is equal to its Latest Finish minus its Expected Duration.
E. Float for an activity is equal to its Latest Start minus its Earliest Start (or Latest Finish minus Earliest Finish).

PERT COMPUTATIONS

Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack
1	0.0	0.0	0.0 *
2	2.0	2.0	0.0 *
3	6.0	6.0	0.0 *
4	9.5	9.5	0.0 *
5	6.3	7.7	1.4
6	14.0	14.0	0.0 *

CPM COMPUTATIONS

Activity From	To	Expected Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Float
1	2	2.0					
1	3	2.3					
2	3	4.0					
3	4	3.5					
1	4	4.2					
2	5	4.3					
3	6	3.3					
4	6	4.5					
5	6	1.2					

13. PROBLEM: Given PERT event times, produce standard CPM activity-oriented output report.

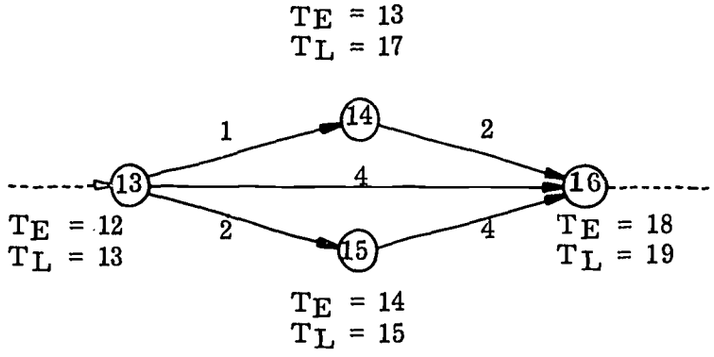
PERT COMPUTATIONS

Event	Earliest Expected Time (T_E)	Latest Allowable Time (T_L)	Slack
1	0.0	0.0	0.0 *
2	10.0	10.0	0.0 *
3	22.5	22.5	0.0 *
4	16.0	23.0	7.0
5	5.5	16.0	10.5
6	30.5	30.5	0.0 *
7	20.5	27.5	7.0
8	36.0	36.0	0.0 *

STANDARD CPM OUTPUT REPORT

Activity From	To	Expected Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Float
1	2	10.0					
1	3	20.0					
2	3	12.5					
2	4	6.0					
1	5	5.5					
3	6	8.0					
4	6	7.5					
4	7	4.5					
5	7	11.5					
3	8	6.0					
6	8	5.5					
7	8	8.5					

14. Types of Activity Float and Their Significance in Scheduling.



Total Float: The maximum time that is available to do a job, mimus its expected duration.

Activity From	To	Total Float
13	14	____
14	16	____
13	16	____
13	15	____
15	16	____

Free Float: The float available to an activity if all activities are started as early as possible.

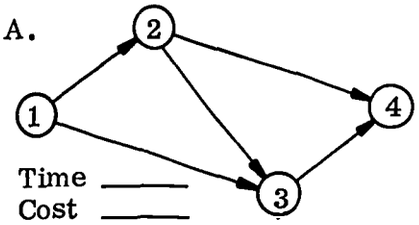
Activity From	To	Free Float
13	14	____
14	16	____
13	16	____
13	15	____
15	16	____

Independent Float: The float available to an activity if all preceding activities are started as late as possible and all succeeding activities are started as early as possible.

15. Examination of the Tradeoff Between Time and Cost Considerations in Planning a Project.

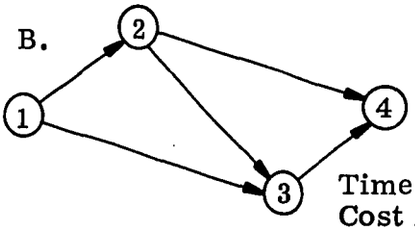
Activity From	To	Normal Time	Normal Cost	Crash Time	Crash Cost	Incremental Cost per Week
1	2	3	$ 500	2	$1000	_____
1	3	7	$ 800	4	$2600	_____
2	3	5	$1000	4	$1400	_____
2	4	8	$ 850	6	$1450	_____
3	4	4	$1000	2	$2400	_____

A.



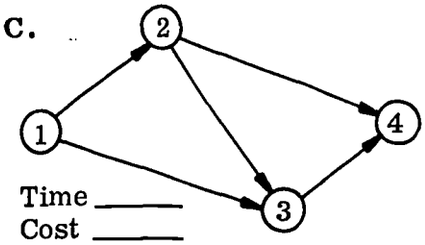
Time _____
Cost _____

B.



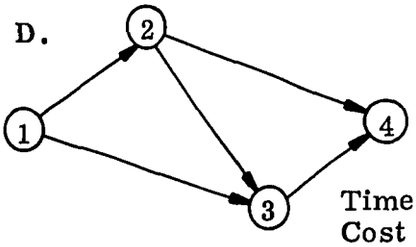
Time _____
Cost _____

C.



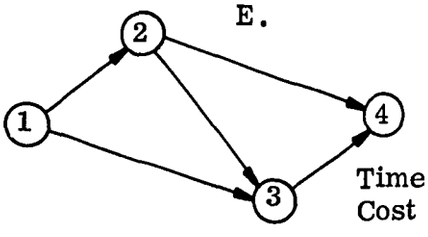
Time _____
Cost _____

D.



Time _____
Cost _____

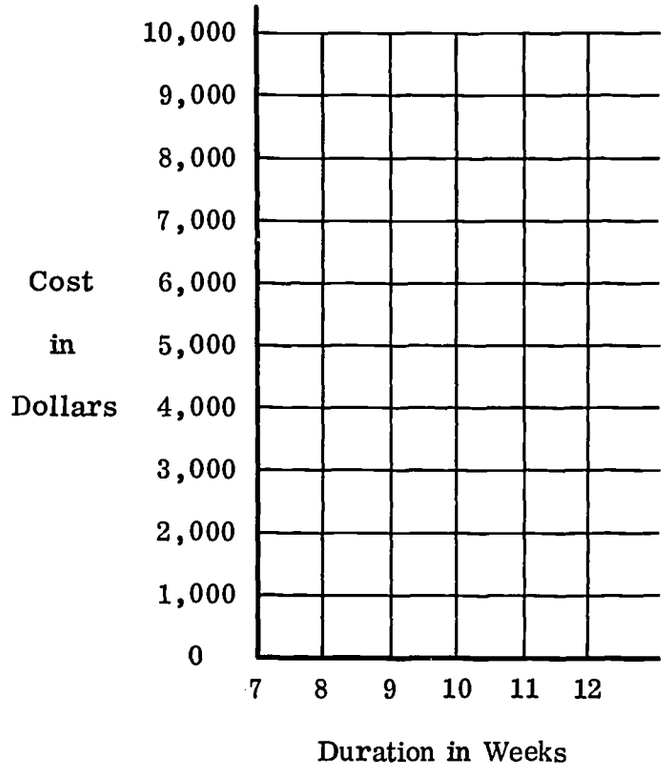
E.



Time _____
Cost _____

16. Examination of the Tradeoff Between Time and Cost Considerations in Planning a Project.

Project Duration	Direct Costs	Indirect Costs	Total Cost
8	_____	$1100	_____
9	_____	$1400	_____
10	_____	$1850	_____
11	_____	$2750	_____
12	_____	$3850	_____



17A. Projected Requirements for a Given Resource for Activities in a Project.

Activity	Time Data From Network			Requirements for Resource XX by Month				
	t_s	Early Start	Late Start	1	2	3	4	5
1 - 2	2	0	0	8	8			
1 - 3	2	0	4	2	1			
2 - 3	4	2	2	2	3	4	4	
1 - 4	4	0	5	1	2	3	2	
3 - 4	3	6	6	6	6	2		
2 - 5	4	2	8	1	2	3	3	
3 - 6	3	6	11	1	2	1		
4 - 6	5	9	9	2	1	3	3	2
5 - 6	2	6	12	4	5			

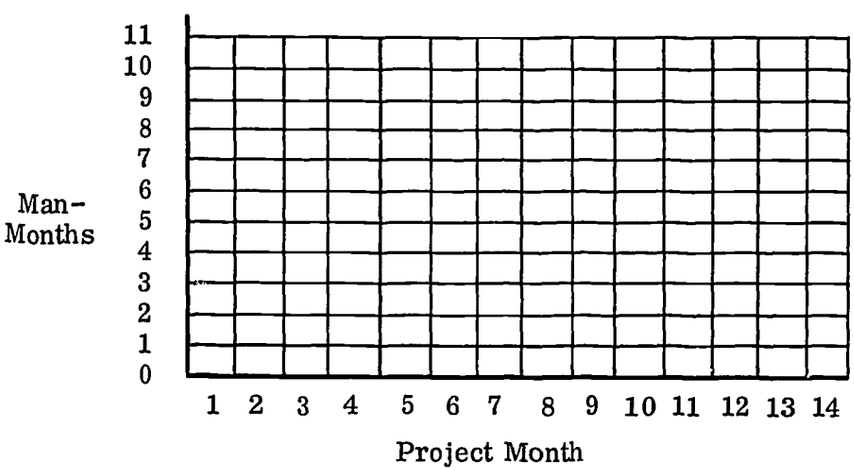
17B. Projected Financial Requirements for Activities in a Project.

Activity	Time Data		Financial Requirements by Month ($000)					Total
	t_s	Sched. Begin	1	2	3	4	5	
1 - 2	2		9	9				18
1 - 3	2		3	2				5
2 - 3	4		2	3	5	3		13
1 - 4	4		2	3	4	2		11
3 - 4	3		9	5	2			16
2 - 5	4		3	1	2	2		8
3 - 6	3		2	2	2			6
4 - 6	5		1	2	1	2	4	10
5 - 6	2		3	4				7

18A. PROBLEM: Compute the projected monthly requirements for Resource XX, assuming that each activity begins on its Earliest Start.

Activity	Early Start	Project Month													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 - 2	0														
1 - 3	0														
2 - 3	2														
1 - 4	0														
3 - 4	6														
2 - 5	2														
3 - 6	6														
4 - 6	9														
5 - 6	6														
Total															

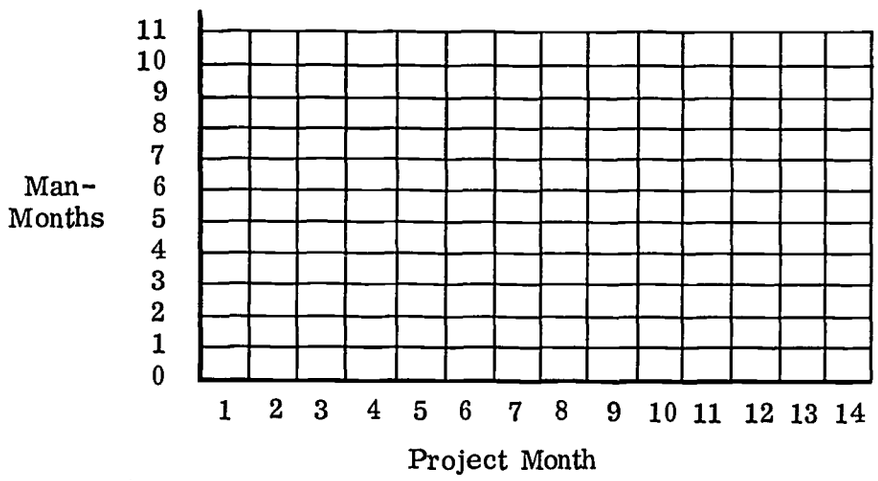
18B. Graphical Presentation of Monthly Requirements for Resource XX.



19A. PROBLEM: Schedule activities in the project so as to level the monthly requirements for Resource XX.

Activity	Sched Start	Project Month													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 - 2															
1 - 3															
2 - 3															
1 - 4															
3 - 4															
2 - 5															
3 - 6															
4 - 6															
5 - 6															
Total															

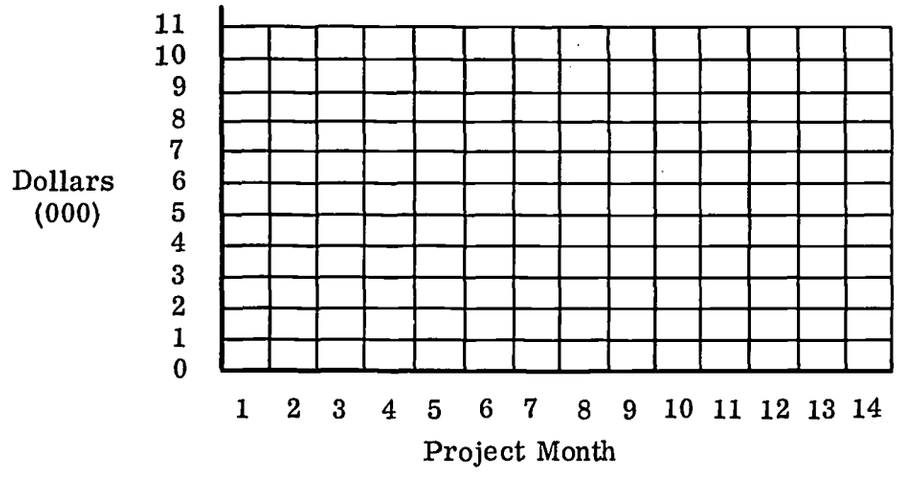
19B. Graphic Presentation of Monthly Requirements for Resource XX.



20A. PROBLEM: Compute the projected financial requirements for the project, using Table 17B and the schedule developed in Table 19A.

Activity	Sched Start	Project Month													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 - 2															
1 - 3															
2 - 3															
1 - 4															
3 - 4															
2 - 5															
3 - 6															
4 - 6															
5 - 6															
Total															
Cumulative Total															

20B. Graphical Presentation of Financial Requirements of Project.



21A. Table showing financial status of activities in the project at the end of the tenth month.

Activity	Actuals Reported by Month										Actual to Date	Latest Estimates						Total to Compl
	1	2	3	4	5	6	7	8	9	10		11	12	13	14	15	16	
1 - 2	7	8	7								22							22
1 - 3				1	2						3							3
2 - 3				3	2	2	5				12							12
1 - 4				2	4	1	4				11							11
3 - 4								7	2	1	10							10
2 - 5										2	2	6	2	3				15
3 - 6												3	3	1	5			12
4 - 6													2	4	3	3	6	18
5 - 6																4	5	9
Total	7	8	7	6	8	3	9	7	2	3	60	9	7	8	8	7	11	110
Cumul. Total	7	15	22	28	36	39	48	55	57	60		69	76	84	92	99	110	

21B. PROBLEM: Produce basic PERT/COST Management Summary Report.

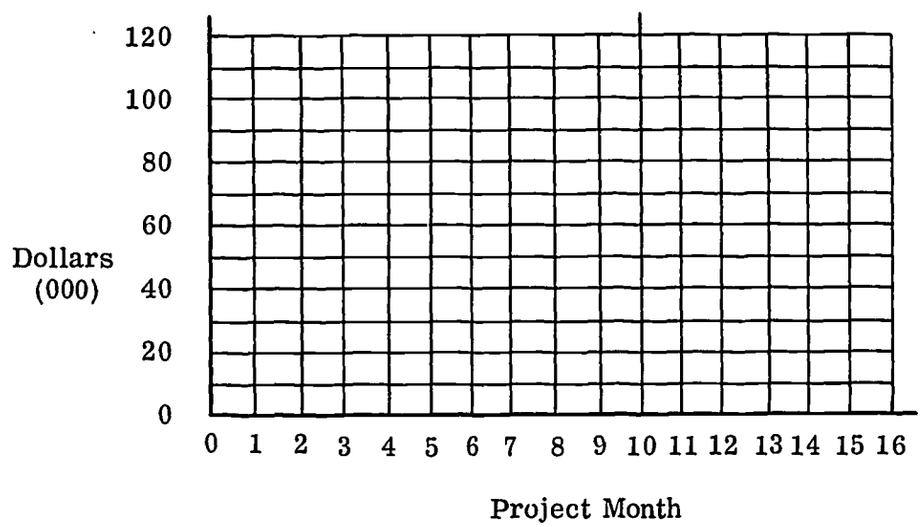
PERT/COST MANAGEMENT SUMMARY REPORT

Activity		Work Performed to Date			Totals at Completion		
From	To	Value	Actual Cost	Over-Run	Planned Cost	Latest Estimate	Over-Run
1	2						
1	3						
2	3						
1	4						
3	4						
2	5						
3	6						
4	6						
5	6						
Total							

22A. PROBLEM: Tabulate planned, actual and latest estimates of project costs, using cumulative totals from Tables 20A and 21A.

	Project Month															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Planned																
Actual																
Latest Estimate																

22B. Graphical Presentation of PERT/COST Data.



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