EDGEWOOD ARSENAL
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EASP 400-15

PERT AND ITS ASSOCIATED MANAGEMENT SCIENCES

by

M. M. Michie

May 1968

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Technical Support Directorate
Plans, Programs and Administrative Office
Edgewood Arsenal, Maryland 21010

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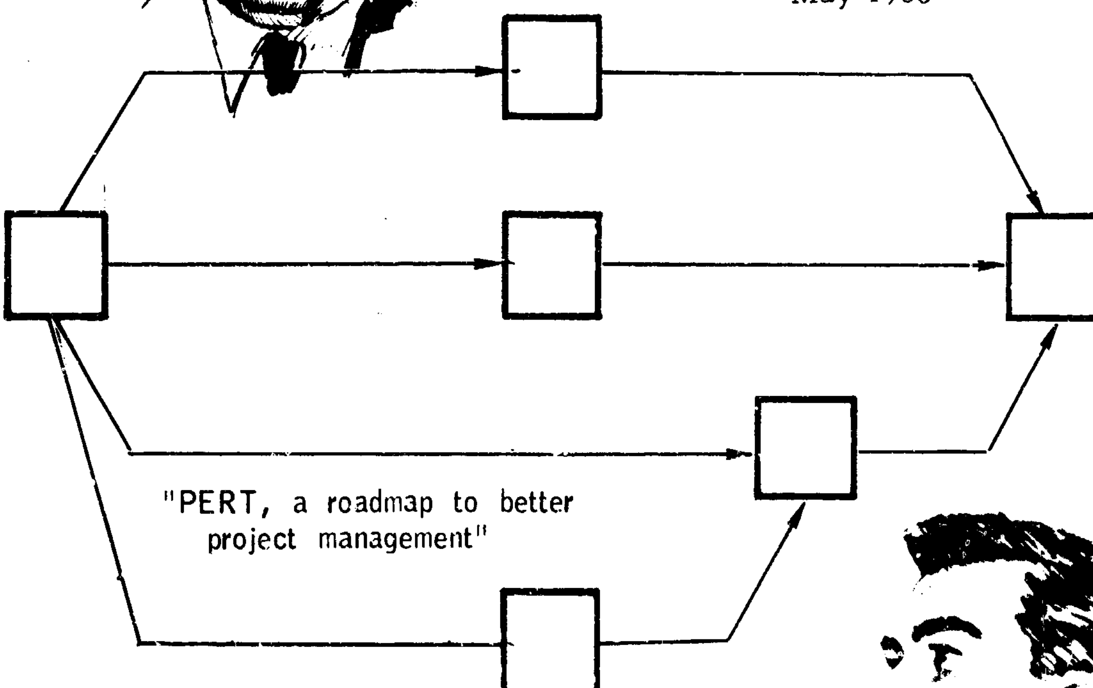

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PREFACE

This text is an introduction to PERT/TIME and its associated management sciences. The instruction is designed to give executives and project managers a basic understanding and appreciation of PERT. The familiarity acquired from the instructional material will permit the manager to work closely with PERT experts in the development of networks and their interpretation.

From the author's experience, few project managers and engineers use a detailed analysis of activity time variances in the course of a project. Therefore, statistical probability theory is eliminated.

This text includes basic instruction in project cost optimization within the PERT/TIME work breakdown structure, and therefore should give the manager familiarity with the advantages of PERT/COST.

The content of this course may be covered in 12 hours of lecture - seminar instruction, with 6 hours of outside work on the part of the participants. If more expertise in a particular area is desired, it is believed that this text will provide a foundation for comprehension of literature in specialized or more advanced areas of PERT systems.

I express my gratitude to Lt John H. Williams, and Lt Hugh M. Peter, Jr., for their contributions and help in preparing this course.

CONTENTS

INTRODUCTION

Management, like invention, is no longer a matter of individual effort. The complexity of directing and controlling modern day programs has challenged conventional management techniques. Each program must be carefully planned, scheduled, evaluated and managed toward attainment of specific objectives.

Recent years have seen the rapid growth of new management planning and control techniques. One of the most useful, most discussed, and least understood of these is PERT. (Although there are distinct differences between PERT, CPM, and their many variations, the term PERT is increasingly applied to all critical path scheduling).

PERT's usefulness as a management tool for small, less complex projects has been largely overshadowed because of its initial application to large and complex development projects. PERT has been demonstrably effective for efforts across a broad range of projects in size and complexity. PERT has proved its value as a management planning and control tool for projects ranging from the production of a Broadway play or the construction of a supermarket, to the development of the vastly complex Polaris Weapons System.

Known collectively as "critical path analysis", PERT & CPM have been around for about ten years. CPM or Critical Path Method was developed through a joint effort by the Dupont Company and Univac Division of Sperry Rand in 1957 in an attempt to find a dependable way to schedule the fantastically complicated business of building a chemical plant.

CPM served the purpose well and has since been used in millions of dollars of chemical plant construction, not only by Dupont but by Monsanto and others.

PERT, or Program Evaluation & Review Technique is essentially a variation of CPM. It was formally announced in 1959 by the U. S. Navy as a scheduling technique used in the Polaris Weapon program. It has been given much of the credit for the completion of the first Polaris missile two years ahead of schedule.

After starting in the rarefied atmosphere of chemical plants and missiles, critical path scheduling was inevitably looked on as high flown theory - too complicated for the average business. But as it trickled down into the subcontract levels of construction and military work, it really caught on. Its reputation as a valuable planning and scheduling tool began to spread. During 1962 PERT really arrived. More than 30 variations of the technique have found their way into commercial applications in research, engineering, and manufacturing.

Two things are required in order to apply PERT effectively to a project; first, the fundamentals of PERT [including the work, breakdown structure, networking and time estimating] must be mastered. Secondly, PERT must be applied intelligently to each project in full acknowledgment of the managerial requirements, the complexity of the program and the cost and time involved in implementation.

A management device or technique, regardless of the degree of sophistication, is only a tool and can never be a substitute for effective management.

Let's see what PERT is and how it can be applied.

PERT FILM

PERT MILESTONE SYSTEM

MF 20 9809

Adapted Navy Film

MN 9704

Time: 28 min - in color

WHAT PERT CAN DO FOR YOU

PERT gives a clear understanding of a project by a graphic display. It is said that a picture is worth a thousand words. Let's see what this picture shows:

a. The tasks required

b. The order in which they must be performed

c. The time by which they must be completed

d. The allowable delay

e. Indicates early warning of trouble spots

f. Pinpoints those activities responsible for delays

g. Indicates a simple and accurate check of progress

h. Permits the individual to predict the completion of a project

i. Provides a basis for scheduling work and workers

j. Simplifies communications: Up and down the line

k. Provides historical data Past-Future

l. Helps control costs

m. Fixes responsibility and assures continuity of effort (regardless of individuals)

n. Avoids omission of important tasks

o. Makes it possible to evaluate and forecast outcome of alternate plans and to select the best method

p. Provides management by exception

q. Acts as a tool for the man to judge his own ability at forecasting and controlling a project

THE NETWORK & DEVELOPMENT

PERT is the acronym for Program Evaluation & Review Technique. It is a management technique for describing operations or systems of a non-repetitive type. It consists primarily of a pictorial representation commonly described as a network. This network is described by activities and events and their interrelationships.

All activities take time to accomplish, and for now we will assume that any number of men can work on an activity. The beginning or ending of an activity we will call an event which is assumed to take no time - or is instantaneous.

Throughout this instruction we will indicate activities by arrows and events by rectangular boxes. Many network events are represented by circles. But, circles have the disadvantage of not being as practical as rectangles for holding information.

To get an idea of what thought orientation is involved in setting up a network, lets consider a simple problem.

Breaker Manufacture:

We want to decide what activities are necessary to manufacture a breaker. We know from past experience that we will need five (5) components to make this breaker. They are a frame, flange, rotor, cap, and cap die. We may readily procure the flange, rotor, and cap from outside suppliers. However, it is necessary for us to design and fabricate our own frame and cap die.

The actual assembly of these components is simple and consists of placing the rotor in the frame, then installing the cap, and completing the operation by inserting the flange.

From the preceding information, lets set down the activities which might be required to accomplish this task.

Order Flange	Submit Invitation for Bids
Order Rotor	Evaluate Bids & Award Contracts
Order Cap	Insert Rotor in Frame
Design Frame	Install Cap
Design Cap Die	Insert Flange Assembly
Fabricate Frame	
Fabricate Cap Die	

Once you have established the independent activities, it then becomes necessary to place them in their proper sequence. Since some tasks or activities are dependent upon one another, you must tie the activities together so that they can be performed in logical sequence. From the activities as shown, we might say there are three general classes of activity.

<u>Procurement</u> - <u>Tooling</u> - <u>Assembly</u>

The activities included in their respective categories are as follows:

Procurement	Tooling	Assembly
1. Order flange	1. Design frame	1. Insert rotor in frame
2. Order rotor	2. Design can die	2. Install cap
3. Order can	3. Fabricate frame	3. Insert flange assembly
4. Submit invitation for bids	4. Fabricate can die	
5. Evaluate bids & award contracts		

You recognize immediately that the order of activity of these events is not correct. Using the given activities, what order would you place them in? Please fill in below.

Procurement	Tooling	Assembly
4.	2.	1.
______	______	______
______	______	______
______	______	
______		

For the sake of uniformity, lets assume that the following lineups will do the job efficiently:

Procurement	Tooling	Assembly
1. Submit invitation for bids	1. Design cap die	1. Insert rotor in frame
2. Evaluate bids and award contracts	2. Design frame	2. Install cap
3. Order rotor	3. Fabricate cap die	3. Insert flange assembly
4. Order cap	4. Fabricate frame	
5. Order flange		

In general there are two types of activities. Those which can be accomplished while others are being performed (parallel) and those which cannot be accomplished until the completion of others (series).

In diagramming a network, there are three basic rules which should be adhered to: They are:

<u>RULE 1</u>. In placing any activity on a network, identify the activity which comes before it. This is the <u>preceding</u> activity if any.

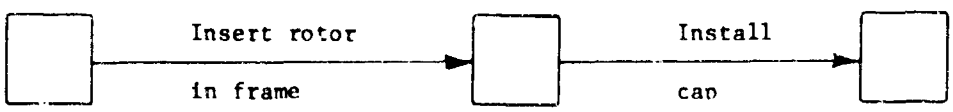
<u>RULE 2</u>. Identify any activities that occur at the same time as the one you are placing on the network; these are <u>concurrent</u> activities.

RULE 3. Identify the activity that follows the one you're trying to place on the network; this is the <u>succeeding</u> activity.

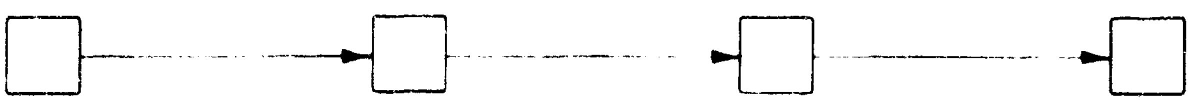
Let's take one part of the problem at a time, starting with <u>Assembly</u>.

Assembly: Draw an arrow to represent our first activity and label it with the first activity.

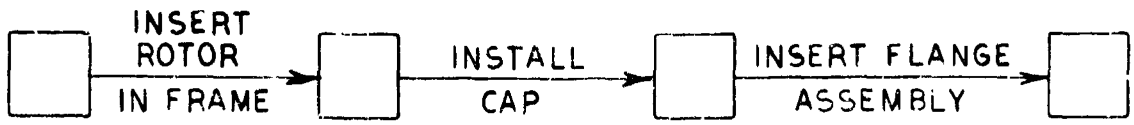
Now, ask yourself Rule 1. Are there any activities which come before this activity? No. Then apply Rule 2? Are there any activities that occur at the same time? No. Then apply Rule 3? Yes, there are activities that follow the first activity. Follow Activity 1 by Activity 2. And while we're at it let's insert the events (as open rectangles).



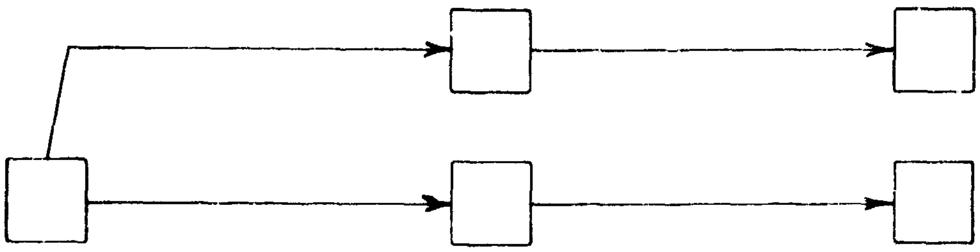
Ask yourself the same three rule questions again about Activity No. 2. Notice that Activity No. 3 can fit Rule 3, or it can be performed after Activity No. 2. So, lets place Activity No. 3 so that it occurs after Activity No. 2. Our drawing might look like this. Fill in the activities.



Your network probably looks like this.

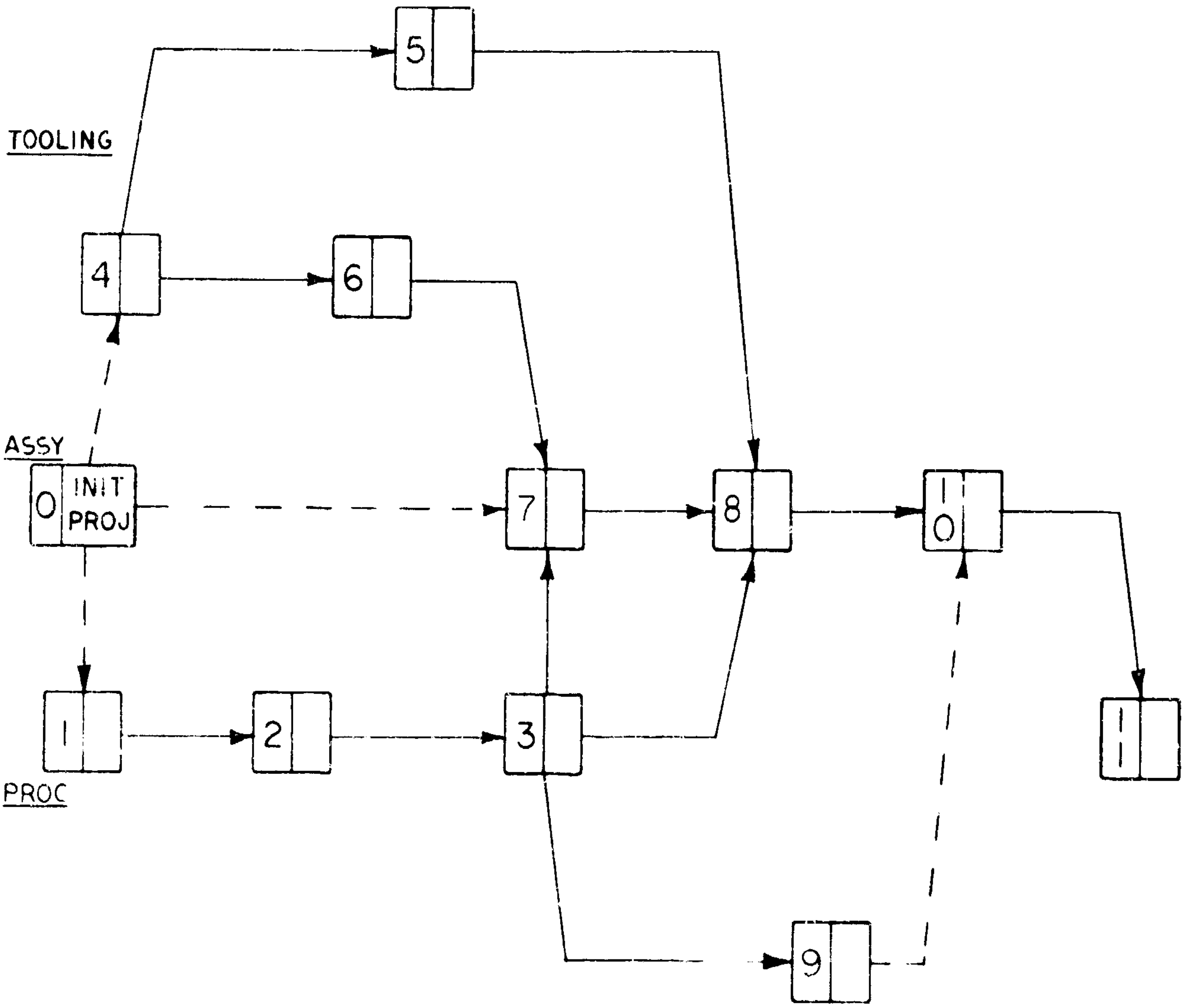


Next, lets take the TOOLING. Fill in the activities in the network below and see if the logic is sound. Notice that you can fill in the activities from last to first if you like:

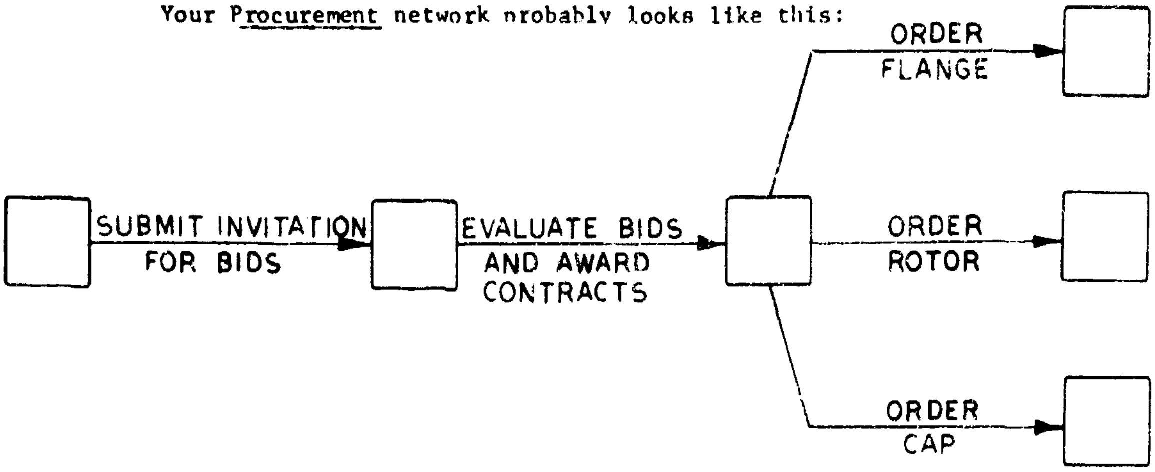


Observe that the diagram states that Design frame and Fabricate frame are activities parallel to Design cap die and Fabricate cap die. Finally, lets construct a network for PROCUREMENT OPERATIONS.

EXHIBIT I



Your Procurement network probably looks like this:



Since these three functions collectively represent the manufacture of the breaker, it would be ideal to tie them all together to show their interdependencies and interrelationships. If we take our three networks and link them together, our network may look like EXHIBIT 1.

Fill in the activities.

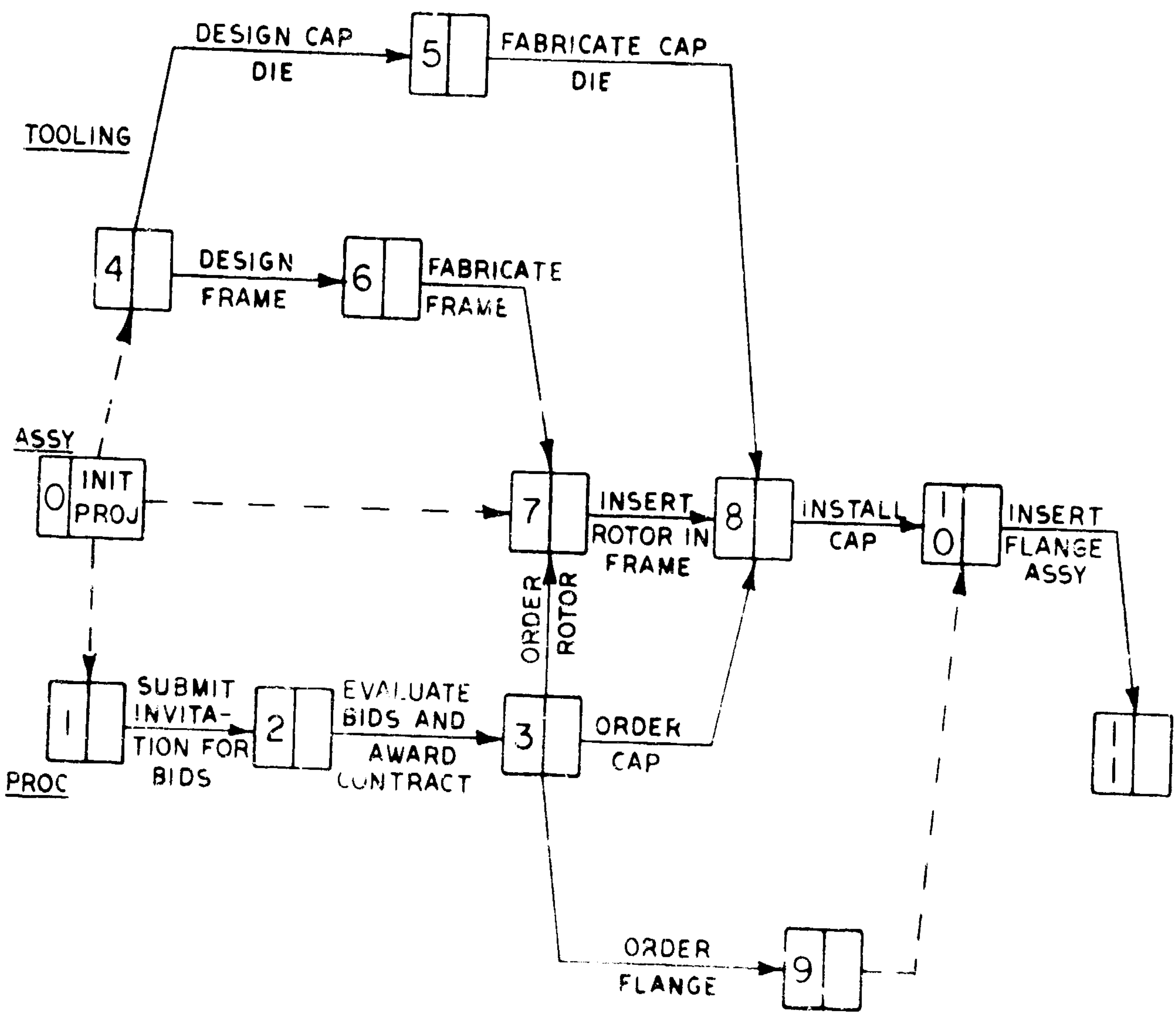
EXHIBIT 1

NOTE: Dependency lines are dotted lines which have no time duration. They are used to represent the logical dependency of one activity on another when other means of networking are awkward or cause technical problems.

Check your answer against the network in EXHIBIT 2. Remember, there are many variations of the example shown, but you must strive for diagram and activity simplicity. It is this simplicity which may sell the entire work proposal system.

EXHIBIT 2.

EXHIBIT 2


TOOLING
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SUBMIT INVITA- TION FOR BIDS
2
EVALUATE BIDS AND AWARD CONTRACT
3
4
DESIGN CAP DIE
5
FABRICATE CAP DIE
DESIGN FRAME
6
FABRICATE FRAME
7
ORDER ROTOR
INSERT ROTOR IN FRAME
8
ORDER CAP
INSTALL CAP
10
INSERT FLANGE ASSY
11
ORDER FLANGE
9

EXPECTED TIME

Suppose you want a brochure printed. You call the printer and outline the job and he tells you the date on which he can deliver the brochure. The printer gave you the date of the final event. He got that date by adding the times of the several activities involved. Now we're talking about activities and events, how do they tie in.

Let's take an example: PRINT BROCHURE →

This is an activity indicating the consumption of time.

Now,

This diagram indicates both the activity and possible events connected with the activity. Note that the events are instantaneous and can be indicated by points in time, such as 1968, or Feb 1, or Dec 65. The activities on the other hand require a specified time such as 6 days, 4 weeks, or 9 months. The unit of time does not matter as long as we are consistent throughout the network. However, large PERT networks usually are indicated in weeks.

Since activities take time, we will need an estimate of how much time will be needed to complete each activity. But, where do we get the activity times? The best place to go for activity time information is directly to individuals responsible for the job. They are the experts. There is danger to be recognized in going to the worker or his supervisor. Either one may stretch the job time estimate to fit the dollars allotted.

To offset the bias that may be present in the first time estimate, PERT employs three time estimates: optimistic, most likely and pessimistic.

The first estimate to ask for is the most likely time it will take to complete an activity. This is the time most frequently required for completion of the activity. It could also be commonly called "most probable time". Statisticians like to call this time the Modal time required to do a job, if it were repeated a great number of times.

The second time estimate is the optimistic time. There should be no hope in completing the activity in less than the optimistic time. This is the least time in which the activity can be comleted -- about one time in a hundred attempts.

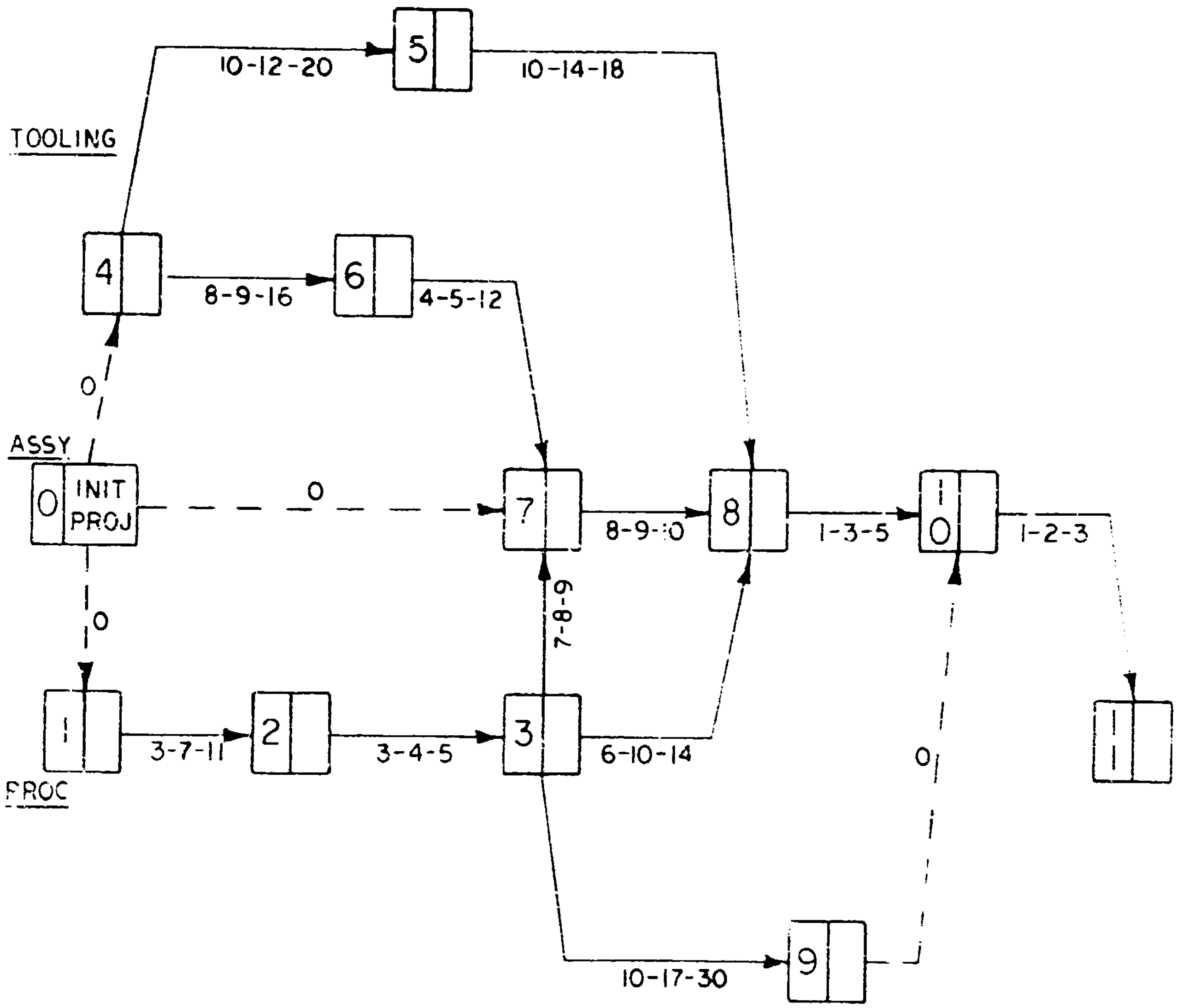
The third time estimate is the pessimistic time. This is the time which would not be exceeded, barring "Acts of God". This is the greatest time in which the activity will be comleted -- about one time in a hundred attempts.

Our goal in getting three subjective estimates is to use them to calculate a single weighted average time. This time we will call the expected time of the activity.

The three time estimates are related to the expected time by this formula: $t_e = \frac{a + 4m + b}{6}$ where a = the most optimistic time, b = the most pessimistic time and m = the most likely time.

Notice in this formula that m the most likely time is multiplied by 4 to give it four times as much weight as the extreme values.

EXHIBIT 3



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10-14-18
8-9-16
4-5-12
0
0
0
8-9-10
1-3-5
1-2-3
7-8-9
3-7-11
3-4-5
6-10-14
0
10-17-30

Theoretically, this formula and the three-time approach will provide sound estimates for network development. However, it has become fairly common procedure to accept one-time estimates for PERT development. If one-time estimates prove reliable they should be used. If it is believed that the estimators are padding time or do not know their business, then the three-time procedure should be followed.

EXPECTED TIME COMPUTATION

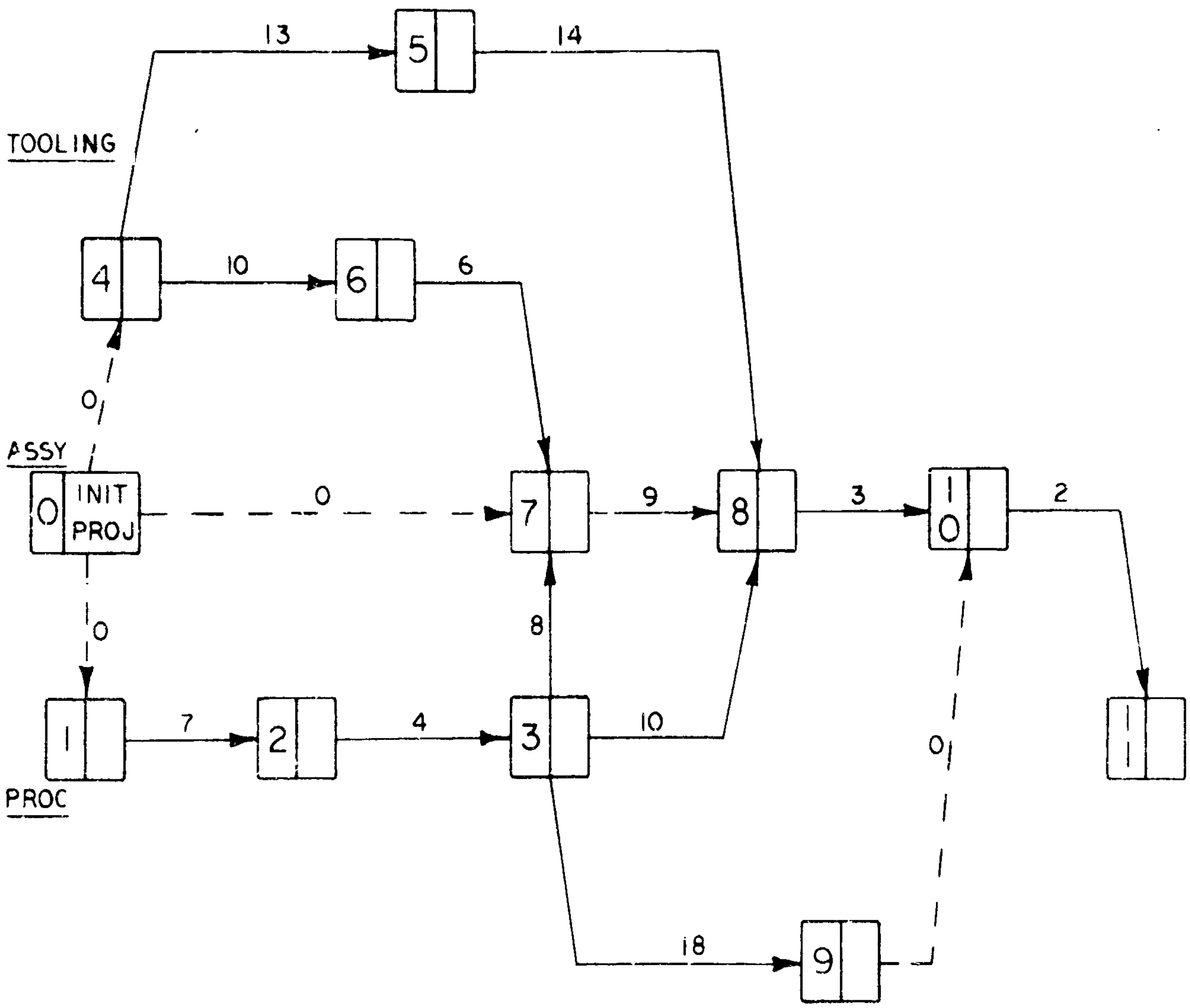
Lets assume that we had requested and received optimistic, most likely, and pessimistic time values for our Breaker problem. We now need to compute the expected times. The network in EXHIBIT 3 gives the estimates in weeks.

Using the formula below, calculate the expected time for Activity 1-2.

$$t_e = \frac{a + 4\,m + b}{6} = \frac{3 + 28 + 11}{6} = 7$$

Compute the expected times for EXHIBIT 3 and place these values on EXHIBIT 3 above the estimates values.

EXHIBIT 4



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9

EARLIEST TIMES

Now that we have the expected time (t_e) for each activity in the project, let's calculate how long it will take to accomplish the entire project. To get total project time, begin with Event 1, by finding the Earliest Event Time (T_E). Refer to EXHIBIT 4.

No time has been expended prior to Event 1, so indicate on EXHIBIT 4 at Event 1, that $T_E = 0$. The time to reach Event 2 is equal to the expected time to complete Activity 1-2 or 7 weeks. Write in the T_E time of 7 weeks in Event 2.

The time to reach Event 3 is equal to the expected time to complete Activity 2-3 or 4 weeks, added to the T_E at Event 2, or 4 + 7 = 11.

Now for Event 7. There are three paths leading to this event. Let's take them one at a time.

1-2, 2-3, 3-7, requires 7 + 4 + 8 = 19 weeks

0-7 requires 0 = 0 weeks

4-6, 6-7, requires 10 + 6 = 16 weeks

The network arrows indicated that Event 7 can only take place after the activities prior to it have been completed. Remember this rule. Therefore, Event 7 cannot occur before 19 weeks from the start. Place this number at Event 7 and label it T_E.

The Earliest Event Time then is the earliest that an event can occur, and is calculated by determining the time between the start of the project and the event in question. This means adding the Expected Time (t_e) of each activity to the Earliest Time (T_E) of the preceding event. In the case of two or more times leading to the event, use the path requiring the longest time.

Solve through the rest of the network and determine the earliest time to complete the project. If your answer is 33 weeks, you have probably done the job correctly.

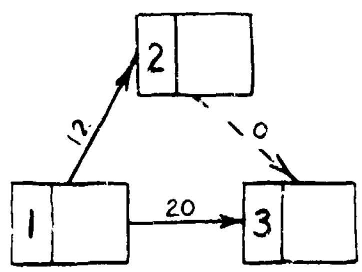
PROCESS PLANT RENOVATION

RENEWAL OF A SECTION OF IN-PLANT PIPING IN A PROCESS PLANT

Activity	Description	Hours
1-2	Measure and Sketch	12
1-3	Outline Project	20
2-3	Dummy	0
3-4	Determine Equipment Requirements	16
3-5	Determine Material Requirements	16
3-6	Determine Manpower Requirements	16
3-7	Obtain Fund Approval	32
3-8	Develop Project Plan	52
4-8	Dummy	0
5-8	Dummy	0
6-8	Dummy	0
7-8	Dummy	0
8-9	Assemble Crews	96
8-10	Stop Using Old Line	150
8-11	Dummy	0
9-12	Erect Scaffold	12
10-12	Deactivate System	8
11-13	Make List of Materials for Procurement Department	8
12-14	Dummy	0
12-17	Dummy	0
12-20	Remove Old Pipe	35
13-15	Procure Pipes	200
13-16	Procure Valves	225
14-18	Ship to Site	72
15-14	Deliver and Accept	8
16-17	Deliver and Accept	8
17-21	Ship to Site	72
18-19	Prefabricate New Pipe Sections	40
19-20	Dummy	0
20-21	Place New Pipe Sections	32
21-22	Weld Pipes	8
21-23	Place Valves	8
22-24	Dummy	0
23-24	Dummy	0
24-25	Connect Valves	8
25-26	Pressure Test	6
25-27	Insulate	24
26-27	Dummy	0
27-28	Dismantle Scaffold	4
27-29	Clean-up	4
28-29	Dummy	0

PROCESS PLANT RENOVATION

WORKSHEET



WORK SHEET

1 DRAW NETWORK
2-PLACE ON te's
3 SOLVE FOR EARLIEST TIMES (T_E)

Here is a problem in the science of deductive thinking. See how long it takes you to solve this problem concerning this fictional baseball team. NAME THE POSITION EACH PLAYS.

A. Andy dislikes the catcher.

B. Ed's sister was engaged to the second baseman.

C. The center fielder was taller than the right fielder.

D. Harry and the third baseman lived in the same building.

E. Paul and Allen each won $20 from the pitcher playing pinochle.

F. Ed and the outfielders played poker during their free time.

G. The pitcher's wife was the third baseman's sister.

H. All the battery and infield, except Allen, Harry and Andy, are shorter than Sam.

I. Paul, Andy and the shortstop lost $150 each at the track.

J. Paul, Harry and Bill and the catcher took a trouncing from the second baseman at pool.

K. Sam was undergoing a divorce suit.

L. The catcher and third baseman each had two children.

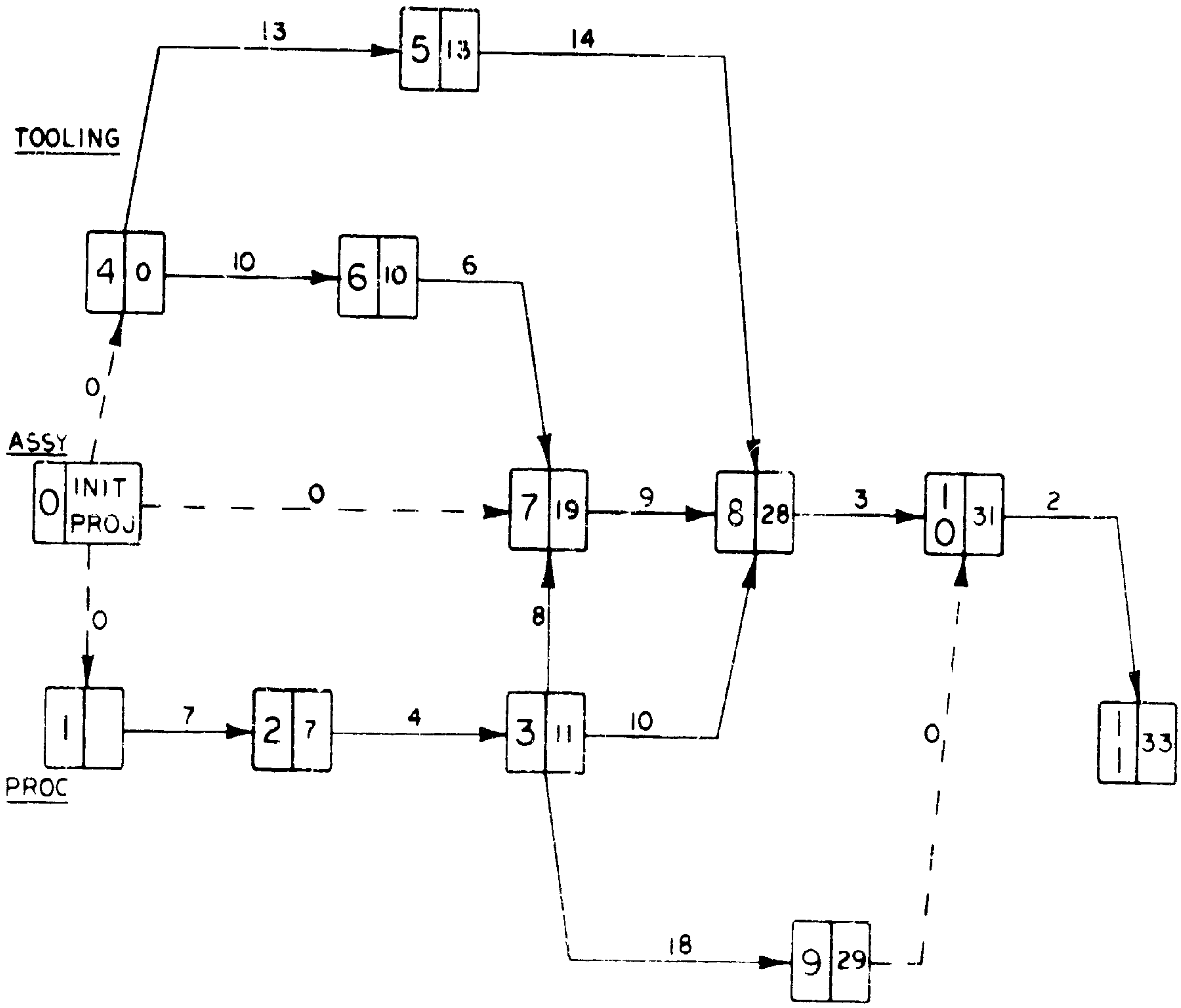
M. Ed, Paul, Jerry, the right fielder and the center fielder were bachelors, the others were married.

N. The shortstop, the third baseman and Bill had cleaned up $100 betting on a fight.

O. One of the outfielders was either Mike or Andy.

P. Jerry was taller than Bill. Mike was shorter than Bill. Each of them was heavier than the third baseman.

EXHIBIT 5



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3 11
10
0
11 33
PROC
18
9 29

LATEST TIMES (T_L)

Having found the earliest time (T_E) at which each event can occur, we now want to calculate the latest time at which each event can be completed without delaying completion of the project.

We previously computed earliest times by adding expected activity times to previous event times, starting with the first event and working through the diagram to the final event.

Now to find the latest event times, we start at the final event and subtract the activity times immediately prior to the final event. We calculate earliest event times by working forward and latest event times by working backward.

We try to complete the project no later than the earliest completion date. This means the earliest and latest time for the final event will be the same, in this case 33 weeks.

Using EXHIBIT 5, write the latest completion date (T_L) in the final event above T_E. Thus, T_L and T_E are both 33 weeks as indicated.

Now, calculate the latest time at event 10. Subtract the expected time of Activity 10-11 from the latest time of event 11 or 33 - 2 = 31. Since there is only one path leading from event 10, the T_L for event 10 is 31.

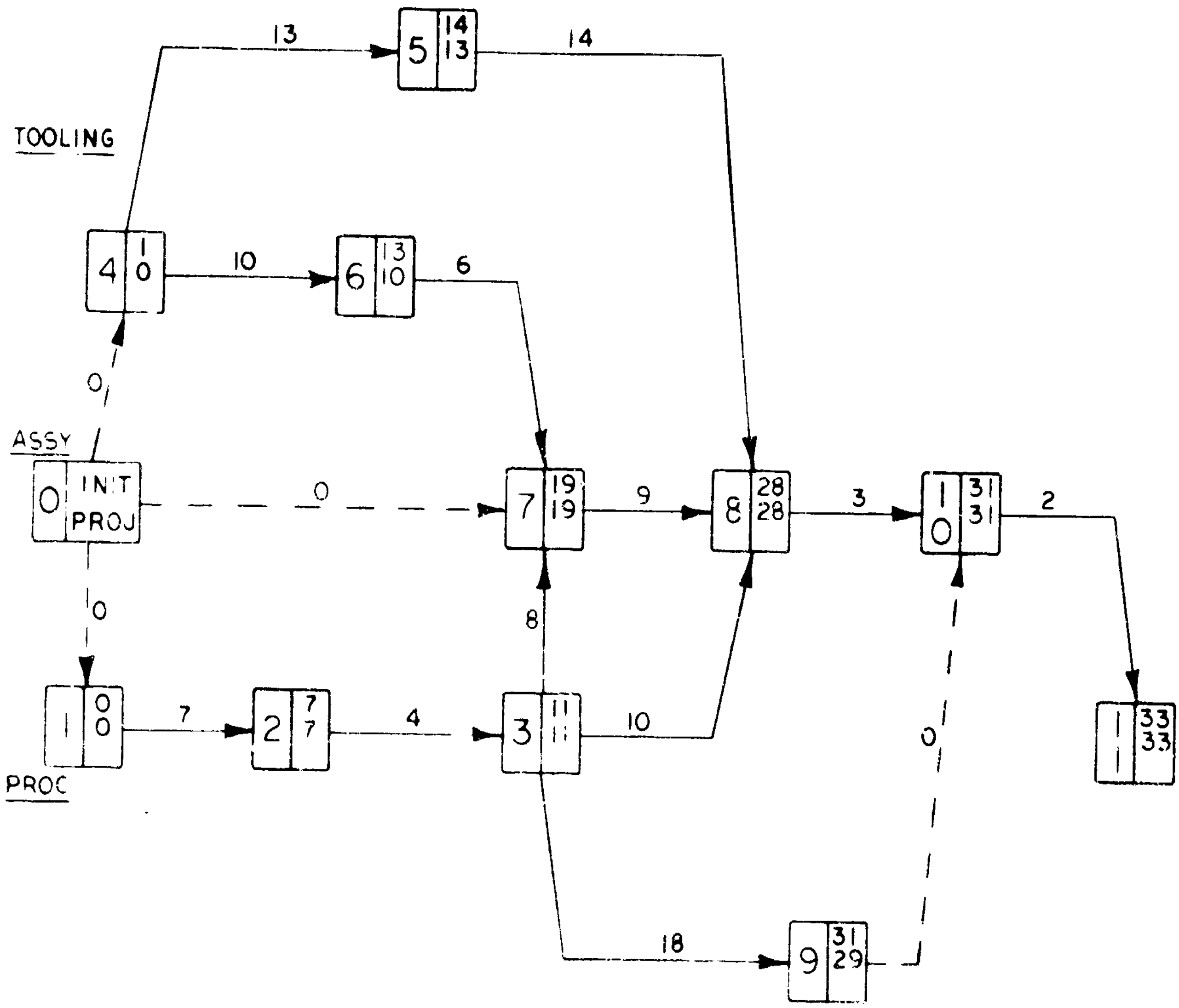
Calculate the latest time at event 8. $T_L - t_e = 31 - 3 = 28$. Again, there is only one path from event 8, so write 28 for T_L in event 8.

Let's try event 3. Notice there are three paths leading from this event. Along path 3-8 we calculate 28 - 10 = 18. But wait a minute, let's try another path. Along 3-7, 7-8, we have 28 - 9 = 19, and 19 - 8 = 11. The last path 3-9, 9-10, gives us 31 - 0 = 31, and 31 - 18 = 13. This gives us a choice of three values for T_L. If we use a T_L of 18, this would indicate we could start Activity 3-7 on the 18th week, Activity 7-8 on the 26th week, Activity 8-10 on the 35th week, and Activity 10-11 on the 38th week. Our project would then take 38 + 2 or 40 weeks. A similar exercise in arithmetic would show that using a T_L of 13 weeks will cause us to finish the project in 35 weeks. Since we expect to complete the project in 33 weeks, we must select the T_L of 11 for event 3.

To compute the latest time then, go backward through the network, subtracting the expected time of each activity from the latest time of each succeeding event. In the case of two or more paths leading backward to an event, use the smallest value.

Solve through the rest of the network and determine the latest times for each event. T_L for event 0 should equal zero. (NOTE: T_L for event 0 will only be zero, if the T_L and T_E for the final event are the same).

EXHIBIT 6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11 33 33
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EVENT SLACK TIME

The Event Slack time is the difference between the earliest and latest time of an event. An event may occur at any time within its earliest and latest times and not affect the overall project time. Slack time is the extra time which may be associated with events.

Event Slack time is represented by the formula:

$$T_L - T_E = \text{Slack}$$

Observing EXHIBIT 6, we may compute the event slack time for events as follows:

EVENT 1	0 - 0	= 0
EVENT 4	1 - 0	= 1
EVENT 6	13 - 10	= 3

Calculate the remainder of the event slack times and fill in the slack times in the proper places in EXHIBIT 6.

EXHIBIT 7

ACTIVITY	T_L	T_E	t_e	FLOAT
0,1				
0,4				
0,7				
1,2				
2,3				
3,7				
3,8				
3,9				
4,5				
4,6				
5,8				
6,7				
7,8				
8,10				
10,11				

ACTIVITY FLOAT TIME

Activity float is the extra time available when the interval between two events is greater than the duration of the activity to be inserted between them.

To calculate the float time, subtract the earliest time (T_E) of the preceding event from the latest time (T_L) of the following event. From this result, subtract the expected time of the activity.

Activity FLOAT = $[T_L - T_E] - t_e$

Take the T_L, T_E and t_e values from EXHIBIT 6 and fill in the chart in EXHIBIT 7.

Let's calculate the activity float times and see what they mean. First, Activity 1-2. The T_L for this activity is 7, the T_E is 0 and subtracting 7 - 0 = 7 ($T_L - T_E$). Then, t_e is 7 or 7 - 7 = 0 = $(T_L - T_E) - t_e$ = [7 - 0] - 7 = 0. Therefore, activity 1-2 has a float time of 0 weeks. This means that activity 1-2 must start at week 0, so that the program will not be delayed. In other words, this activity has no leeway.

Second, let's try activity 4-6. Filling in the formula $[T_L - T_E] - t_e$ = [13 - 0] - 10 = 3, or the activity float for this activity is three weeks. This means that activity 4-6 can start as late as week 3, after the beginning of the program and not delay the completion date.

Third, filling in the formula $[T_L - T_E] - t_e$ for activity 6-7 gives: [19-10] - 6 = 3.

This indicates that activity 6-7 can be started as many as 3 weeks after its earliest start date and still be completed on time. It also means that if 6-7 is started at week 10 and completed in its proper time of 6 weeks, there must be a 3 week delay before event 7 can be reached.

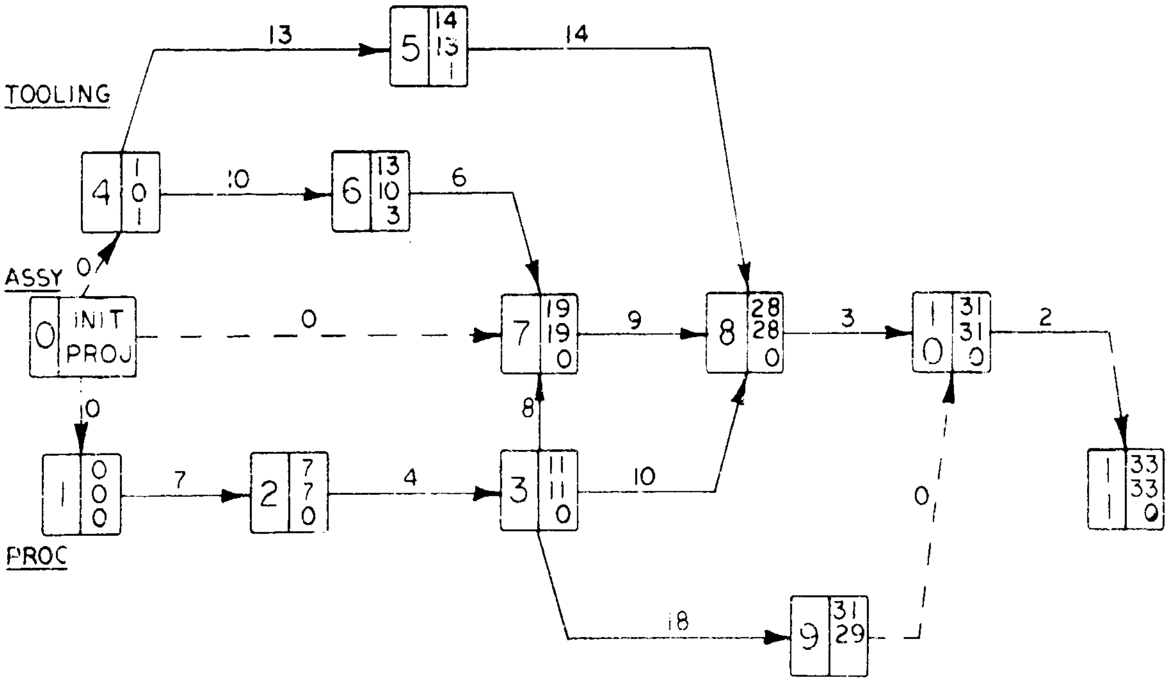
This is true because the earliest time at which event 7 can be completed is at 19 weeks. Why? Well, remember! Event 7 is dependent upon and cannot start before the completion of those activities which lead into it. Activity 3-7 is not complete until the 19th week, so it is the limiting activity.

Compute the remaining float times for the network and complete EXHIBIT 7.

Activity float can be very helpful in scheduling projects for optional resource allocation. It can also indicate to a foreman the latest time which he can begin a job and complete it on time.

EXHIBIT 8

ACTIVITY	T_L	T_E	t_e	FLOAT
0,1	0	0	0	0
0,4	1	0	0	1
0,7	19	0	0	19
1,2	7	0	7	0
2,3	11	7	4	0
3,7	19	11	8	0
3,8	28	11	10	7
3,9	31	11	18	2
4,5	14	0	13	1
4,6	13	0	10	3
5,8	28	13	14	1
6,7	19	10	6	3
7,8	28	19	9	0
8,10	31	28	3	0
10,11	33	31	2	0



CRITICAL PATH

Within each network is a path composed of activities and events, which, if delayed, would affect the project time. These are called critical activities and events and make up the critical path. The critical path is the longest path through the network with the least amount of slack. Critical activities are activities that have the least float time. Likewise, critical events have the least slack time.

We calculated earlier that Activity Float was $[T_L - T_E] - t_e$ and Event Slack was $T_L - T_E$. By referring to EXHIBIT 8, where the float times are indicated, you will notice that the activities with zero float are: (0-1), (1-2), (2-3), (3-7), (7-8), (8-10) and (10-11). Mark them off on the network or on EXHIBIT 8 with marks (#) to indicate the critical path.

Again, referring to EXHIBIT 8, notice that all event slack times on the critical path equal zero.

In cases where the activity float is not computed, the critical path can be determined where the event slack time $(T_L - T_E)$ is least on the longest path through the network. Notice that activity 3-8 is not on the critical path.

When $T_L = T_E$ for the last event of the network, least slack is equal to zero.

COMPLETE PROCESS PLANT

RENOVATION PROBLEM AS FOLLOWS:

Using the Process Plant Renovation Worksheet Pg 22:

4. Calculate TL's

5. Calculate Slack

6. Determine the Critical Path

NETWORK DEVELOPMENT EXAMPLE

SITUATION:

Mrs. Kingston is having a dinner party for her debutante daughter. Assume servants (maid, cook, butler, etc.) are available. Formal invitations will be issued indicating time and place. Start with "develop idea for dinner party" and end with "receive guests".

PROBLEM:

What activities should be performed to assure the success of the party?

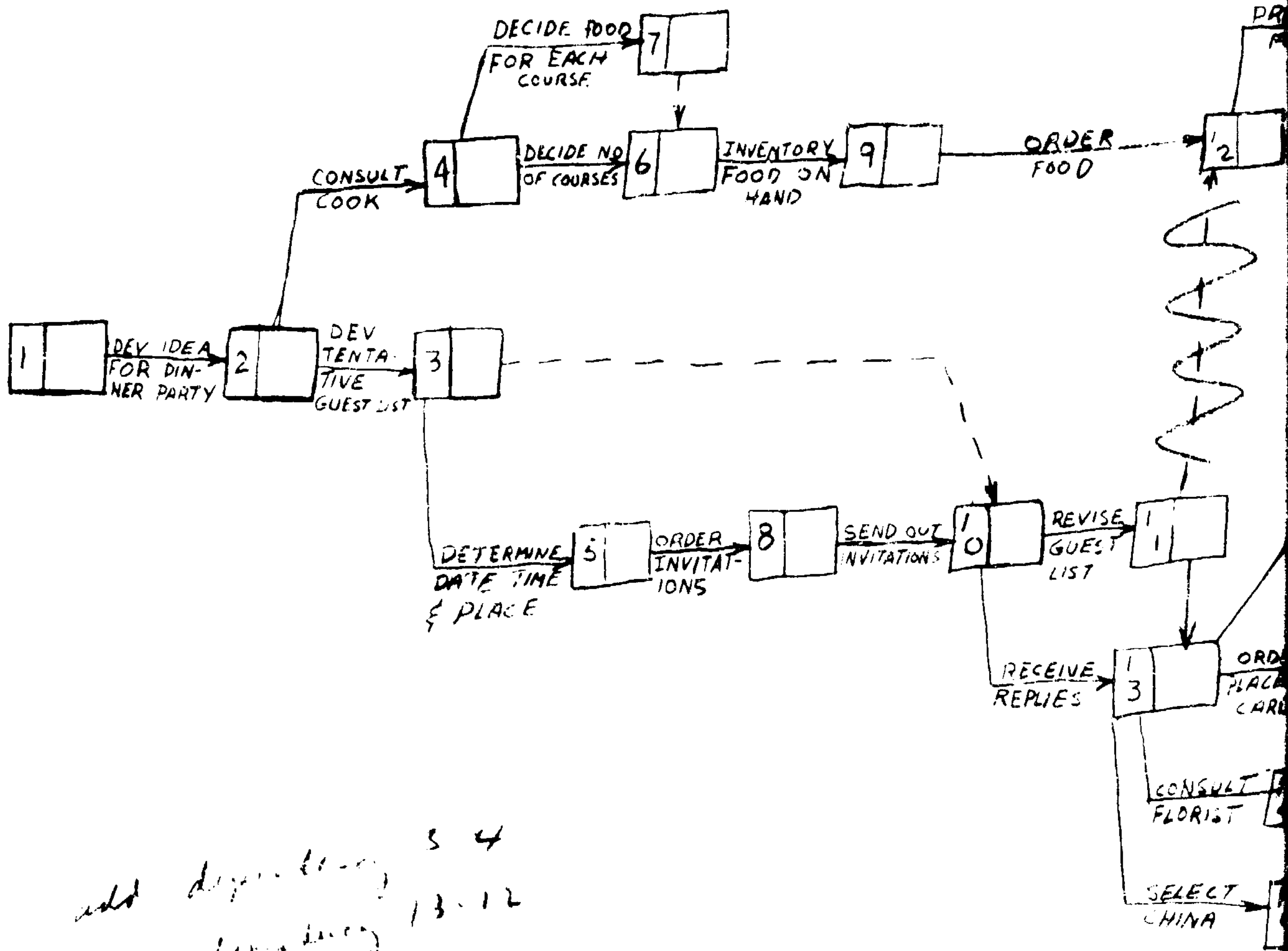
DEBUTANTE DINNER PARTY

Possible Activities:	Days
1. Develop tentative guest list	2
2. Decide number of courses	2
3. Decide food for each course	1
4. Send out invitations	2
5. Instruct servants	1
6. Order food	3
7. Revise guest list	3
8. Select china, silver, crystal, etc.	1
9. Set table	1
10. Consult florist	1
11. Prepare seating arrangement	2
12. Prepare food	3
13. Order invitations	12
14. Consult cook	2
15. Determine date, time and place	4
16. Order place cards	1
17. Order floral arrangements	1
18. Delivery and placement of arrangement (s)	4
19. Inventory of food on hand	1
20. Notify newspaper	1
21. Receive replies	14
22. Receive guests	1
23. Develop idea for dinner party	3

Problem Continued.

Prepare a PERT network for the above activities.

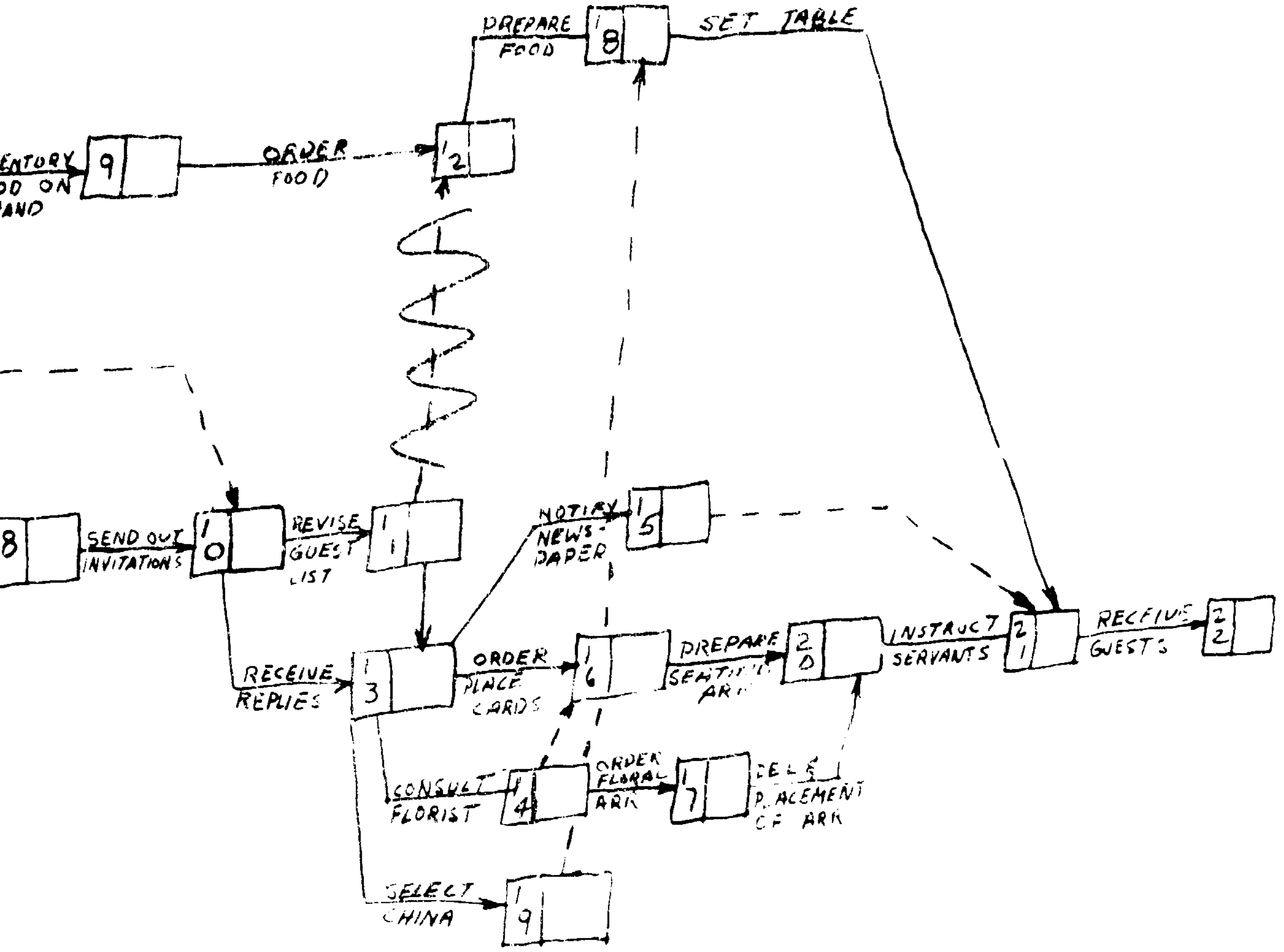
DEBUTANTE DINNER PARTY



add dependency 3 4
add dependency 13-12

A

...TANTE DINNER PA...



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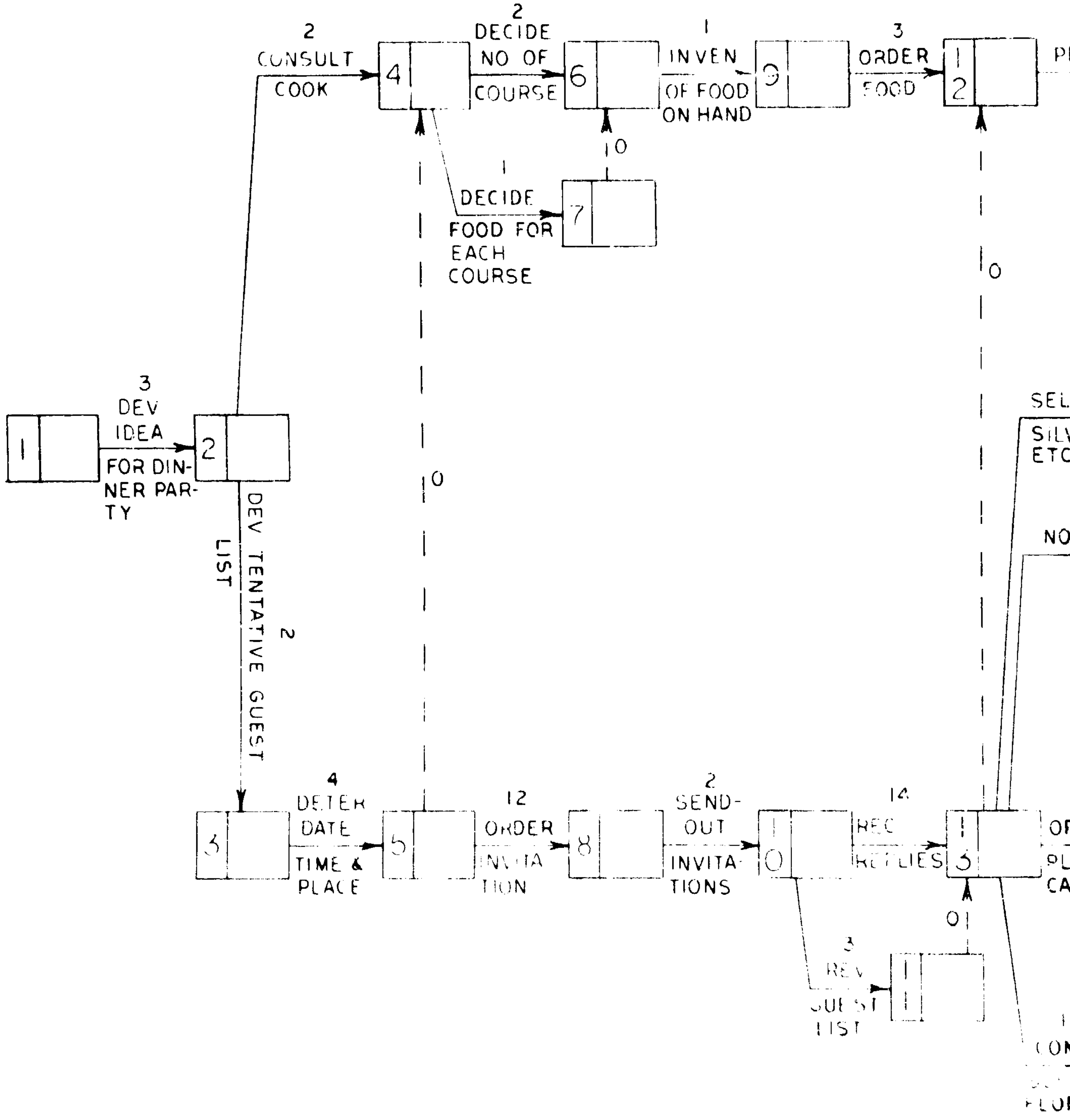
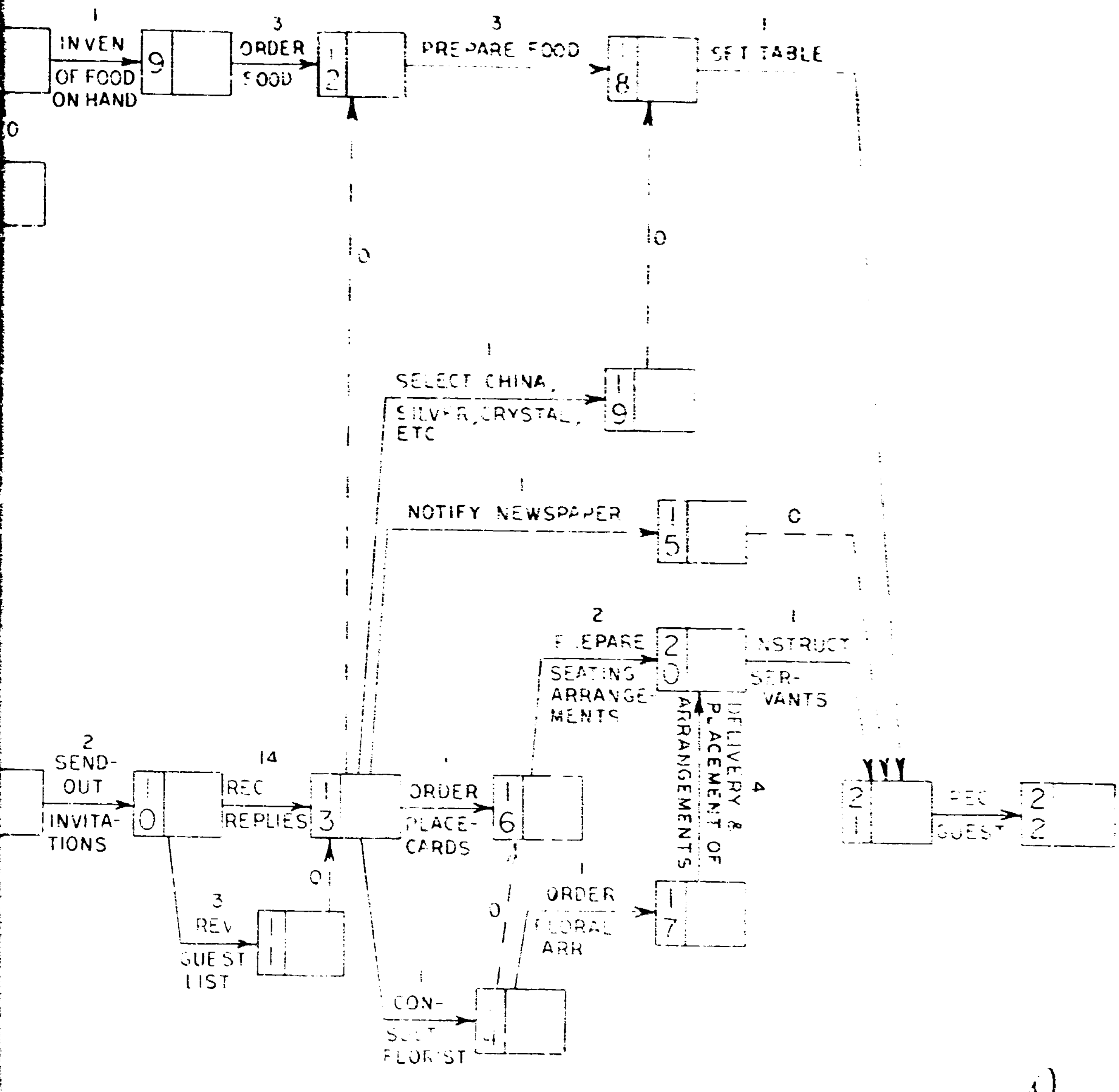
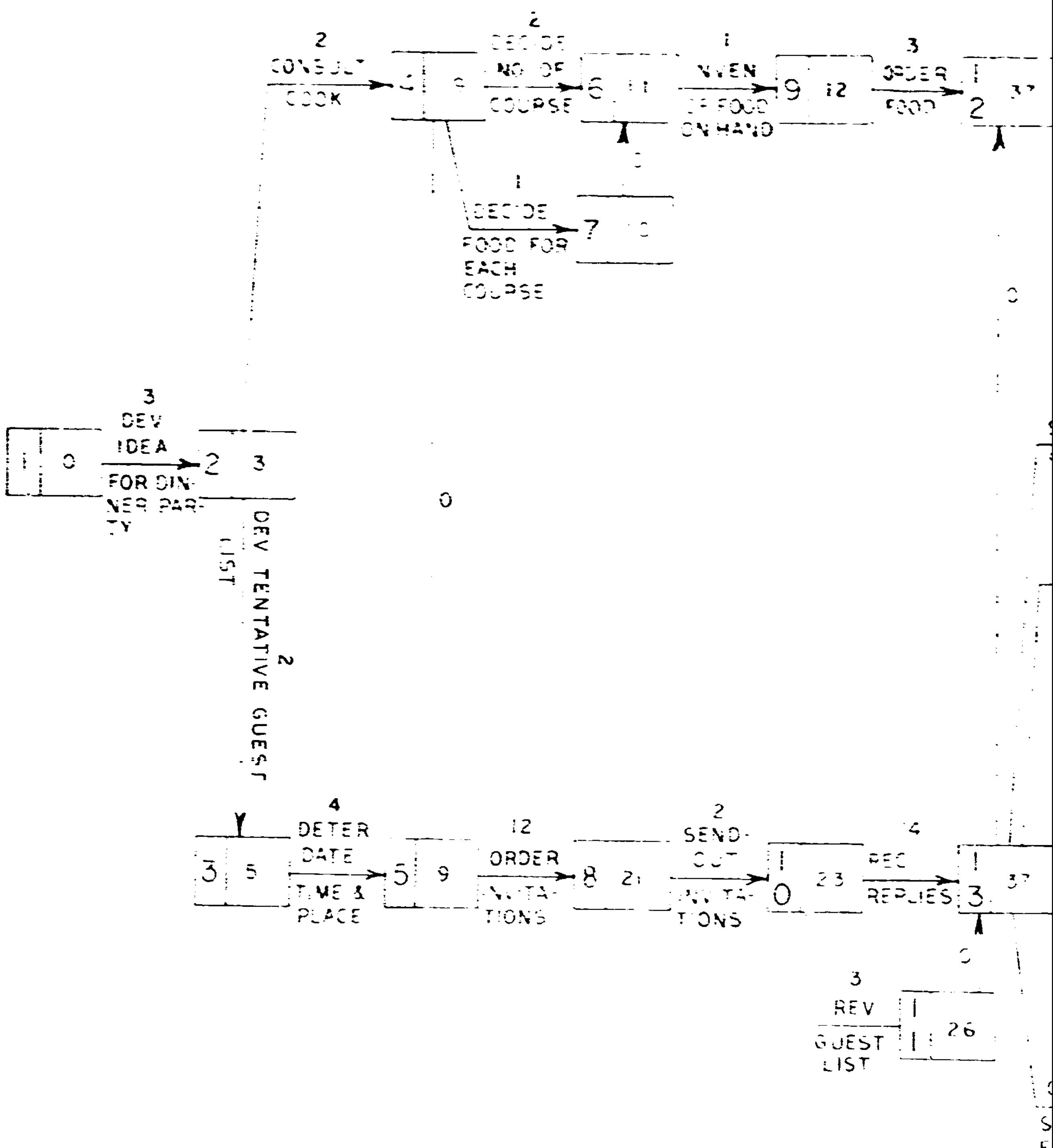
DEBUTANTE DINNER PAR



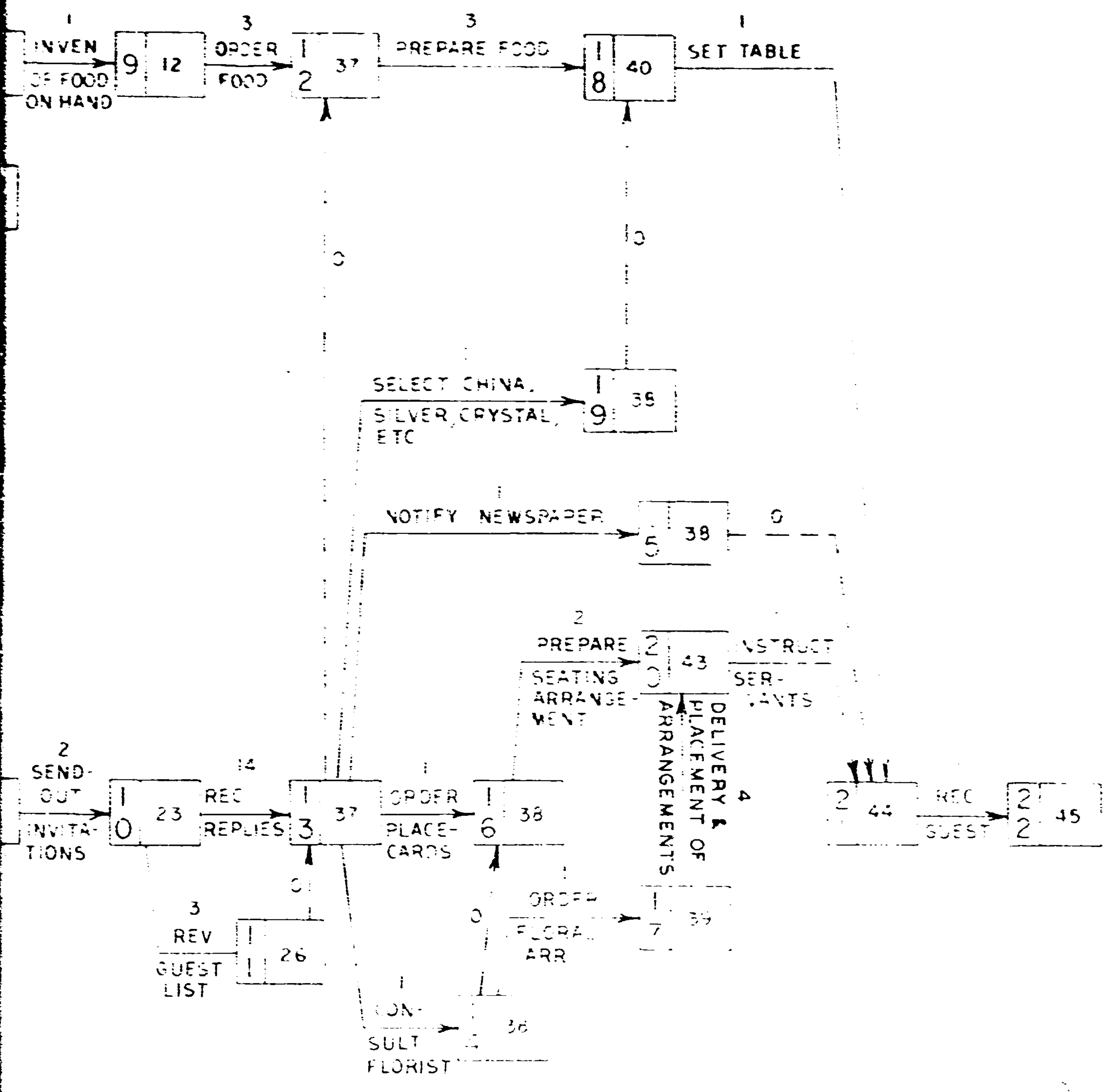
ESUTANTE DINNER PARTY



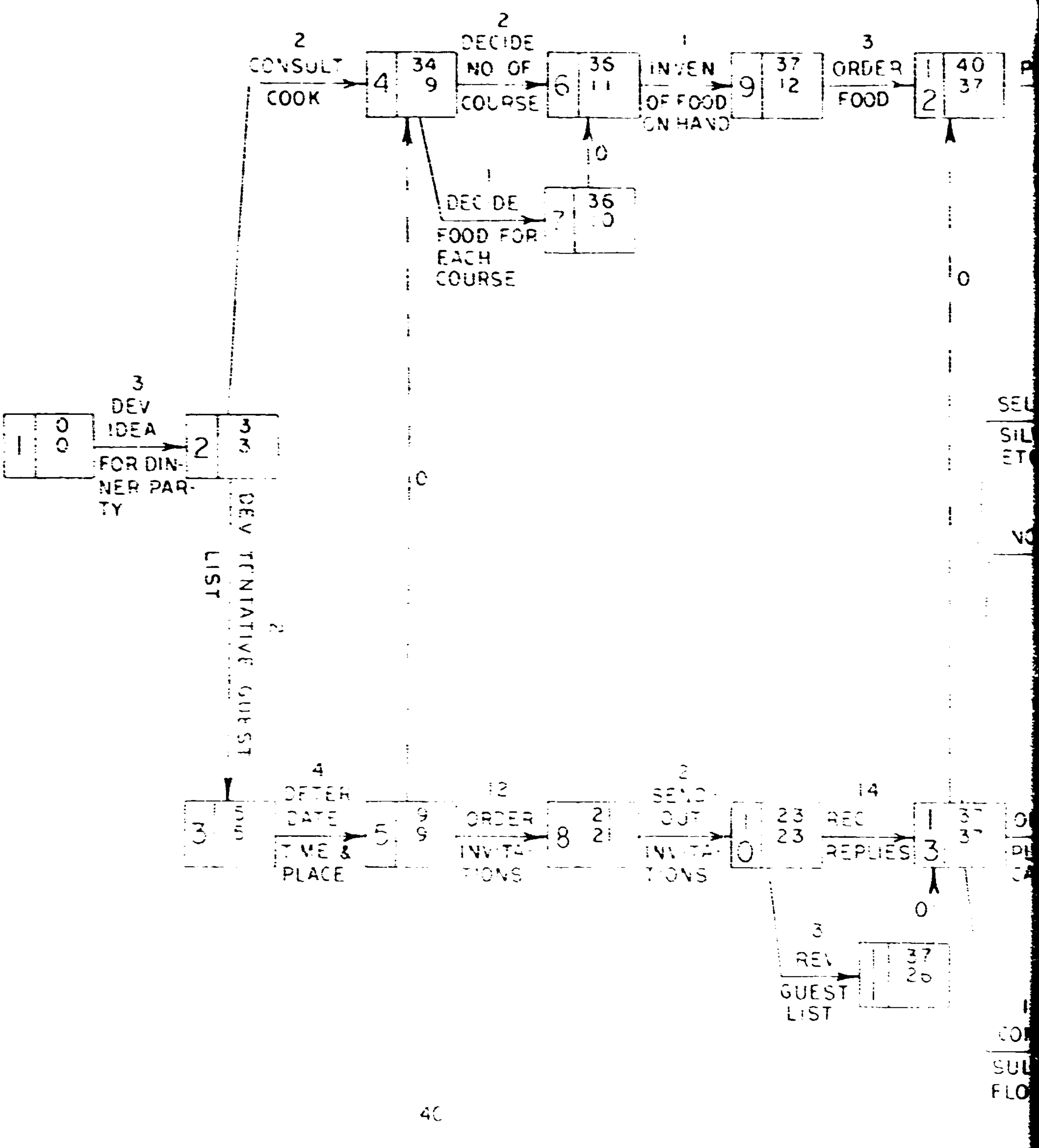
DEBUTANTE DINNER P



BUTANTE DINNER PARTY



DEBUTANTE DINNER PAR



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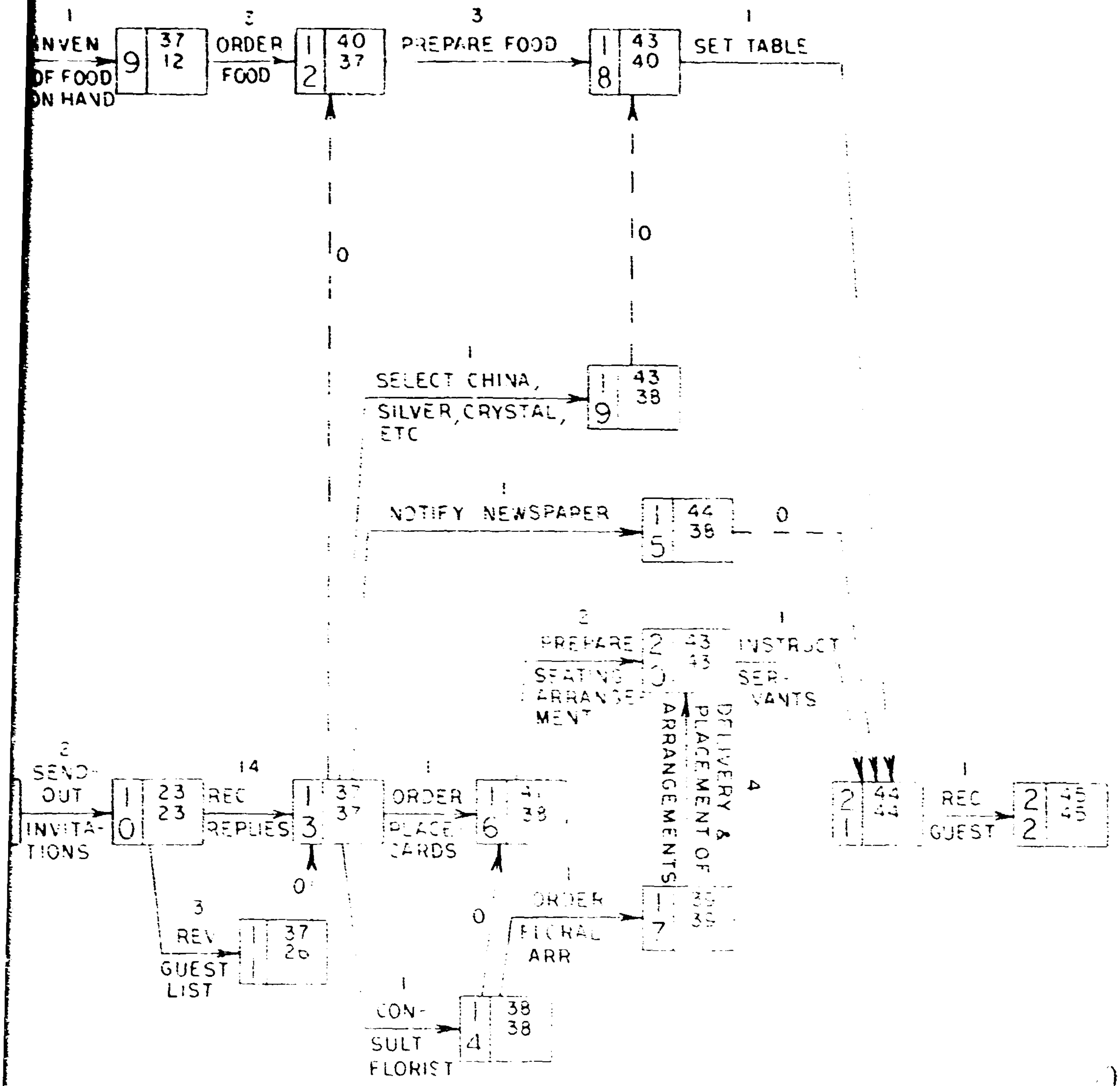
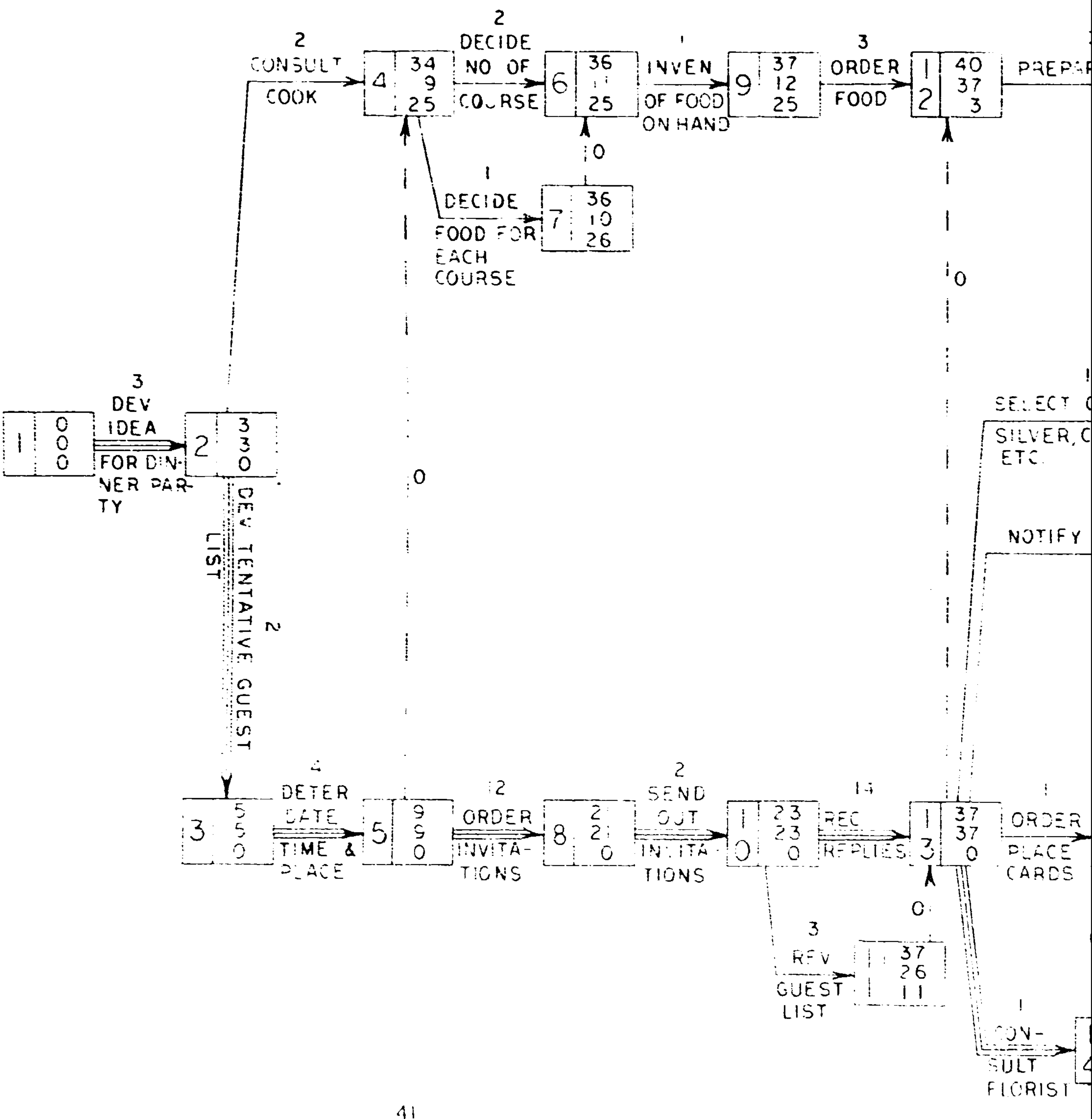
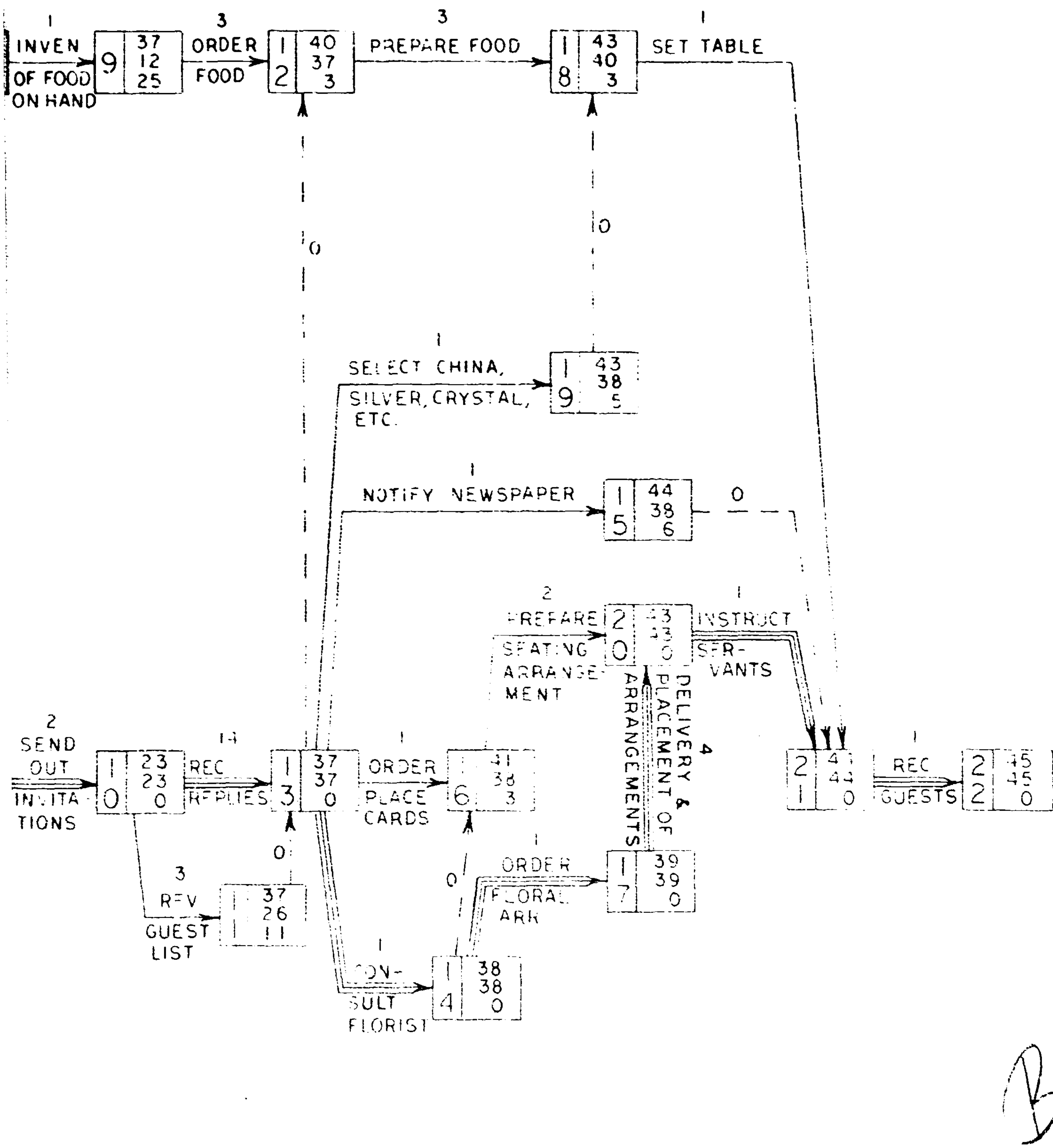
UTANTE DINNER PARTY



DEBUTANTE DINNER PARTY



UTANTE DINNER PARTY



ACTIVITY NETWORK

CHANGING A TIRE

DESCRIPTION OF ACTIVITIES

Listed below are a number of activities which may be involved in a plan or network for changing a flat tire. Time estimates (durations) in minutes have been assigned for each activity.

Activity	Duration
Remove lugs	3
Replace screwdriver	1
Tighten lugs	2
Close trunk	1
Position jack	4
Put on spare	2
Put flat in trunk	4
Remove hub cap	1
Get lug wrench	2
*Stop car	2
Get spare tire	7
Remove tire	1
Drive off safely	3
Replace jack	3
Jack up car	1
Get screwdriver	2
Open trunk	2
Replace lugs	3
Get jack	5
Loosen lugs	2
Replace hub cap	1
Lower car	2
Replace wrench	1

First Requirement:

Construct a PERT network for the tire changing operation using the information shown:

Parameters:

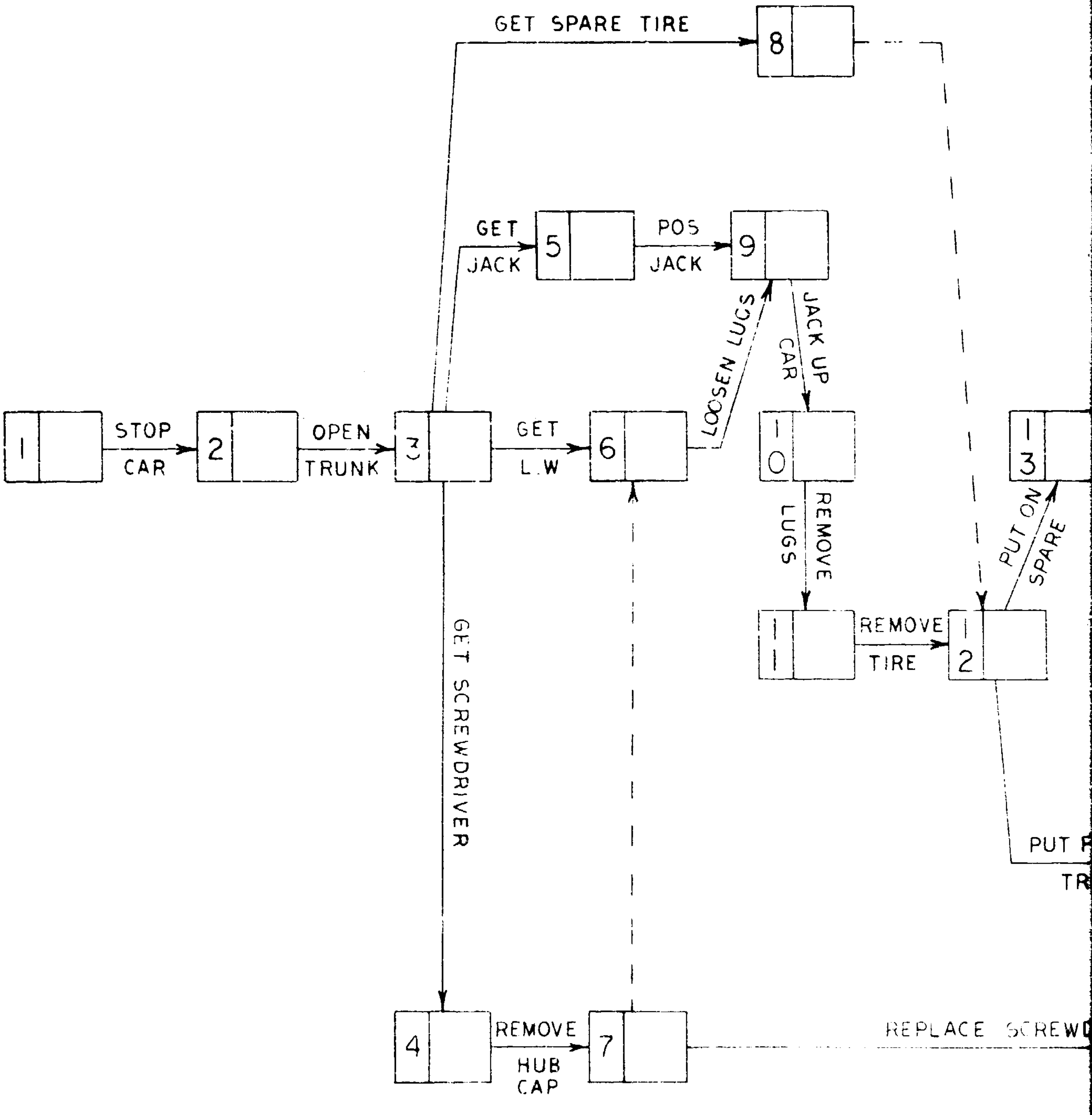
1. There is no limit on the number of people available to accomplish the operation.

2. All tasks take the time period listed and must be performed, regardless of the number of people employed.

3. Loosen the wheel lugs before the car is jacked up.

4. Lower the car before tightening the lugs.

*First Activity

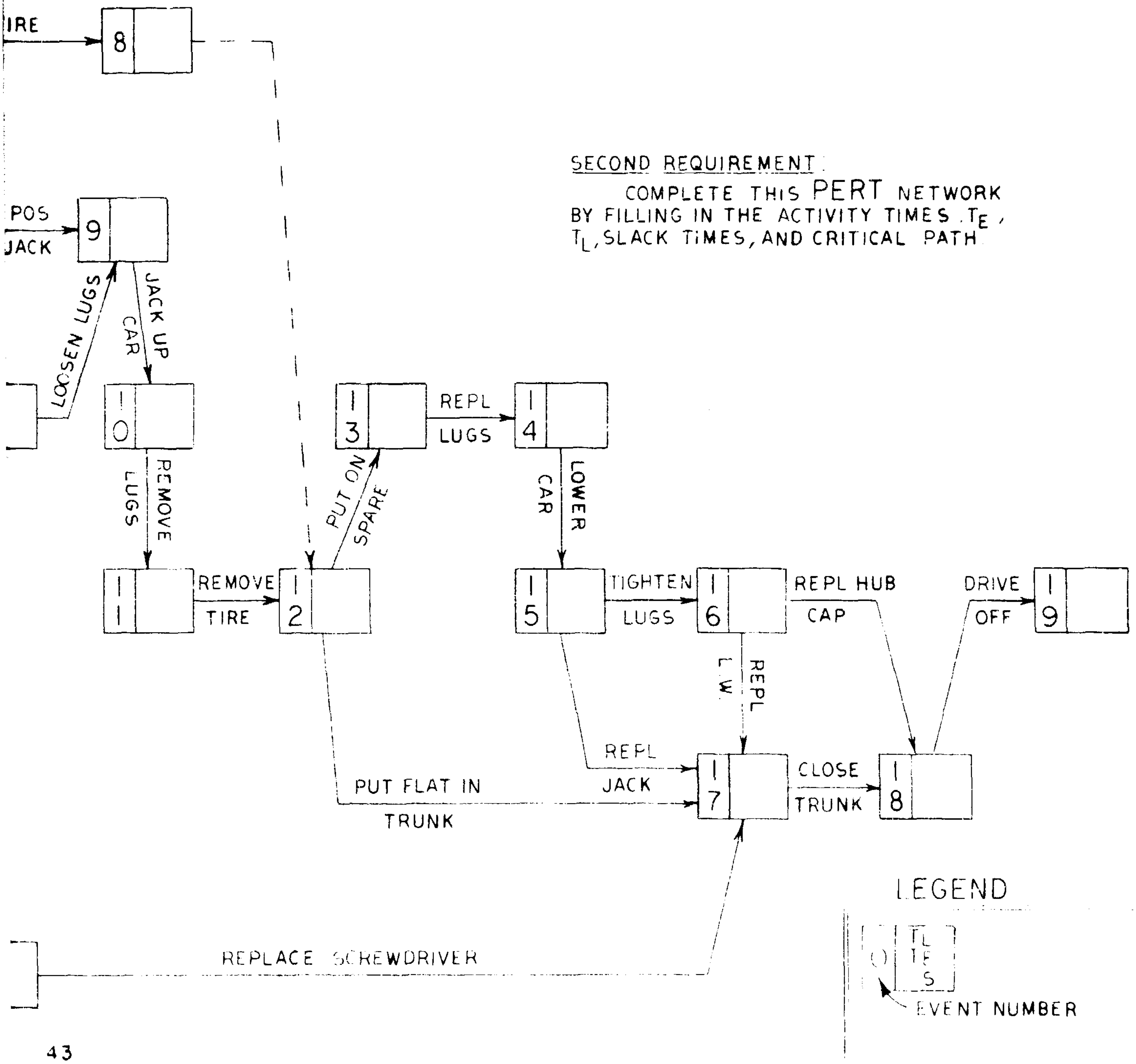


GET SPARE TIRE
GET JACK
POS JACK
STOP CAR
OPEN TRUNK
GET L.W
LOOSEN LUGS
JACK UP CAR
REMOVE LUGS
REMOVE TIRE
PUT ON SPARE
GET SCREWDRIVER
REMOVE HUB CAP

CHANGING A TIRE

SECOND REQUIREMENT:

COMPLETE THIS PERT NETWORK BY FILLING IN THE ACTIVITY TIMES T_E, T_L, SLACK TIMES, AND CRITICAL PATH.



THIRD REQUIREMENT - (MANPOWER SCHEDULE)

Construct a manpower distribution matrix using the tire problem PERT Network according to the following:

1. Start all activities at the earliest possible time (T_E).

2. Compute the earliest completion time by adding the activity expected time to the earliest start time of that activity.

3. Draw a solid line, representing the activity duration, through these points.

4. Draw a dotted line from the activity completion time found in Step 3, to the latest possible completion time indicated on the PERT Network. The time indicated by the dotted line shall be referred to as excess time.

5. Each overlapping activity requires one man for its completion with one exception - activity 14-15 requires two men.

CHANGING A TIRE

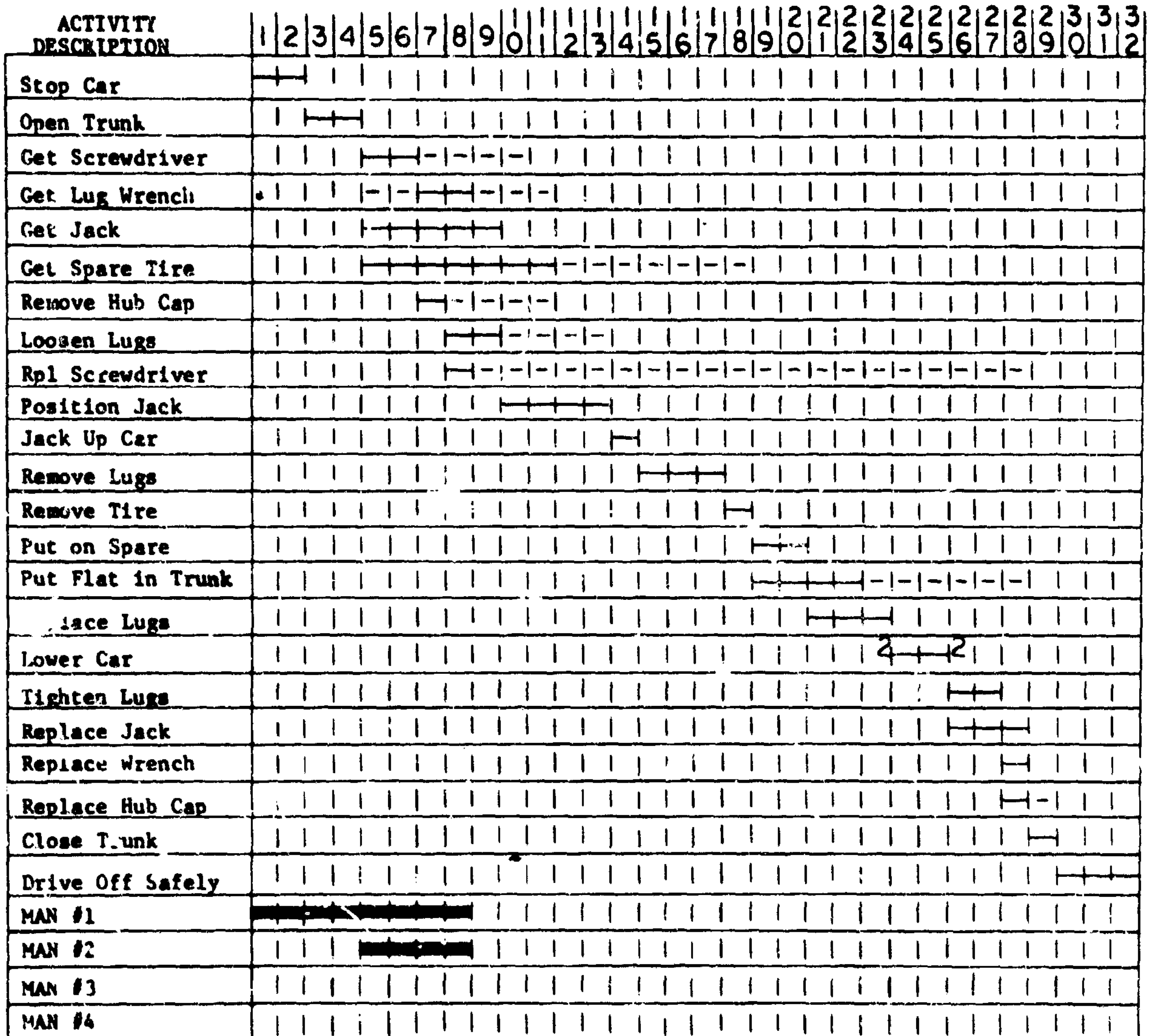
MANPOWER DISTRIBUTION

ACTIVITY DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Stop Car			1+2																													
Open Trunk					2+3																											
Get Screwdriver											3+4																					
Get Lug wrench												3+6																				
Get Jack										3+5																						
Get Spare tire																			3+8													
Remove Hub cap																																
Loosen Lugs																																
Rpl Screwdriver																																
Position Jack																																
Jack up Car																																
Remove Lugs																																
Remove Tire																																
Put on Spare																																
Put Flat in Trunk																																
Replace Lugs																																
Lower Car																																
Tighten Lugs																																
Replace Jack																																
Replace Wrench																																
Replace Hub C																																
Close Trunk																																
Drive Off Safely																																
MAN # 1																																
MAN # 2																																
MAN # 3																																
MAN # 4																																

MEN REQUIRED ________

CHANGING A TIRE

MANPOWER DISTRIBUTION



BY SHIFTING ACTIVITIES INTO THE EXCESS TIME RANGE WHEN ADVANTAGEOUS, WHAT IS THE MINIMUM NUMBER OF MEN REQUIRED? INDICATE YOUR SOLUTION ON THE MANPOWER DISTRIBUTION CHART. ALSO INCLUDE A MANPOWER SUMMARY

MEN REQUIRED ________

NOTE THAT THE FIRST SEVEN ACTIVITIES HAVE BEEN SHIFTED

COMPUTER PRINTOUT OF TIRE PROBLEM

Several Computer programs from major manufacturers of Electronic Data Processing machines are available for handling PERT Networks. These programs range from PERT/TIME routines, which may be put on a small machine, to PERT/COST routines, which require extensive storage.

The page following this written narrative is a sample printout from a Honeywell PERT/TIME 400/1400 program. It represents a portion of the tire problem, where time in minutes has been changed to weeks.

In the upper left hand corner of the printout appears the title block stating the name of the using organization. In the right corner, is a time block which includes a reference date and report date. The reference date is time zero, or the start of the project. The report date is the time the Computer Run was processed.

In the top center of the page, is a statement indicating that output is sequenced by CUMULATIVE EXPECTED TIME. That is, the order of printout is based on earliest times, starting with the first activity to be finished, working to the last. When two activities have the same earliest time, sequence is determined by placing the activity with least slack first.

Next, we see a line consisting of ACT, TITLE.ACT - EXPECTED TIME, etc. A number sign appearing under ACT tells us that the activity is currently in progress. Underneath the title is the description of the activity. At the end of the title, is a symbol indicating which man is performing the work - 1ST man or 2ND man (1STM or 2NDM).

To the right of title is ACTIVITY EXPECTED TIME, or the duration of the activity. Next, comes CUMULATIVE EXPECTED TIME (earliest time) given in terms of weeks past the reference time of zero. Following this is LATEST REQUIRED TIME (latest time). The SLACK, which is next in line is the difference between T_L and T_E. The EXPECTED DATE is the earliest time in terms of calendar dates. The REQUIRED DATE is an identical presentation of latest times. The SCHEDULED DATE is the time by which you wish the job completed, in order to accomplish the project with two men.

Compare this printout to the times found on the completed tire problem network and manpower distribution. The Calendar Conversion Table for EXHIBIT 9 is the basis for converting weeks to dates on this printout.

PERT BRANCH
TECH SUPPORT DIRECTORATE
EDGEWOOD ARSENAL
TIRE PROBLEM NETWORK

OUTPUT SEQUENCE
CUMULATIVE EXPECTED

A C T	PRECEDING EVENT NO.	SUCCEEDING EVENT NO.	TITLE		---------WEEKS-- ACT. EXPD TIME	CUM. EXPD TIME
	0001	0002	STOP CAR	1STM	2	2
	0002	0003	OPEN TRUNK	1STM	2	4
	0003	0004	GET SCREWDRIVER	1STM	2	6
#	0003	0006	GET LUG WRENCH	1STM	2	6
	0004	0007	REMOVE HUB CAP	1STM	1	7
	0007	0006	DEPENDENCY LINE		0	7
	0007	0017	REPLACE SCREWDRIVER	1STM	1	8
#	0003	0005	GET JACK	2NDM	5	9
	0006	0009	LOOSEN LUGS	1STM	2	9
	0003	0008	GET SPARE TIRE	1STM	7	11
	0008	0012	DEPENDENCY LINE		0	11
	0005	0009	POSITION JACK	2NDM	4	13
	0009	0010	JACK UP CAR	2NDM	1	14
	0010	0011	REMOVE LUGS	2NDM	3	17
	0011	0012	REMOVE TIRE	2NDM	1	18

A

PAGE 1
REPORT DATE 072867
REFERENCE DATE 060167
FILE I.D. 042T
NETWORK NO. TIPRNET

OUTPUT SEQUENCE
CUMULATIVE EXPECTED TIME

TITLE		WEEKS ACT. EXPD TIME	CUM. EXPD TIME	LATE REQD TIME	SLACK	EXPD. DATE	REQD. DATE	SCHD. DATE
R	1STM	2	2	2	0	061567	061567	
NK	1STM	2	4	4	0	062967	062967	
WDRIVER	1STM	2	6	10	4	071367	081067	
WRENCH	1STM	2	6	11	5	071367	081767	072767
UB CAP	1STM	1	7	11	4	072067	081767	080367
CY LINE		0	7	11	4	072067	081767	
SCREWDRIVER	1STM	1	8	28	20	072767	120767	101267
:	2NDM	5	9	9	0	080367	080367	
UGS	1STM	2	9	13	4	080367	083167	081767
E TIRE	1STM	7	11	18	7	081767	100567	100567
CY LINE		0	11	18	7	081767	100567	
JACK	2NDM	4	13	13	0	083167	083167	
CAR	2NDM	1	14	14	0	090767	090767	
UGS	2NDM	3	17	17	0	092867	092867	
TIRE	2NDM	1	18	18	0	100567	100567	

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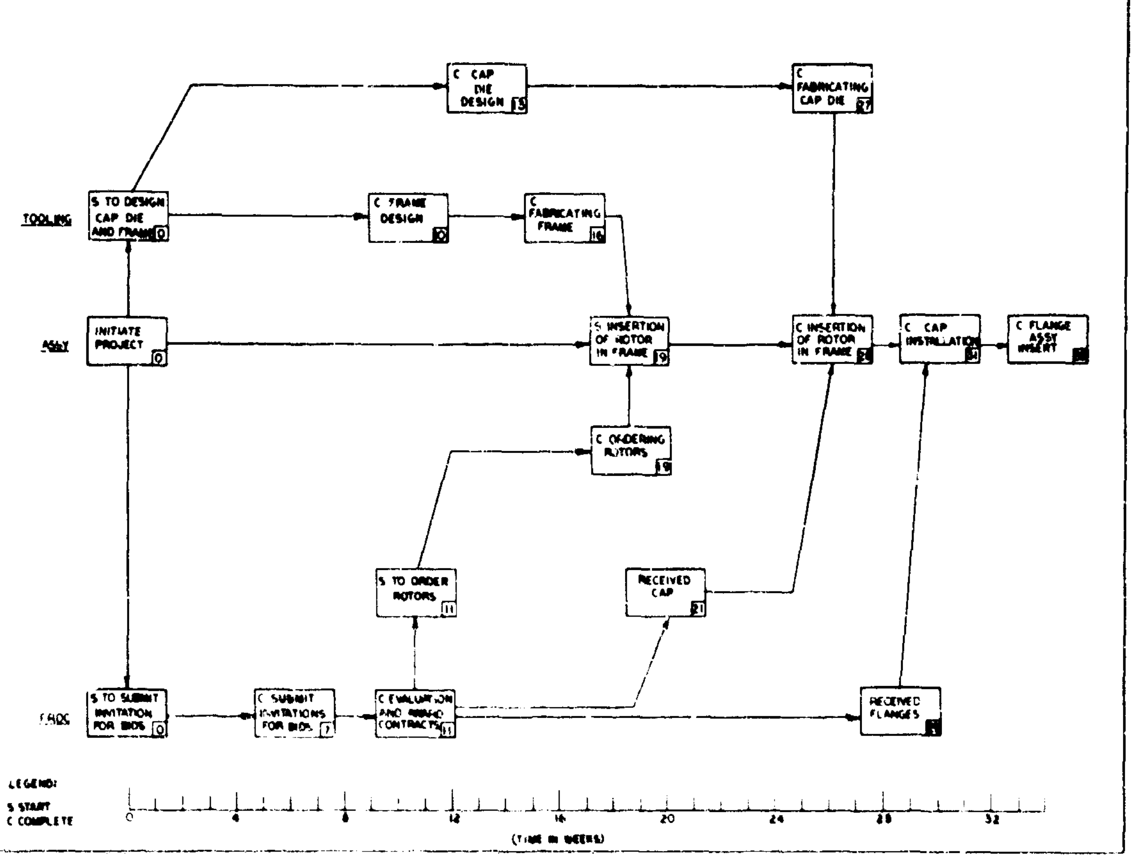
EXHIBIT 9



C CAP DIE DESIGN 15
C FABRICATING CAP DIE 27
TOOLING
S TO DESIGN CAP DIE AND FRAME 0
C FRAME DESIGN 10
C FABRICATING FRAME 16
ASSY
INITIATE PROJECT 0
S INSERTION OF ROTOR IN FRAME 19
C INSERTION OF ROTOR IN FRAME
C CAP INSTALLATION
C FLANGE ASSY INSERT
C ORDERING ROTORS 19
S TO ORDER ROTORS 11
RECEIVED CAP 21
S TO SUBMIT INVITATION FOR BIDS 0
C SUBMIT INVITATIONS FOR BIDS 7
C EVALUATION AND AWARD CONTRACTS 11
RECEIVED FLANGES
LEGEND:
S START
C COMPLETE
0
4
8
12
16
20
24
28
32
(TIME IN WEEKS)

CONVERSION TABLE

EXHIBIT #9

0 = 1 Jun 67
1 = 8 Jun 67
2 = 15 Jun 67
3 = 22 Jun 67
4 = 29 Jun 67
5 = 6 Jul 67
6 = 13 Jul 67
7 = 20 Jul 67
8 = 27 Jul 67
9 = 3 Aug 67
10 = 10 Aug 67
11 = 17 Aug 67
12 = 24 Aug 67
13 = 31 Aug 67
14 = 7 Sep 67
15 = 14 Sep 67
16 = 21 Sep 67
17 = 28 Sep 67
18 = 5 Oct 67
19 = 12 Oct 67
20 = 19 Oct 67
21 = 26 Oct 67
22 = 2 Nov 67
23 = 9 Nov 67
24 = 16 Nov 67
25 = 23 Nov 67
26 = 30 Nov 67
27 = 7 Dec 67
28 = 14 Dec 67
29 = 21 Dec 67
30 = 28 Dec 67
31 = 4 Jan 68
32 = 11 Jan 68
33 = 18 Jan 68
34 = 25 Jan 68
35 = 1 Feb 68
36 = 8 Feb 68
37 = 15 Feb 68
38 = 22 Feb 68
39 = 29 Feb 68
40 = 7 Mar 68

EVENT ORIENTED NETWORK

You probably recognized that the network you just completed was activity oriented. That is, all time considerations were for the activities. It might be that instead of wanting to know how long an activity takes, you would rather know when it is complete or when a new one starts. You can event orient your network to show this.

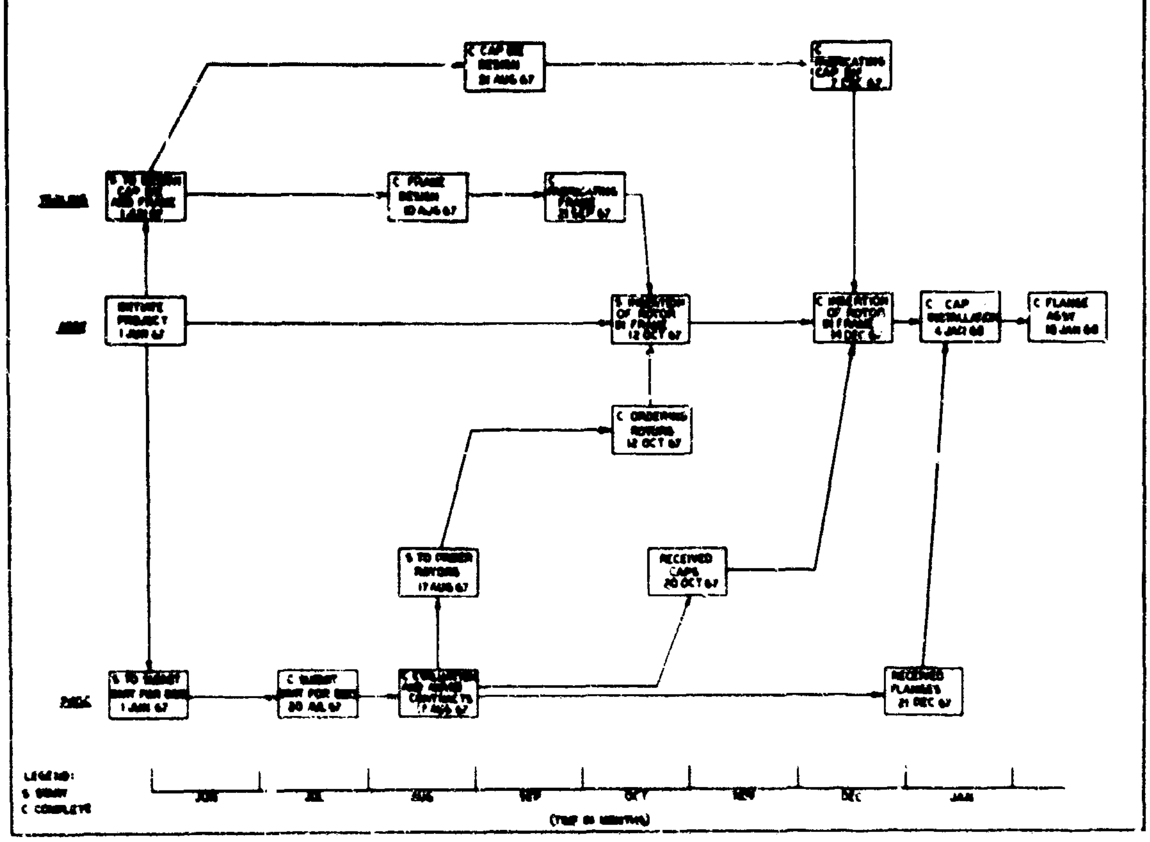
As stated earlier, events are instantaneous and indicate a point in time. An event oriented network might reflect target dates on which to either start or complete events.

EXHIBIT 9 is an event oriented (sometimes called Milestone) network of the Breaker problem.

The times in the lower right corners represent the number of weeks from the start time, that we anticipate the event shown in that rectangle will be complete. For example, "design frame" should be completed the end of the tenth week.

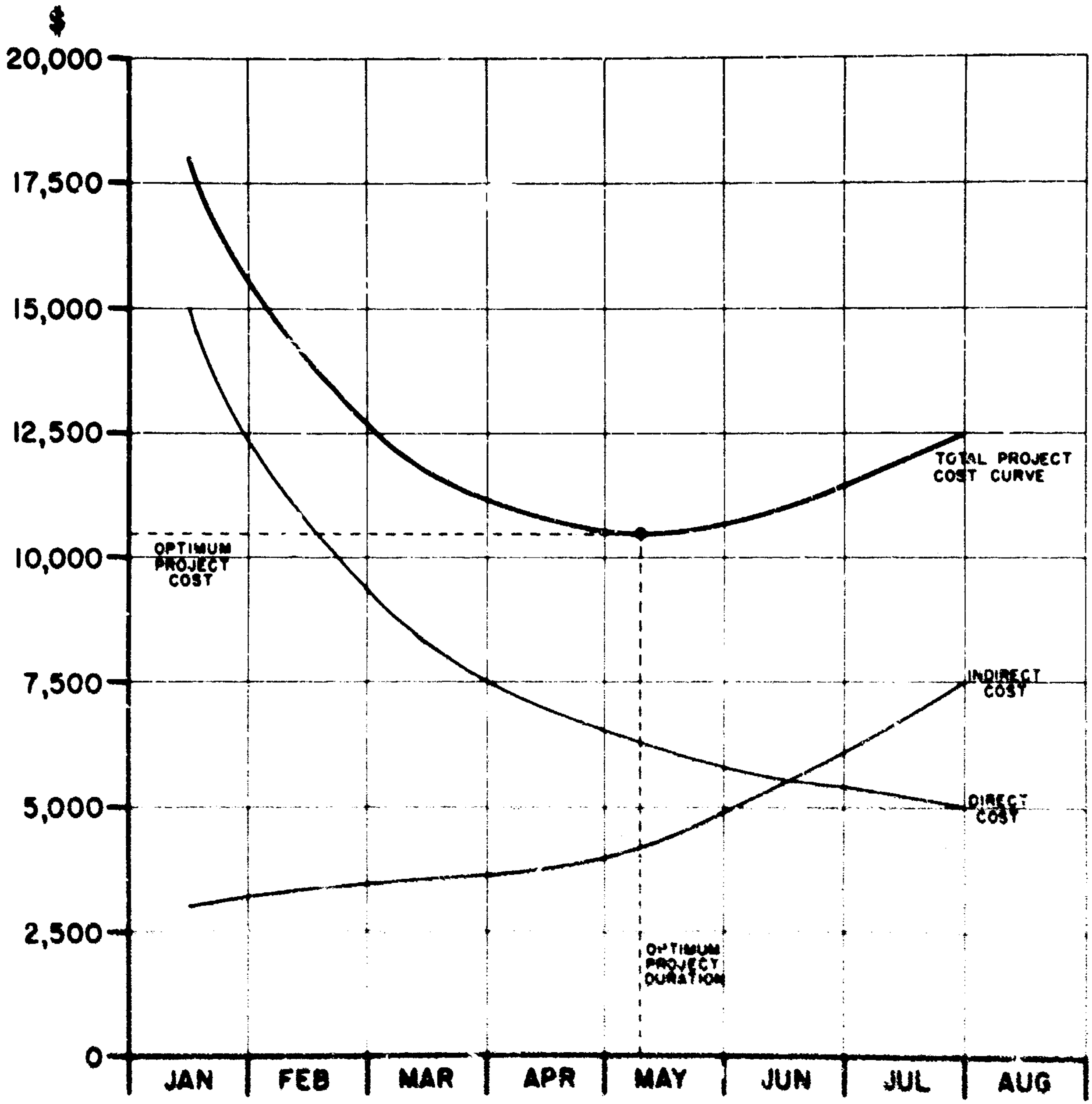
Calendar dates for event completions can also be determined when you know the starting date. For example, suppose we wish to start our Breaker program on 1 June 1967. What will the event times be? By referring to EXHIBIT 9, we see that "complete installation of cap" is scheduled for completion thirty-one weeks after the project starts. The Calendar Conversion table on page 51 indicates the calendar date corresponding to this week number. According to the calendar this completion date will be 4 January 1968 as indicated in EXHIBIT 10.

EXHIBIT 10



C CAP DIE DESIGN 31 AUG 67
S TO PROPER ROTORS 17 AUG 67
C ORDERING ROTORS 12 OCT 67
RECEIVED CAPS 20 OCT 67
C CAP INSTALLATION 4 JAN 68
C FLANGE ASSY 18 JAN 68
RECEIVED FLANGES 21 DEC 67
C SUBMIT BRAT FOR BIDS 30 AUG 67
LEGEND:
C COMPLETE
(TIME IN MONTHS)

PROJECT COST ANALYSIS



PROJECT COST ANALYSIS

(Partition Warehouse)

Months Required	Direct Labor Costs	Indirect Costs
.5	15,000	3,000
1.0	12,400	3,100
2.0	9,300	3,400
3.0	7,500	3,600
4.0	6,500	4,000
5.0	5,750	4,900
6.0	5,400	6,000
7.0	5,000	7,500

1. Optimum project duration is at 6 May.
2. Optimum project cost is $10,300.
3. Although the optimum duration is at 6 May, there are other dates when cost are equal.

   Ex: 16 Mar and 6 July - cost is $11,700.

EXHIBIT 11

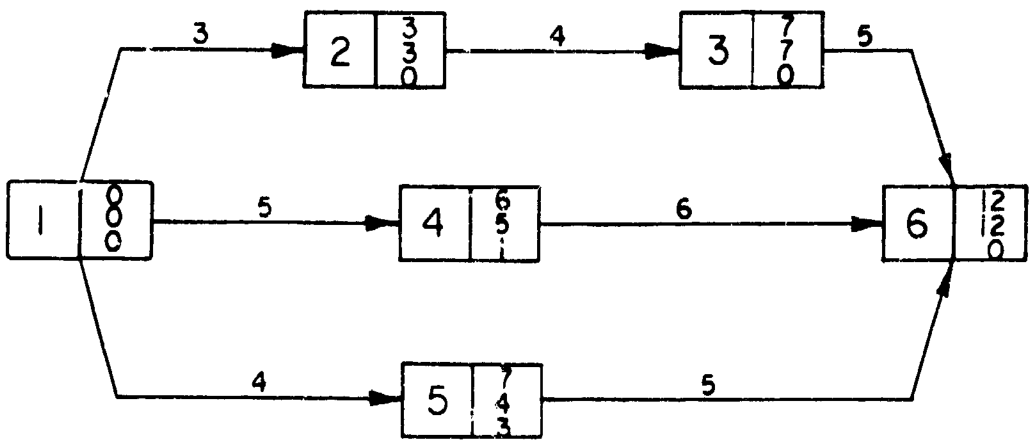


EXHIBIT 12

PROJECT COSTS

ACTIVITY	NORMAL t_e	CRASH t_e	COST AT NORMAL t_e	EXTRA CRASH COST PER WEEK
1,2	3	2	$120	$30
1,4	5	3	$260	$40
1,5	4	4	$220	—
2,3	4	3	$210	$60
3,6	5	3	$200	$50
4,6	6	4	$280	$70
5,6	5	4	$270	$30

COSTS

Another important project variable is money. Each activity in a project takes a certain amount of time and costs a certain amount of money. When it is necessary to reduce the project time, you should be able to spot which activities to shorten. In this exercise, we consider both time and costs in determining which activities to reduce in order to get optimum cost for the entire project.

Let's assume that these costs are direct labor costs and that you as a foreman know the following:

1. The expected number of weeks for each activity.

2. The number of weeks you would require to perform each activity on a crash basis.

3. The normal costs for each activity.

4. The additional crash costs per activity*.

The problem can be set up as follows:

The network and information in EXHIBIT 11 and EXHIBIT 12 are for the development of a bomb filling operation. The PERT manager asks you to reduce the project time to 10 weeks. Use the most economical method and determine the cost. What is the critical path for the 10 week operation? Refer to EXHIBITS 11 and 12.

Our first problem is to determine how much the normal cost will be for the twelve week schedule. So add up the normal costs from EXHIBIT 12 as follows:

*Extra Crash Cost per week = the additional cost for shortening a particular activity by one unit of time.

Activity 1,2	=	$120
Activity 1,4	=	260
Activity 1,5	=	220
Activity 2,3	=	210
Activity 3,6	=	200
Activity 4,6	=	280
Activity 5,6	=	270
		$1560

Thus, $1560.00 represents the normal 12 weeks costs. In order to complete the project in less than 12 weeks will require more than the normal cost. We are sure of this, but we don't know how much or which activities we can change in order to give us the most economical operation.

From 12 weeks to 10 weeks means that we must shorten our program by 2 weeks. But, which activity or activities will give us the most economical solution? There are three paths through the network. Let's define the possible ways of shortening our network on the basis of these paths.

They are:

1. For path 1-5, 5-6" These two activities add up to less than 10 weeks so there is no point in changing either of their activity times.

2. For path 1-4, 4-6: Reduce either activity by 1 week.

3. For path 1-2, 2-3, 3-6:

   a. Reduce 1-2 and 2-3 by 1 week each.

   b. Reduce 1-2 and 3-6 by 1 week each.

   c. Reduce 2-3 and 3-6 by 1 week each.

   d. Reduce 3-6 by 2 weeks.

Let's start with step 2 where we must reduce the overall time by one week.

STEP 2 - Change 1-4 to 4 weeks - additional cost is $40

and 4-6 remains 6 weeks

or Change 4-6 to 5 weeks - additional cost is $70

and 1-4 remains 5 weeks

Notice that it is cheaper to put activity 1-4 on a 4 week schedule, so change the time on that activity to 4.

STEP 3a - Change 1-2 to 2 weeks - additional cost is $30

and Change 2-3 to 3 weeks - additional cost is 60

and 3-6 remains 5 weeks

$90

STEP 3b - Change 1-2 to 2 weeks - additional cost is $30

and Change 3-6 to 4 weeks - additional cost is 50

and 2-3 remains 4 weeks

$80

STEP 3c - Change 2-3 to 3 weeks - additional cost is $60

and Change 3-6 to 4 weeks - additional cost is 50

and 1-2 remains 3 weeks

$110

STEP 3d - Change 3-6 to 3 weeks - additional cost is $100

and 1-2 remains 3 weeks

and 2-3 remains 4 weeks

$100

Considering steps 3a, 3b, 3c, and 3d which is the most economical? Step 3b is correct. So change activities 1-2 to a 2, and 3-6 to a 4, on EXHIBIT 11. All paths leading to the completion of the project are 10 weeks or less. Now let's compute our most economical cost.

Activity		Additional Cost
1-2		$ 30
1-4		40
3-6		50
	Total Add'l Cost	$ 120
	Total original cost	1,560
	New Total Cost	$ 1,680

Any other combinations of changes would have cost more and thus been less economical.

INTRODUCTION

THE LAUNCHING OF A NEW PRODUCT

In the description of this problem, activity costs have been assigned. EXHIBIT A indicates the duration and cost under a NORMAL operation, a CRASH operation and an Optimum CRASH operation.

In solving this problem, the cost of the NORMAL operation was developed by adding all normal costs together EXHIBIT I. A similar network (EXHIBIT II) was then developed to depict the same program on a crash basis. In like manner, all crash costs were added together. At this point it is readily apparent that this crash cost is not the optimum crash cost. To optimize cost requires that crash dollars be used only when they are necessary. For example, why reduce a non-critical path to seven (7) days when ten (10) days will do the job at less expense. The optimum crash program then takes into consideration dollars as well as time. In some cases, dollars have to be sacrificed for time in order to keep with the rules of activity completion. EXHIBIT III indicates the optimum crash for this problem.

THE LAUNCHING OF A NEW PRODUCT

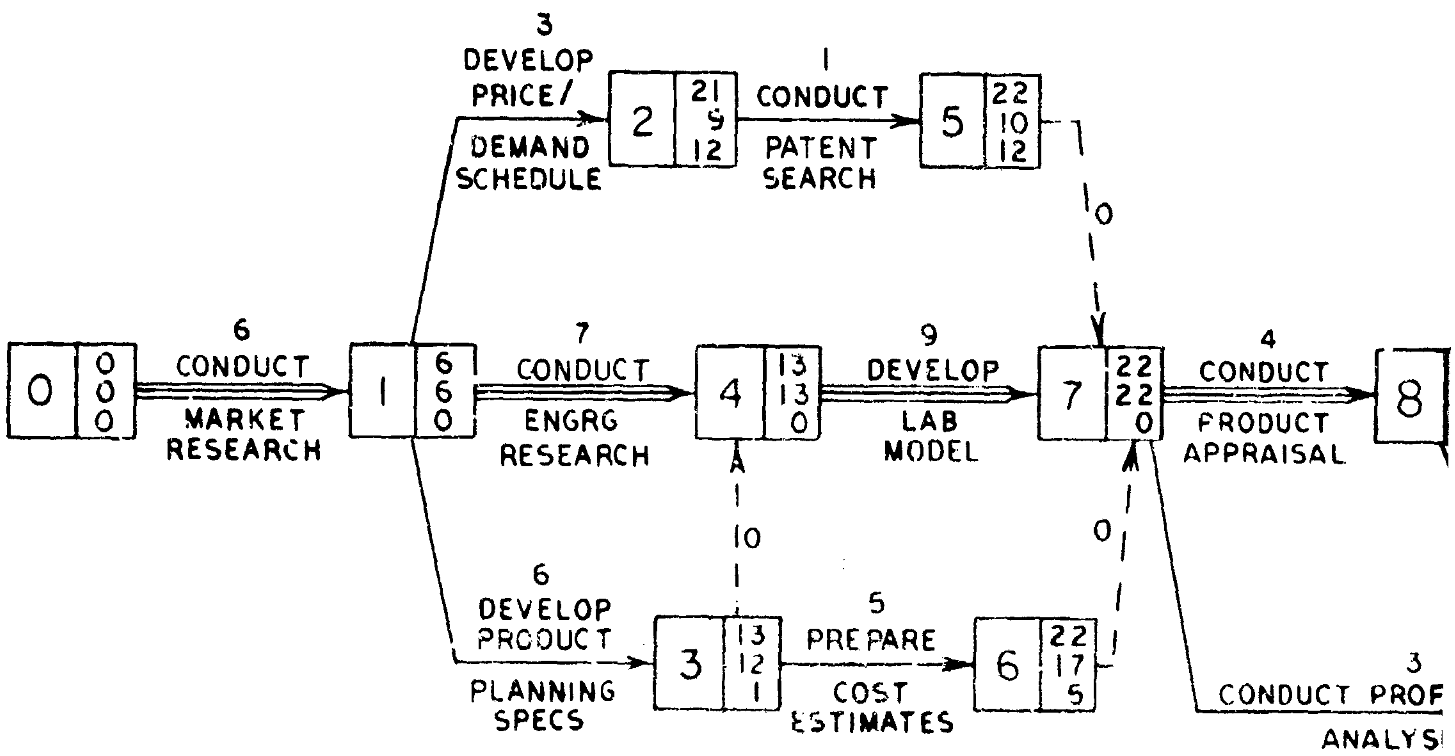
Activity Description	NORMAL Duration	NORMAL Tot Cost	CRASH Duration	CRASH Tot Cost	Optimum Crash Duration	Optimum Crash Tot Cost
Conduct Market Res	6	30,000	2	125,000	2	125,000
Dev Price Demand Sched	3	6,250	1	27,400	3	6,250
Dev Product Plng Specs	6	28,120	4	48,500	4	48,500
Conduct Engr Research	7	33,750	4	159,590	4	159,590
Conduct Patent Search	1	10,000	1	10,000	1	10,000
Prepare Cost Estimates	5	9,380	2	26,420	5	9,380
Dev Lab Model	9	51,250	5	158,760	5	158,760
Conduct Product Appraisal	4	15,650	2	51,950	2	51,950
Conduct Profit & Loss Analysis	3	5,630	1	24,750	3	5,630
Design Final Product	8	40,620	5	151,870	5	151,870
Train Sales Force	1	5,000	1	5,000	1	5,000
Prepare Advertising	6	18,750	3	47,500	6	18,750
Issue Drawings and Specs	2	3,120	1	7,100	1	7,100
Determine Price	3	5,130	1	16,420	3	5,130
Establish Distr Outlets	8	56,250	5	132,500	8	56,250
Release Advertising	3	4,380	3	4,380	3	4,380
Determine Mfg Methods	2	5,630	1	14,200	2	5,630
Procure Raw Materials	3	3,750	2	9,250	3	3,750
Procure "Buy" Items	8	11,880	5	28,880	5	28,880
Prepare Service Literature	2	5,000	1	12,000	2	5,000
Design & Procure Pkg	4	10,500	1	73,700	4	10,500
Train Prod Personnel	1	9,370	1	9,370	1	9,370
Mftr "Make" Items	4	68,750	1	237,380	1	237,380
Assemble	4	44,380	3	95,750	3	95,750
Train Svc Organization	2	11,500	1	27,500	2	11,500
Test	2	12,500	2	12,500	2	12,500
Box, Pack and Ship	2	5,000	1	11,230	1	11,230
		$ 511,540		$ 1,528,900		$ 1,255,030

*When CRASH must be made, total duration is used.

EXHIBIT A

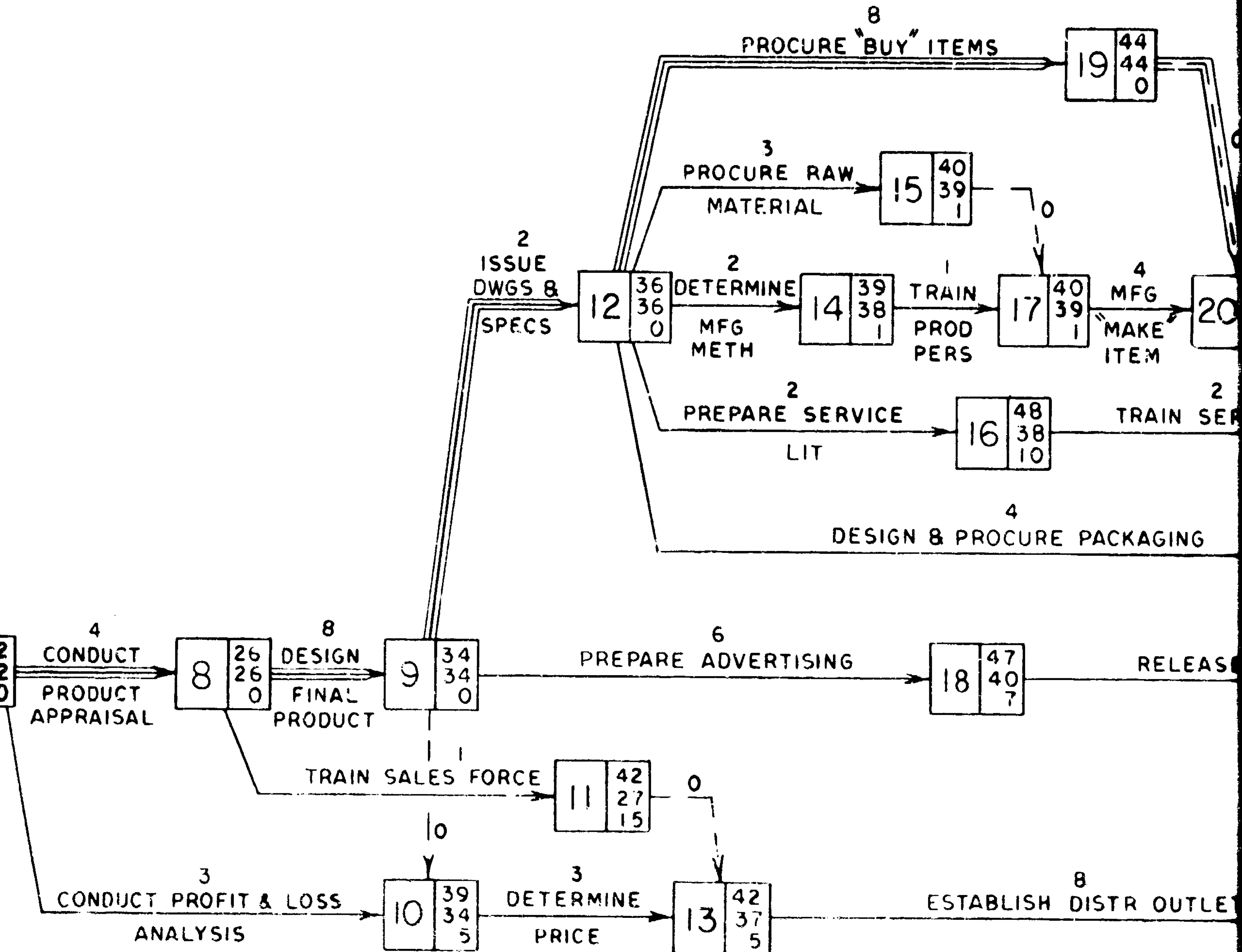
THE LAUNCHING OF A NEW PRODUCT

EXHIBIT NO. 1



NORMAL TOTAL COST $51154

	ACTIVITY DESCRIPTION	DURA-TION	COST
0–1	CONDUCT MARKET RESEARCH	6	30,00
1–2	DEVELOP PRICE DEMAND SCHEDULES	3	6,25
1–3	CONDUCT ENGINEERING RESEARCH	7	33,75
1–4	DEVELOP PRODUCT PLANNING SPECS	6	28,12
2–5	CONDUCT PATENT SEARCH	1	10,00
4–7	DEVELOP LAB MODEL	9	51.25
3–6	PREPARE COST ESTIMATES	5	9 38
7–8	CONDUCT PRODUCT APPRAISAL	4	15.65
7-10	CONDUCT PROFIT AND LOSS ANALYSIS	3	5 63

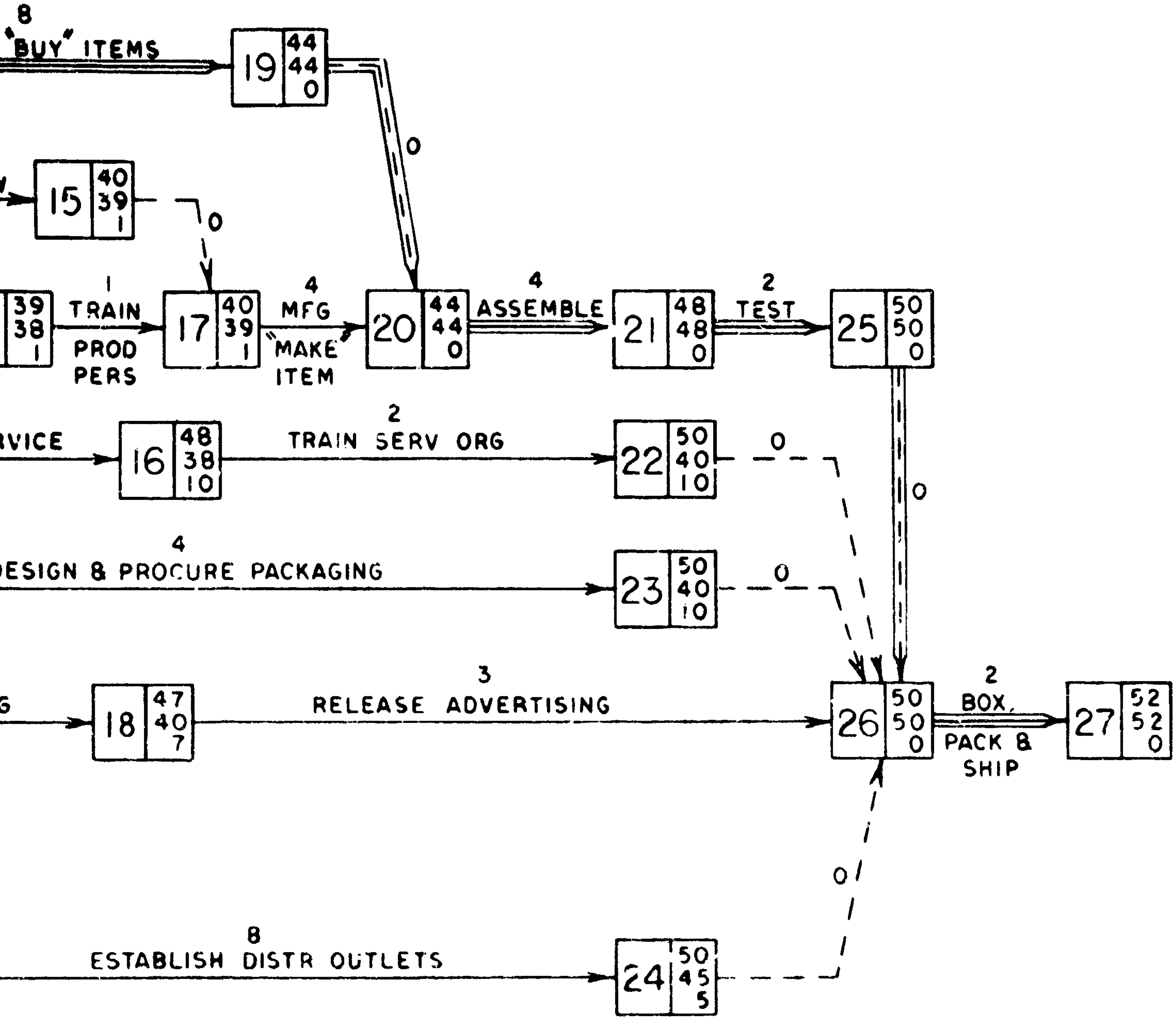


TOTAL COST $511,540

	DURATION	COST
	6	30,000
ULES	3	6,250
CH	7	33,750
PECS	6	28,120
	1	10,000
	9	51,250
	5	9,380
	4	15,650
LYSIS	3	5,630

8-9	DESIGN FINAL PRODUCT	8	40,620
8-11	TRAIN SALES FORCE	1	5,000
9-12	ISSUE DRAWINGS AND SPECS	2	3,120
9-18	PREPARE ADVERTISING	6	18,750
10-13	DETERMINE PRICE	3	5,130
12-14	DETERMINE MANUFACTURING METHODS	2	5,630
12-15	PROCURE RAW MATERIALS	3	3,750
12-16	PREPARE SERVICE LITERATURE	2	5,000
12-19	PROCURE "BUY" ITEMS	8	11,880

12-23	DESIGN AND
13-24	ESTABLISH
14-17	TRAIN PRO
16-22	TRAIN SERV
17-20	MANUFACTU
18-26	RELEASE A
20-21	ASSEMBLE
21-25	TEST
26-27	BOX PACK A

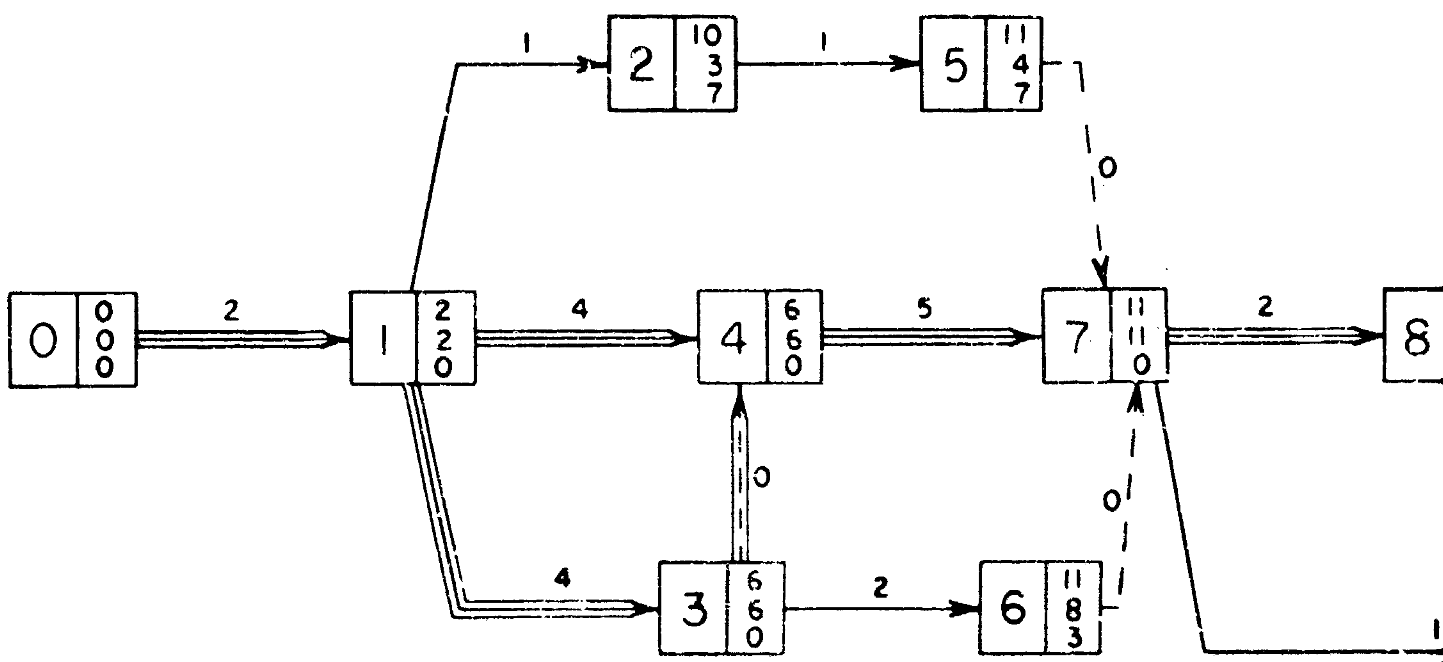


8	40,620	12-23 DESIGN AND PROCURE PACKAGING	4	10,500
1	5,000	13-24 ESTABLISH DISTRIBUTION OUTLETS	8	56,250
2	3,120	14-17 TRAIN PRODUCTION PERSONNEL	1	9,370
6	18,750	16-22 TRAIN SERVICE ORGANIZATION	2	11,500
3	5,130	17-20 MANUFACTURE "MAKE" ITEMS	4	68,750
2	5,630	18-26 RELEASE ADVERTISING	3	4,380
3	3,750	20-21 ASSEMBLE	4	44,380
2	5,000	21-25 TEST	2	12,500
8	11,880	26-27 BOX PACK AND SHIP	2	5,000

7/25/67/DRAWING NO 170-A

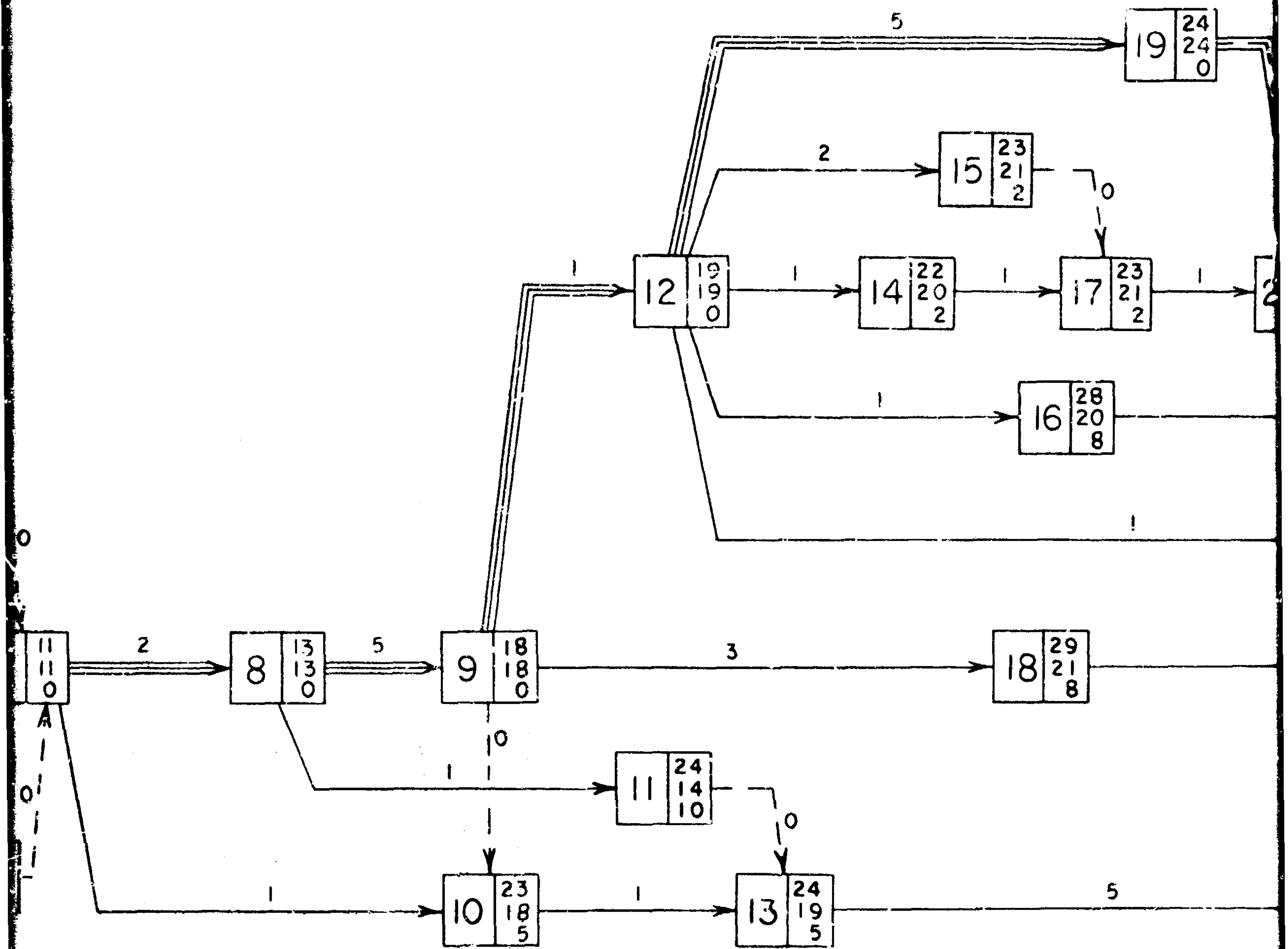
THE LAUNCHING OF A NEW PRODUCT

EXHIBIT NO: 2



TOTAL CRASH – TOTAL COST $1,52

	ACTIVITY DESCRIPTION	DURATION	COST
0-1	CONDUCT MARKET RESEARCH	2	125.0
1-2	DEVELOP PRICE DEMAND SCHEDULES	1	27.4
1-3	CONDUCT ENGINEERING RESEARCH	4	159.5
1-4	DEVELOP PRODUCT PLANNING SPECS	4	48.5
2-5	CONDUCT PATENT SEARCH	1	10.0
4-7	DEVELOP LAB MODEL	5	158.7
3-6	PREPARE COST ESTIMATES	2	26.4
7-8	CONDUCT PRODUCT APPRAISAL	2	51.9
7-10	CONDUCT PROFIT AND LOSS ANALYSIS	1	24.1

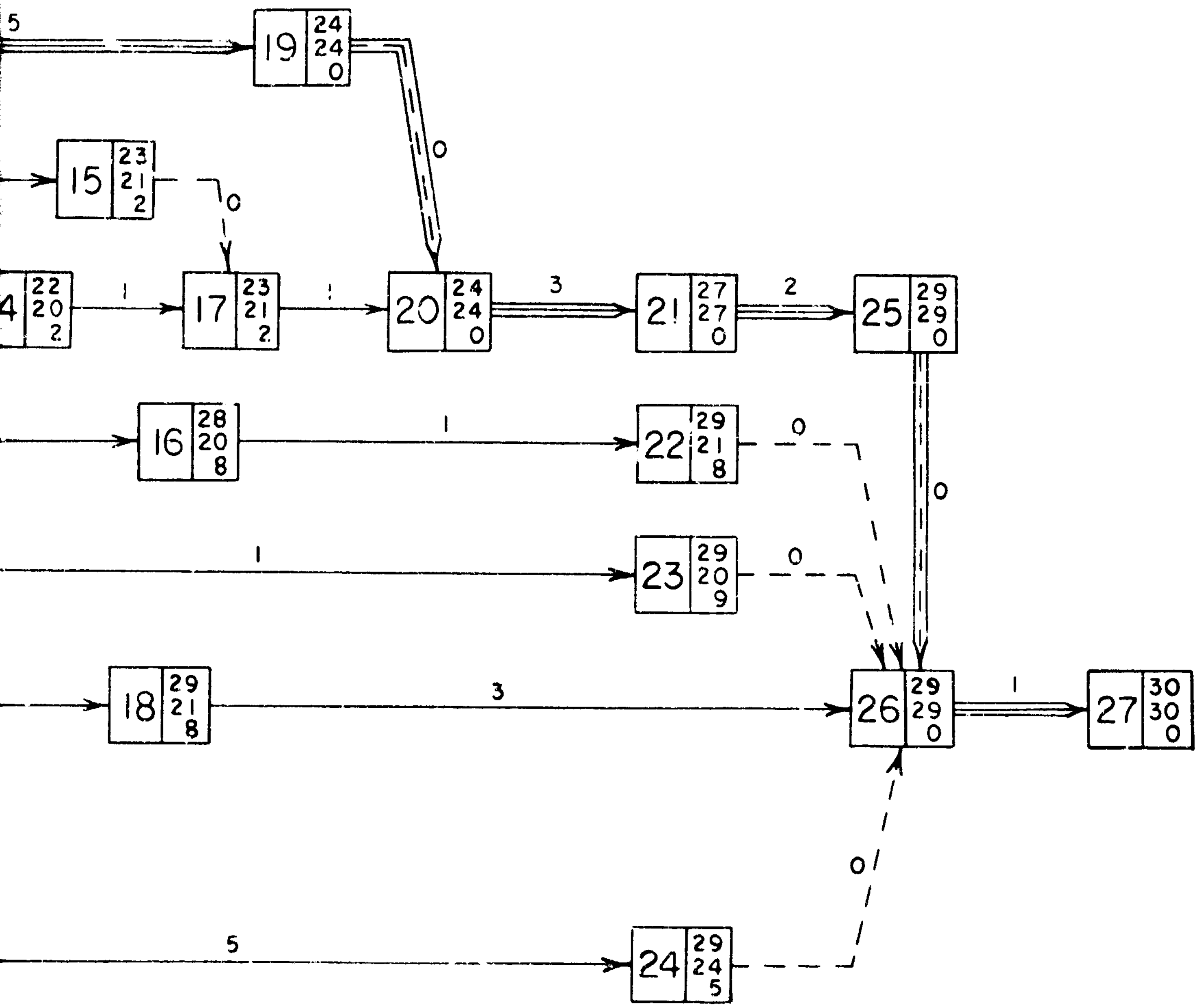


H—TOTAL COST $1,528,900

ON	DURATION	COST
H	2	125,000
HEDULES	1	27,400
ARCH	4	159,590
G SPECS	4	48,500
	1	10,000
	5	158,760
	2	26,420
AL	2	31,950
ANALYSIS	1	24,750

8-9	DESIGN FINAL PRODUCT	5	151,870
8-11	TRAIN SALES FORCE	1	5,000
9-12	ISSUE DRAWINGS AND SPECS	1	7,100
9-18	PREPARE ADVERTISING	3	47,500
10-13	DETERMINE PRICE	1	16,420
12-14	DETERMINE MANUFACTURING METHODS	1	14,200
12-15	PROCURE RAW MATERIALS	2	9,250
12-16	PREPARE SERVICE LITERATURE	1	12,000
12-19	PROCURE "BUY" ITEMS	5	28,880

12-23	DESIGN A
13-24	ESTABLIS
14-17	TRAIN PR
16-22	TRAIN SE
17-20	MANUFAC
18-26	RELEASE
20-21	ASSEMBL
21-25	TEST
26-27	BOX, PACK

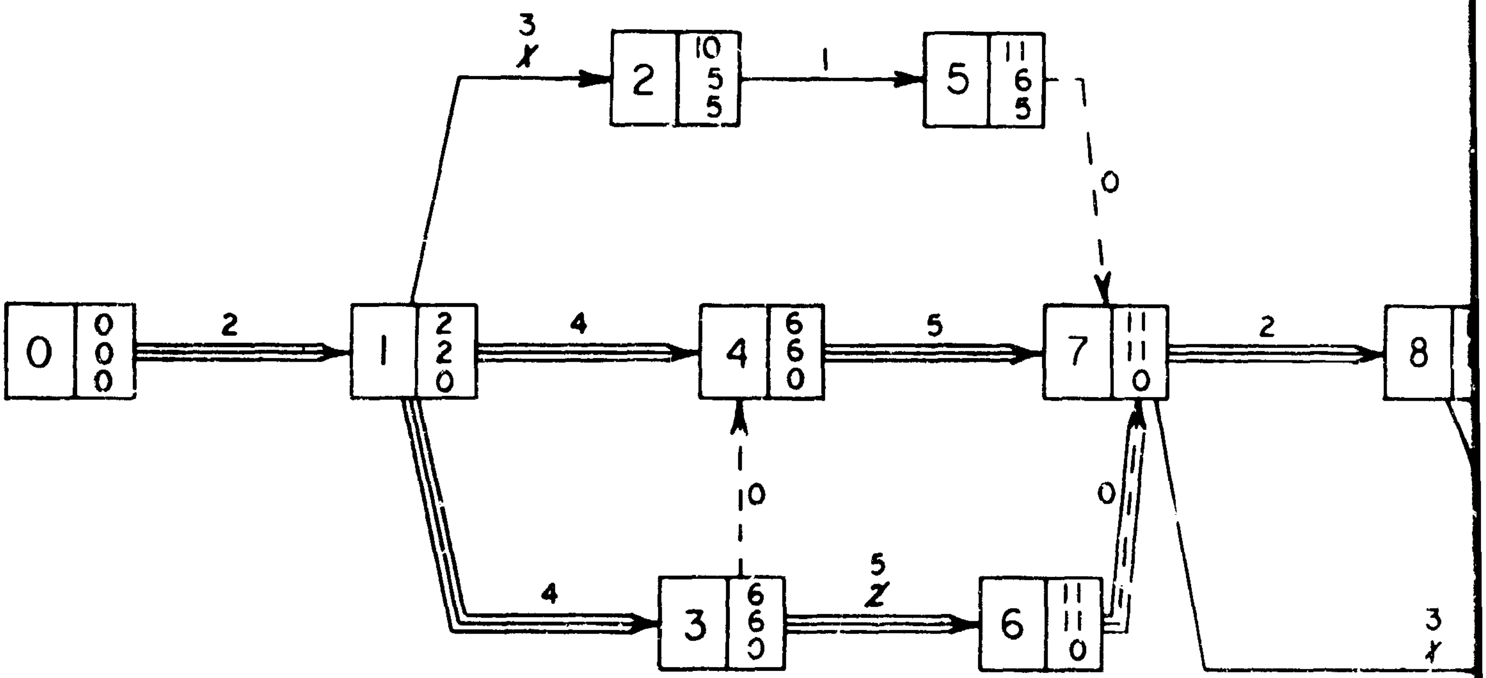


5	151,870	12-23 DESIGN AND PROCURE PACKAGING	1	73,700
1	5,000	13-24 ESTABLISH DISTRIBUTION OUTLETS	5	132,500
1	7,100	14-17 TRAIN PRODUCTION PERSONNEL	1	9,370
3	47,500	16-22 TRAIN SERVICE ORGANIZATION	1	27,500
1	16,420	17-20 MANUFACTURE "MAKE" ITEMS	1	237,380
1	14,200	18-26 RELEASE ADVERTISING	3	4,380
2	9,250	20-21 ASSEMBLE	3	95,750
1	12,000	21-25 TEST	2	12,500
5	28,880	26-27 BOX, PACK AND SHIP	1	11,230

7/26/67/DRAWING NO 170-B

THE LAUNCHING OF A NEW PRODUCT

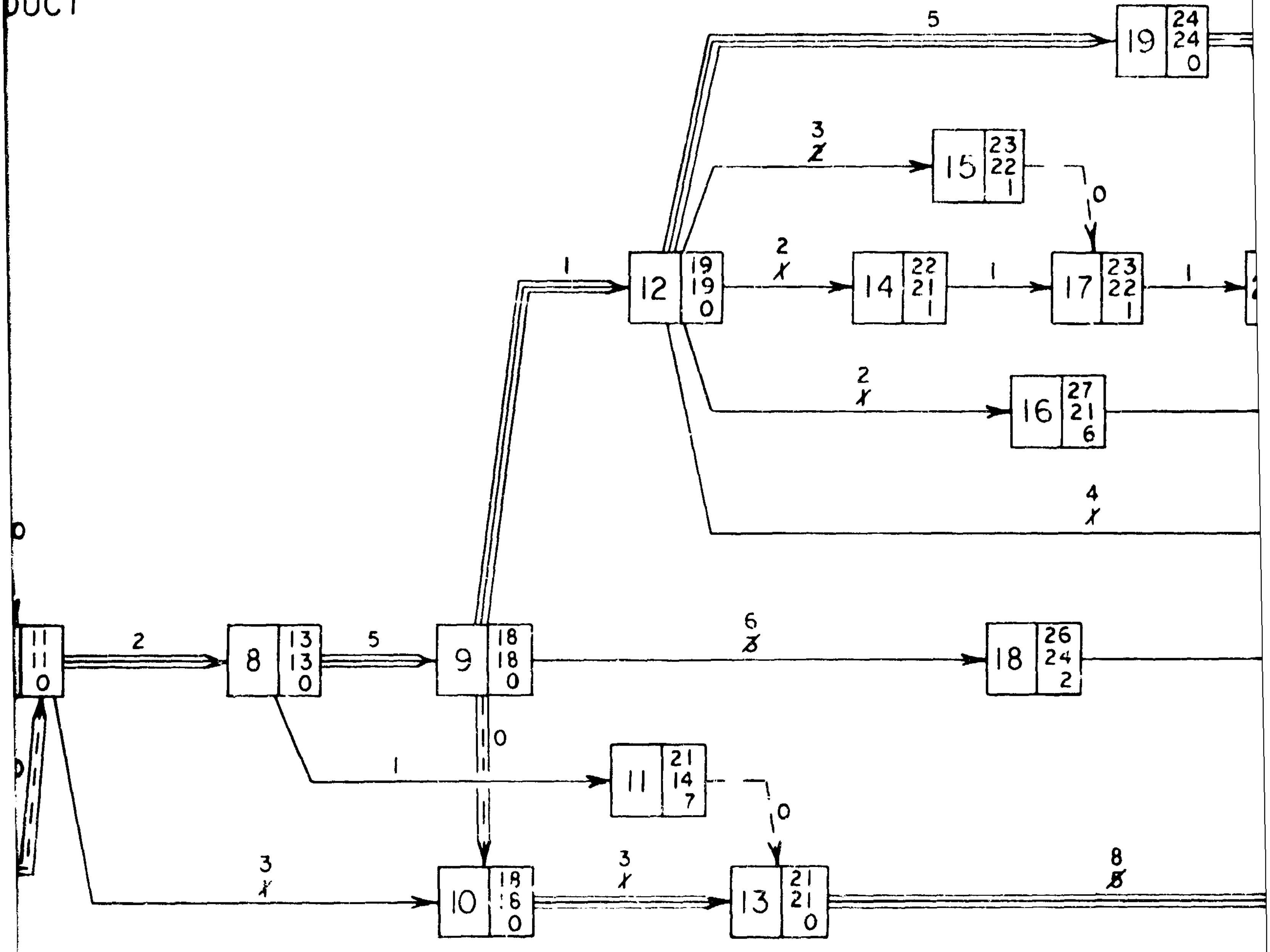
EXHIBIT NO: 3



PARTIAL CRASH - TOTAL COST $1,2

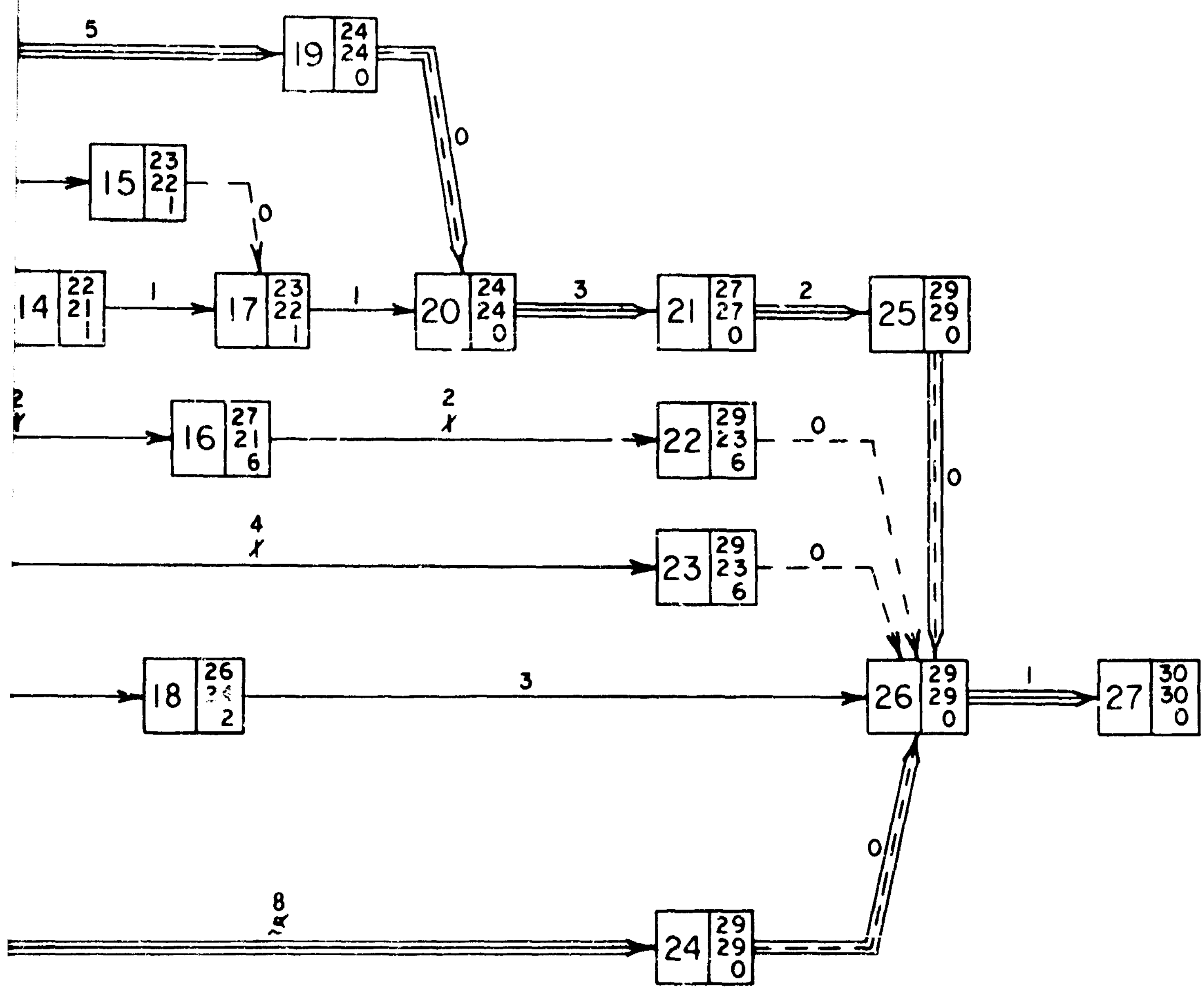
	ACTIVITY DESCRIPTION	DURATION	COST
0-1	CONDUCT MARKET RESEARCH	2	125,000
1-2	DEVELOP PRICE DEMAND SCHEDULES	3	6,250
1-3	CONDUCT ENGINEERING RESEARCH	4	159,590
1-4	DEVELOP PRODUCT PLANNING SPECS	4	48,500
2-5	CONDUCT PATENT SEARCH	1	10,000
4-7	DEVELOP LAB MODEL	5	158,760
3-6	PREPARE COST ESTIMATES	5	9,380
7-8	CONDUCT PRODUCT APPRAISAL	2	51,950
7-10	CONDUCT PROFIT AND LOSS ANALYSIS	3	5,630

DUCT



IASH-TOTAL COST $1,255,030

N	DURATION	COST						
	2	125,000	8-9	DESIGN FINAL PRODUCT	5	151,870	12-23	DESIGN A
DULES	3	6,250	8-11	TRAIN SALES FORCE	1	5,000	13-24	ESTABLIS
ARCH	4	159,590	9-12	ISSUE DRAWINGS AND SPECS	1	7,100	14-17	TRAIN PR
SPECS	4	48,500	9-18	PREPARE ADVERTISING	6	18,750	16-22	TRAIN SE
	1	10000	10-13	DETERMINE PRICE	3	5,130	17-20	MANUFACT
	5	158,760	12-14	DETERMINE MANUFACTURING METHODS	2	5,630	18-26	RELEASE
	5	9380	12-15	PROCURE RAW MATERIALS	3	3750	20-21	ASSEMBL
L	2	51950	12-16	PREPARE SERVICE LITERATURE	2	5,000	21-25	TEST
NALYSIS	3	5,630	12-19	PROCURE "BUY" ITEMS	5	28880	26-27	BOX, PACK



5	151,870	12-23	DESIGN AND PROCURE PACKAGING	4	10,500
1	5,000	13-24	ESTABLISH DISTRIBUTION OUTLETS	8	56,250
1	7,100	14-17	TRAIN PRODUCTION PERSONNEL	1	9,370
6	18,750	16-22	TRAIN SERVICE ORGANIZATION	2	11,500
3	5,130	17-20	MANUFACTURE "MAKE" ITEMS	1	237,380
DS 2	5,630	18-26	RELEASE ADVERTISING	3	4,380
3	3,750	20-21	ASSEMBLE	3	95,750
2	5,000	21-25	TEST	2	12,500
5	28,880	26-27	BOX, PACK AND SHIP	1	11,230

7/26/67/DRAWING NO: 170-C

EXHIBIT 13

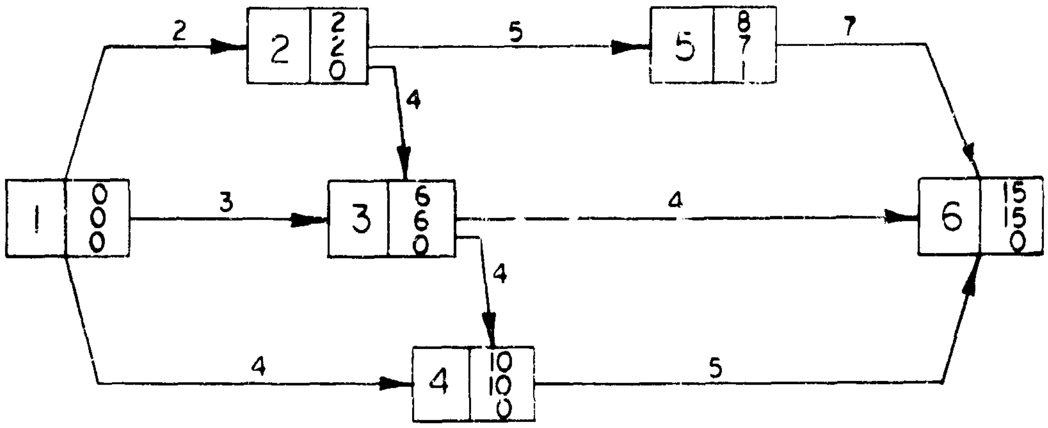


EXHIBIT 14

ACTIVITY	t_e	MEN NEEDED
1,2	2	2
1,3	3	4
1,4	4	3
2,3	4	2
2,5	5	1
3,4	4	2
3,6	4	3
4,6	5	4
5,6	7	2

MEN AVAILABLE - 7

EXHIBIT 15

MEN AVAIL	ACT.	WEEKS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
7	1,2																		
	1,3																		
	1,4																		
	2,3																		
	2,5																		
	3,4																		
	3,6																		
	4,6																		
	5,6																		
TOTAL																			

EXHIBIT 16

MEN AVAIL	ACT.	WEEKS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
9	1,2																		
	1,3																		
	1,4																		
	2,3																		
	2,5																		
	3,4																		
	3,6																		
	4,6																		
	5,6																		
TOTAL																			

MANPOWER DISTRIBUTION

The last use that we will make of the network is in solving <u>manpower</u> problems. Nearly all activities require money, machines and men.

Up to now we have assumed no limits on personnel. Obviously, there will be personnel constraints on some activities. Some typical constraints may be:

1. A lack of men with special training.

2. An inability to supply raw materials to more than a given number of men.

3. The number of men who can work efficiently on a job without getting in the way of one another.

4. The number of men that can be supervised by a foreman.

5. The lack of money.

There are others of course.

Now again look at our network (EXHIBIT 13). The earliest time that the project can be completed is 15 weeks. This means that based on our previous assumptions, we can, in some way, complete the task in that time or a greater length of time.

We must next determine the number of men required to do each job. The foreman has said that his original time estimate on activity 1-2 was based on the assumption that two men would be available for this task. By like means we can determine the numbers of men used as a basis to determine the expected times for all activities.

EXHIBIT 14 indicates the men needed for each part of the project.

Now suppose we have only a limited number of men available to complete the project. We want to know if we can complete the project in 15 weeks as shown on the network. Suppose, for example, there are 7 men available to do the work at any one time.

According to EXHIBIT 14, there are two men required for activity 1-2. Place a 2 beside activity 1-2 under weeks 1 and 2 in EXHIBIT 15. This takes care of 2 of the men available for the first two weeks. The network indicates that activity 1-3 can run concurrently with activity 1-2 so that we can place the 4 men available for that activity in weeks, 1, 2 and 3. We now have six men in use for the first two weeks (4 men for the 3rd week).

Looking at activity 1-4, we note that we can start that activity with week 1 if there are enough men available. Activity 1-4 requires three men, but three men are not available until week 3. Therefore, place 3's opposite activity 1-4 beginning in week 3 and ending week 6. Notice now that 7 men are used in week 3.

Going ahead with activity 2-3, we notice that according to the network we cannot start this activity until after activity 1-2 is complete (remember the rules!); this means week 3. But in that week we already have in use all our 7 men. Can we then start our 2 men in week 4? Yes! Place 2's in weeks 4, 5, 6 and 7. Get the idea? There are restrictions.

1. <u>The preceding activity must be complete before starting the next.</u>
2. <u>You can only use men if they are available.</u>

Complete EXHIBIT 15. How many weeks does it take to do the job with the 7 men available?

There is only one problem. Our PERT Network indicates that the job should be completed in 15 weeks and we're over that time. Our problem is to determine how many men are required to do the job in the allotted time of 15 weeks, and when should they be used.

Work through EXHIBIT 16 using either 8, 9, 10 or 11 men. Trial and error will show you that 9 men will reduce the number of weeks required to 15. If you use 10 or more men, you will still require 15 weeks to complete the job. It is probably not practical to use more than 9 men on the job, due to the costs involved.

REVIEW

During the final class session, about one hour will be devoted to a review of the fundamentals of PERT described in the first 33 pages of this text. It will consist of a written problem requiring:

1. The drafting of a small network.
2. The computation of Expected time values (t_e).
3. The computation of Earliest time values (T_E).
4. The computation of Latest time values (T_L).
5. The computation of Slack times (S).
6. The depiction of the Critical path.

LINE OF BALANCE

(MODIFIED)

The LINE OF BALANCE Chart is readily adaptable to the depiction of repetitive processes. It indicates the performance of an operation or procedure as compared to some pre-determined proposal. The LINE OF BALANCE Chart considers all lead times. It requires that a new LINE OF BALANCE be struck at each date in question.

The modified LINE OF BALANCE technique as described here does not require a line at each date. For this reason, chart upkeep is simple, and chart reading is greatly simplified.

On the left side of the chart is plotted the cumulative production schedule. For example: (See EXHIBIT A) we expect to produce 2000 bombs the first month, 3000 bombs the second month, 5000 bombs the third month, and 6000 bombs a month thereafter until our production goal is reached. Our plot will go from zero to 2000 to 5000 to 10,000 to 16,000, etc. Our entire production will be 100% so that the right scale indicates percent of production. For example: 40,000 units equal 57% of the production.

Knowing our proposed production, we would next like to know whether we have the materials or components to support this production. Here we only consider the major components, that is, those which, if not received on time, will delay production. These materials or assembly components are represented on the right scale.

In order to put these components in their proper perspective, the amount of each component required to support 100% of the production is calculated.

Suppose, for example, 350,000 pounds of rubber are required to produce 70,000 bombs. Then 350,000 pounds represents 100% of the production and 80% would be 280,000 pounds required to support 56,000 bombs. Likewise, 50% of the material or 175,000 pounds represents 35,000 completed bombs. All materials then are represented in percent of the total production objective.

As the components arrive and production begins, plot both in their respective areas. Note that the components are plotted in percent of the total.

What can we find out from this modified L.O.B. Chart?

First, and probably most important, we can find out at any time whether we have enough components to support our current proposed production. To do this, we observe the percents of components on the right side. By projecting these amounts across our chart from right to left to our production schedule, we can determine whether they exist in sufficient quantities. If the quantities are above the production schedule line (they should be, to allow for shipment, etc.), it can be determined when they will run out. To find out how long the item will support production, extend the actual production line until it intersects the horizontal line established by the component amount. At the intersection of the actual projected production and the component amount, drop straight down to the bottom scale and read the date.

This procedure can be reversed to determine what amount of a component is required on a given date.

Let's see what information we can get from the exhibit?

1. What caused the production rate to drop off? ________________

2. When did production stop? ________________________________

3. Assuming that bomb bodies were ordered at the end of the 33rd week, when will we be able to begin production again? ________________

4. What logical conclusions might we make about arming wire?

a. ________________________

b. ________________________

c. ________________________

d. ________________________

5. Assuming that we are back on the original schedule again, when will we run out of white phosphorous? ______________________________

6. When will we have to order white phosphorous so that we do not run out in 5 above? ____

7. How many units can I produce before I run out of WP? _________

8. When will we have to order Xylene so that we do not exhaust our present supply? ___________________

9. How many pounds of Xylene have we received at the present?

____

10. How many bombs can we produce with the Xylene that has been received? ____________________

11. How many pounds of rubber have we received at the present?

____

12. How many pounds of rubber do we currently have in storage?

____

13. When did we order rubber (so that we will not exhaust our supply?) ________________

Second, we can determine from our plot of actual production versus proposed production, how far ahead of or behind schedule we are.

If our actual production appears to the left of the proposed production line, we are ahead of schedule. We can tell how far ahead of schedule we are by measuring horizontally from our current actual production line to the proposed production line. Observe the chart at 37,000 units, Arrows 1&2. Notice the horizontal gap between our actual production line and our proposed schedule. This gap, compared to the time scale at the bottom of the chart indicates the number of days ahead of schedule for production. In this case, production is running 6 weeks ahead of schedule.

If our actual production appears to the right of the proposed production line, we are behind schedule. The same measurement procedure can be used to determine the number of days behind schedule.

Third, we can determine from our plot actual production versus proposed production, how many units ahead of or behind schedule we are. This time we measure vertically from the actual production at the current time to the proposed production line. In our example, observe the chart at the end of Week 27, Arrows 3 & 4. Notice the vertical gap between our proposed production and our actual production schedule. This gap, compared to the units scale on the left indicates the number of units ahead of the proposed schedule. In this case, production is running 8000 units ahead of schedule.

If our actual production line appears below the proposed production line, we are behind schedule. The same measurement procedure can be used to determine the number of units behind schedule.

Fourth, a comparision of the proposed production quantities for a given period with the actual production figures for that same period, will provide an index of performance as compared to the proposed standard. A suggested method is to divide the actual production for the month by the proposed production for the same month. The result multiplied by 100 will give the percent performance as compared to the norm for that period. Lets consider the month of July from EXHIBIT A.

Actual production for the month - 5,000 units

Proposed production for the month - 6,000 units

$$\frac{5,000}{6,000} \times 100 = 83\%$$

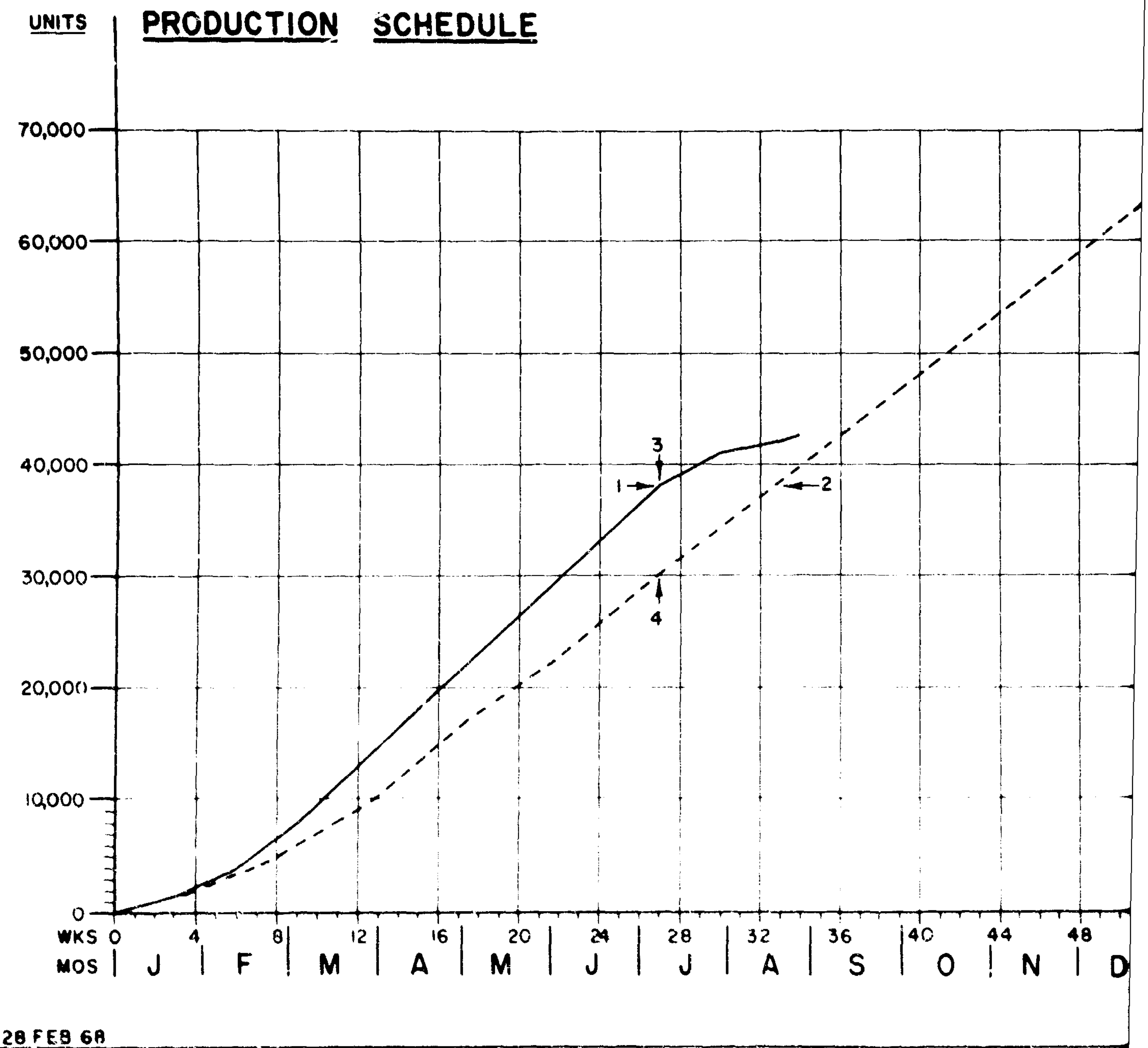
This indicates that our production was 83% as compared to the 6,000 unit norm of 100%. Or, we produced 17% below the norm for the month.

The four times listed are the most important considerations in the use of the modified L.O.B. Chart. There are other refinements, such as the indication of lead time for sub assembly operations or the addition of revised production schedules.

All of these L.O.B. variations coupled with PERT network for the nonrepetitive part of a project, can assist in the metering and forecasting of a successful project.

BOMB PRODUCTION - EXHIBIT A

PRODUCTION UNITS REQD	70,000
COMPLETION DATE	NOV 30
BOMB BODIES REQD	70,150 PCS
ARMING WIRES REQD	70,150 PCS
WP REQD	420,000
XYLENE	105,000
RUBBER	350,000



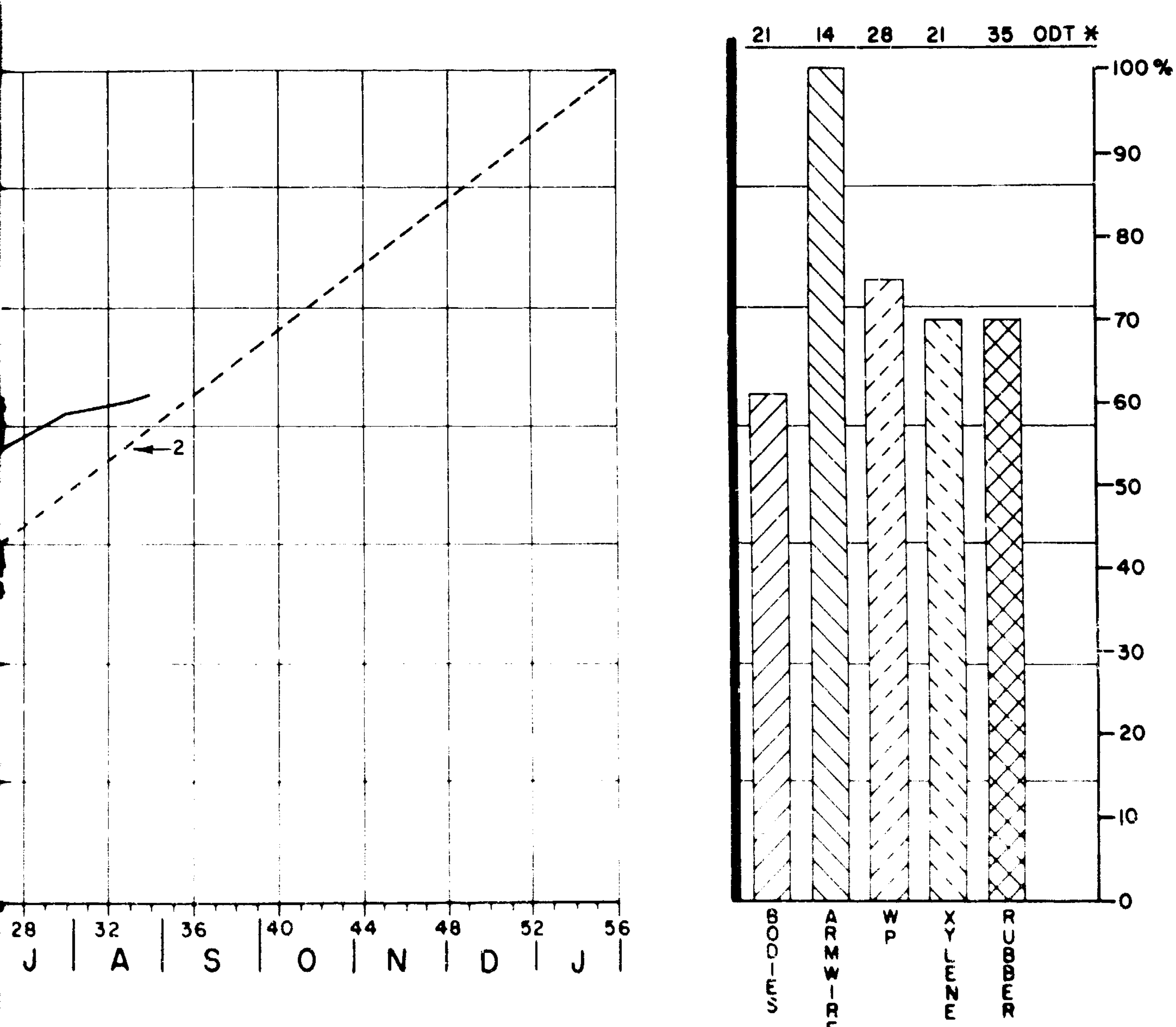
- - - - - PROPOSED PRODUCTION

———— ACTUAL PRODUCTION

* ORDER DELAY TIME-DAYS

A

IBIT A



DELAY TIME-DAYS

CONCLUSION

The PERT Orientation Course has been presented to make you aware of this valuable management tool. We have reviewed a brief history of PERT and how you go about developing a network. We have discussed expected times and made computations to familiarize you with the technique of time development from three estimates. Next we reviewed earliest times and latest times for the completion of activities and events. Float and slack times were next discussed with an eye toward indicating the benefits and results of excess times. The critical path and its uses were then reviewed. Next, we talked about and described Milestone networks and their advantages for short-term projects. The final two sections were devoted to cost calculations possible, and manpower distributions applicable under the PERT program.

The instruction you have received, by no means qualifies you as a PERT expert. It will, however, make you aware of this tool and permit you to have a better understanding of how it works. We hope you will take PERT to work with you each day.

BIBLIOGRAPHY

Gehringer, A.C.: "Line of Balance"; Office of Naval Material, issue 1455.

Miller, Robert W.: "How to Plan and Control with PERT"; Reprinted from Harvard Business Review, March - April 1962.

Bibliography, PERT and Other Network Techniques; Air Force Systems Command, United States Air Force.

Computer Assisted Program Evaluation Review Technique Simulation, VOL I; U. S. Government PERT Coordinating Group, January 1965.

DOD and Nasa Guide, PERT Cost, Systems Design; June 1962.

General Information Manual, PERT, A dynamic project planning and control method; IBM, Technical Publications Dept; 112 East Post Road, White Plains, New York.

Line of Balance Technology, A Graphic Method of Industrial Programming; Office of Naval Material, Department of the Navy; Navexos P1851 (Rev 4-62).

PERT, ASD EXHIBIT ASOE 62-1; Management Procedures Branch Aeronautical Systems Division, September 1962.

PERT Fundamentals, Volume I - Networking, Volume II - Scheduling and Planning, Volume III - Workbook; PERT Orientation and Training Center, Washington 25, D.C.

PERT 400/1400; Honeywell Electronic Data Processing; First Edition, First Printing, March 1964.

Programmed Instruction in PERT/CPM; ENTELEK incorporated; Newburyport, Massachusetts, second printing, February 1963.

Project Planning and Control PERT; AMETA, U. S. Army Management Engineering Training Agency.

QUESTIONNAIRE ON "PERT ORIENTATION COURSE"

1. Did the course convey to you the basic concepts of PERT?
   ________(Yes) __________(No)

2. On the basis of the knowledge acquired in this course, will you be in a position to develop a working knowledge of PERT, and associated techniques through your own efforts? _______(Yes) ______(No)

3. Did the course convince you of the merits of the use of project models for planning and progress control purposes? _______(Yes) _______(No)

4. Was the instruction provided satisfactory? _______(Yes) ______(No)

   If not, what changes do you suggest?

5. Were you given enough problems to test your understanding of PERT?

   __________(Yes) __________(No)

   Would you have preferred more home assignments? ________(Yes) _______(No)

6. Was this 10 hour instruction in PERT and associated techniques sufficient?

   __________(Yes) __________(No)

   Would you have preferred a longer course? _______(Yes) _______(No)

   Would you have preferred a shorter course? _______(Yes) ________(No)

7. What areas of this orientation should be given greater emphasis?

   What areas of this orientation should be given less emphasis?

8. Do you plan to continue your studies in PERT?

_________(Yes) _________(No)

Do you plan to use it in your work on your own initiative?

_________(Yes) _________(No)

9. Do you feel this orientation course would be of advantage to your colleagues? _________(Yes) _________(No)

Should it be continued? _________(Yes) _________(No)

10. Other suggestions?

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Introduction to PERT/TIME	

13. ABSTRACT

(U) This text is an introduction to PERT/TIME and its associated management sciences. The instruction is designed to give executives and project managers a basic understanding and appreciation of PERT. The familiarity acquired from the instructional material will permit the manager to work closely with PERT experts in the development of networks and their interpretation. From the author's experience, few project managers and engineers use a detailed analysis of activity time variances in the course of a project. Therefore, statistical probability theory is eliminated. This text includes basic instruction in project cost optimization within the PERT/TIME work breakdown structure, and therefore should give the manager familiarity with the advantages of PERT/COST. The content of this course may be covered in 12 hours of lecture-seminar instruction, with 6 hours of outside work on the part of the participants. If more expertise in a particular area is desired, it is believed that this text will provide a foundation for comprehension of literature in specialized or more advanced areas of PERT systems.

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PERT/COST						
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Critical path techniques						
Conventional management techniques						
Management planning						
Control techniques						
CPM						
Management tools						
Critical path analysis						
Critical path method						