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STUDENTS NAME ______________________________

NETWORK PLANNING AND CRITICAL PATH METHOD

IN THE DESIGN AND CONSTRUCTION PROFESSION

by

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CONTENTS

			Page
INTRODUCTION			ii
CHAPTER			
ONE	....	HISTORY OF NETWORK PLANNING	1
TWO	....	CONCEPT AND PREPARATION OF THE NETWORK PLAN	4
THREE	....	ASSIGNMENT OF TIME VALUES TO THE NETWORK PLAN	9
FOUR	....	MANUAL COMPUTATION OF NETWORK DATA	12
FIVE	....	ANALYSIS AND EVALUATION OF THE COMPUTED NETWORK	20
SIX	....	ELEMENTARY SCHEDULING, MANPOWER, AND RESOURCE ALLOCATION	22
SEVEN	....	ADVANTAGES AND ADDITIONAL APPLICATIONS OF CPM	29
EIGHT	....	MANUAL RECORD KEEPING CONTROL AND UPDATING WITH NETWORK PLANNING	31
NINE	....	USE OF ELECTRONIC DATA PROCESSING EQUIPMENT FOR COMPUTING NETWORK PLANS	37
TEN	....	USE OF NETWORK PLANNING IN BILLING & CASH FLOW ANALYSIS	44
ELEVEN	....	APPLICATION OF NETWORK PLAN INFORMATION TO PURCHASING	47

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CHAPTER ONE

HISTORY OF NETWORK PLANNING

How long our modern concept of network planning has been used is open to some question. I have a good friend who says he saw limited attempts to use the method on a public building project in the late 1940's. However people who have grown up with network planning techniques trace their modern origin to 1957. But we must go much further back than that to find the first truly effective use of the network plan. In fact we must go back nearly 5000 years ago when music was first reduced to a notation that would enable a performer to play what someone else had conceived and written.

A sheet of music is an ideal network plan in that it -

1. Establishes a scheme of action
2. Graphically depicts a group of inter-related actions or sounds
3. Establishes time and resource (the instruments and musicians available) limitations on each task
4. Has a beginning and an end.

Similarly, the familiar music roll for player pianos is a good example of a network diagram; road maps are nothing more than complex network diagrams showing someone how to take an action to get from one point to another on a trip that has a beginning and an end.

So we can see that network planning is nothing new. The startling fact about the concept is that it has taken so long to apply it in the construction industry where such a technique has been badly needed for years. The question arises - if the method is so good and so powerful a tool, why didn't it blossom forth 10 or 20 years before when our construction problems were almost as numerous although perhaps not so complex? A comparable question might be - why were not fully automatic elevators used from the first installation of vertical transportation? The reason, of course, is that a successful operational combination of any remote pair of developments (in the case of elevators - mechanical power linkages combined with electronics) needs an adequate gestation period to insure a proper birth.

Planning and scheduling of construction work is somewhat similar in that for years the bar graph was an ingrained part of the thinking of any construction man. Those skilled in mathematical and logical disciplines were not interested in this particular problem. However World War II brought the practical and theoretical together in solving operations research (O/R) problems that proved to have extremely high practical

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construction advisors to incorporate all operations on a network planning basis. The past success of network planning leaves little doubt that it is a tool with almost unlimited potential for improving performance over previous levels.

RALPH J. STEPHENSON
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The circles into which each arrow runs and from which each arrow leaves represents an instantaneous point in time at the start or end of each action. If numbers are placed in each circle, a convenient reference short-hand can be used to refer to each of our tasks. The arrows in our action plan are called activities. The circles are called nodes or milestones. Each activity must start and end with a node.

Notice in this action plan we have introduced a factor of desire. Although our pipe smoker could have picked up the tobacco jar (task 2:3) before he picked up his pipe (task 1:2), he has stated his desire to do it the other way around. Desire does not always direct how an action plan is arranged, however. Look at tasks 5:6 and 6:7 - the match cannot be taken and lit until our pipe smoker, Mr. Albert, has picked up and opened the match box. In this case we have a necessary sequence of action. The ability of an action plan to reflect both desired and necessary relationships is a valuable attribute - very important to the proper use of critical path method.

Now let's suppose after Mr. Albert has smoked his first pipe full of tobacco, Mr. Raleigh comes into the room for a friendly evening's conversation. Mr. Raleigh is also a pipe smoker and Mr. Albert asks him if he would like to try some of his new tobacco. The answer is naturally yes, and our plan of action for lighting the two pipes unfolds like this:

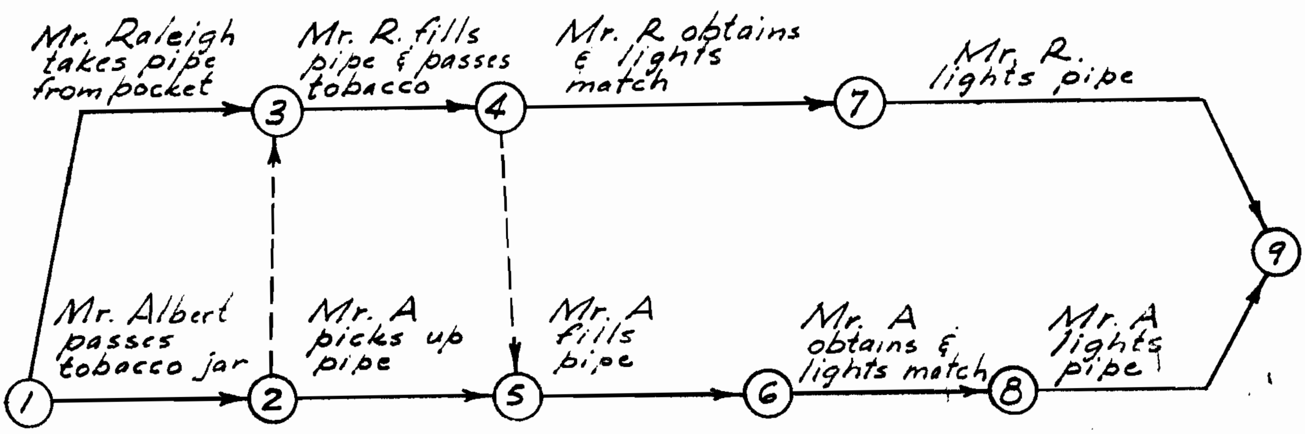

Figure 2

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2. Bricks would be delivered to the street curb edge the night before and would be there in the morning when we started our project.
3. Redwood edge strips would be bought the morning that we started constructing the patio.
4. We will use a basketweave brick pattern.
5. The base will be tamped sand, 3 inches deep.
6. The redwood edging strip along the outside of the patio will be 3/4" x 2½" untreated. No frost wall will be used.
7. The duration of each task will be given in hours.
8. Starting time will be 8 o'clock A.M.
9. Lunch will be at noon and dinner at 6 o'clock, each taking one hour.

From these specifications the action plan shown in Figure 3 was evolved. Everyone has checked this plan over, decided it is OK, and has agreed to work as well as he can in accordance with it. According to our plan we first lay out the area and concurrently have our oldest son go to the lumber yard to purchase the redwood edge strips while our youngest boy brings in the bricks from the street curb. After laying out the patio area we spread the sand base, level it, tamp it and then begin laying our bricks.

When about 25% of the bricks are laid we plan to have our neighbor start lining and leveling the bricks already in place to insure that the joints are even and the surface level. Once the lining and leveling process has started and we have a little lead time, our boys are to start sweeping sand into the brick joints and setting the edge strip. This whole process continues until all of the bricks are laid, lined, leveled, the edge strip set and all sand swept into the joints; after which we get together and clean up the patio area and yard. So much for the action plan.

If we went no further than this we would have a better than usual picture of how to proceed with the construction. However we have scarcely scratched the surface of usefulness in the network planning technique so let's proceed to the next step.

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CHAPTER THREE

ASSIGNMENT OF TIME VALUES TO THE NETWORK PLAN

Notice to this point we have scarcely considered the concept of time but instead have concentrated our efforts on preparing the best possible plan of action within the general range of resources we know are available. The next step is to evaluate each task in the network and determine how long we think it might take to accomplish. One of the original network techniques, PERT, required three time estimates - most likely, optimistic and pessimistic for each task. The reason was that PERT originated from projects involving research and development in which the work was new and usually being attempted for the first time. Hence, time and costs were not predictable with enough certainty for one value to be adequate.

In construction, however, we are normally dealing with tasks that have been accomplished many times in the past and for which records are available. Examples are the number of masonry units that can be laid in one hour; the number of tons of structural steel that can be erected in one day or the number of yards of concrete that can be poured in a given unit of time.

In construction, we also find by experience that the most commonly used time unit is elapsed time in working hours or working days. To determine the elapsed time or duration we can use several methods but let's explore one that gives us flexibility for future adjustments of the network and assignment of resources and manpower. In the example given in Chapter two we found that there were fourteen action tasks. These tasks were planned in a sequence with a rough idea of the resources that would be available to accomplish them. Now we reduce these task descriptions and the rough resource estimate to an actual total man day or man hour requirement which, in turn, gives us the durations in working days or hours. This information is shown in Figure 4.

Task	Man Hours	Crew Size	Elapsed Time	Task	Man Hours	Crew Size	Elapsed Time
3:5	2	2	1	11:15	3	1	3
3:9	1	1	1	13:23	2	1	2
3:17	2	1	2	15:21	1	1	1
5:7	2	1	2	17:19	1	1	1
7:9	2	2	1	23:27	1	1	1
9:11	2	2	1	25:27	2	1	2
11:13	2	1	2	27:29	4	4	1

Figure 4

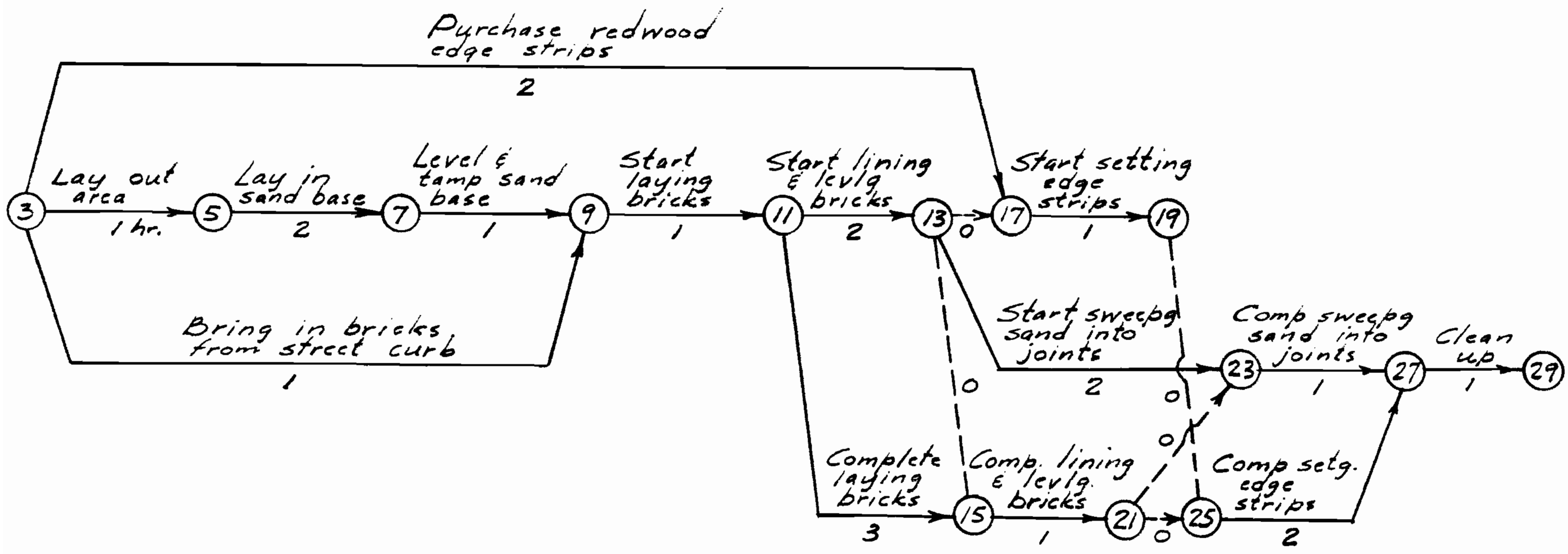
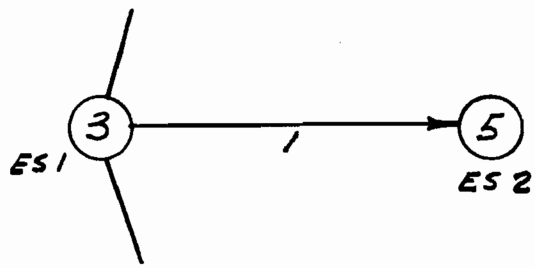

Purchase redwood edge strips
2
Lay out area
1 hr.
Lay in sand base
2
Level & tamp sand base
1
Start laying bricks
1
Start lining & levlg bricks
2
Start setting edge strips
1
Bring in bricks from street curb
1
Start sweepg sand into joints
2
Comp sweepg sand into joints
1
Clean up
1
Complete laying bricks
3
Comp. lining & levlg. bricks
1
Comp setg. edge strips
2
0
3
5
7
9
11
13
15
17
19
21
23
25
27
29

Figure 5

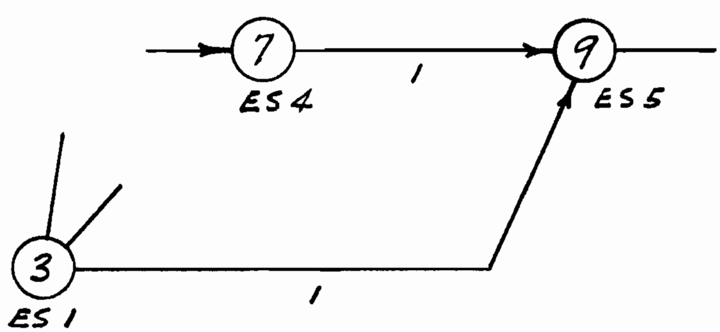


Similar reasoning gives an ES of 4 at node 7.

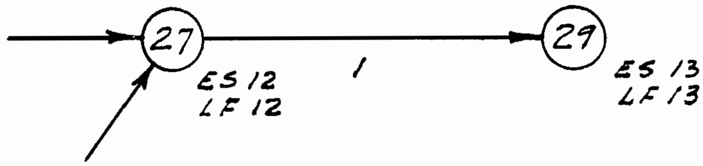
3. Along the activity arrow for leveling and tamping the sand base from node 7 to 9 takes one hour but notice that node 9 has one other arrow entering it. Our rules state that we cannot start from node 9 until all tasks entering it have been completed. Coming into 9 is activity 7:9 of one hour and an activity 3:9 (Bring in bricks from street curb) of one hour. The ES at node 7 is four; so along path 7:9 which takes one hour, we end with an early start time at node 9 of five.

   Inspecting path 3:9 we notice the early start time at node 3 is one, the duration of the activity is one hour which means that the early start time at node 9 along task 3:9 would be one plus one or two. However since <u>all</u> tasks including 7:9 and 3:9 must be completed before we can possibly start out along task 9:11, the earliest time we can possibly start at node 9 is the later of the two, or time five.

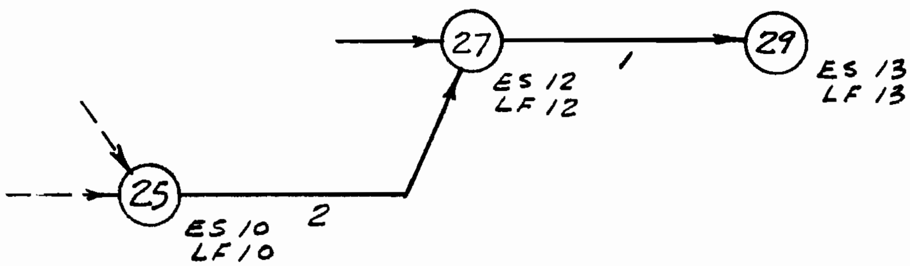
   The correct ES time at a node is always the largest of all computed ES times at the head of the activity arrows coming into that node.



7. If the latest we can finish at node 29 is thirteen, then retracing back along task 27:29 which takes one hour, the latest we can finish our work at node 27 and still complete the entire project in twelve hours is thirteen minus one or the twelfth hour. Enter time twelve after the LF at node 27.

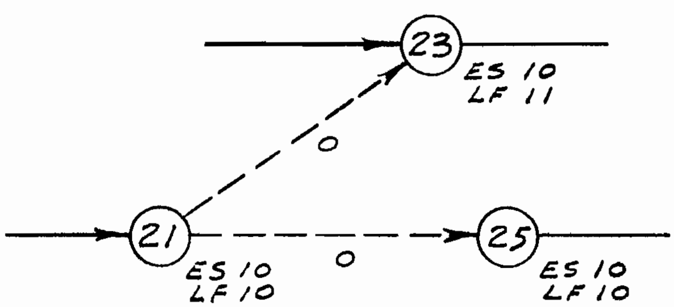


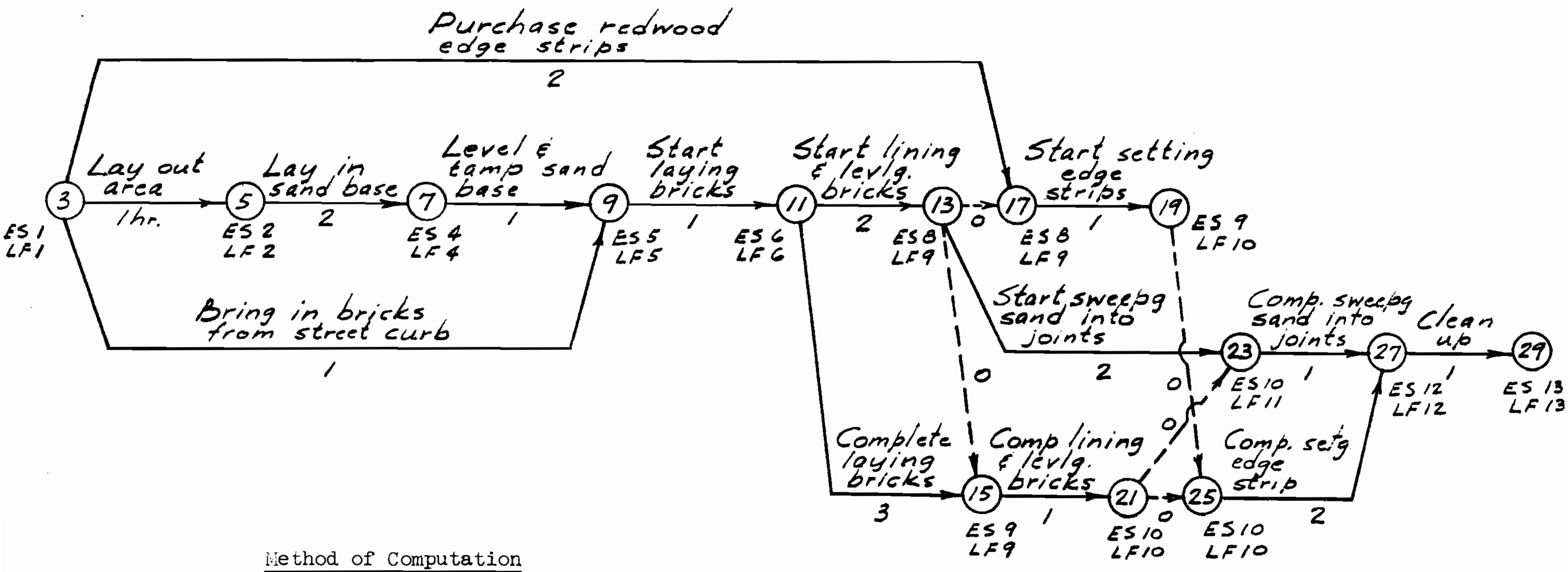
8. At node 25 we must finish no later than the start of the tenth hour after the beginning of the project if we are to finish the entire project on time. This is calculated by subtracting the duration of task 25:27 of two hours from the latest finish of twelve at node 27.



9. Continuing to work backwards, we find two arrow tails coming into node 21. Just as when working forward we had multiple computations when more than one arrow head came into a node, when working backwards to find the latest finishes, we have multiple computations when more than one arrow tail comes into a node.

The LF at node 23 is eleven and the duration of the dummy 21:23 is zero. The LF at node 25 is ten and the duration of dummy 21:25 is also zero. Working backwards along path 23:21 gives us a LF time at node 21 of eleven minus zero or eleven. Working back along path 25:21, the LF at node 21 is ten minus zero or ten. To complete the project on time from node 21 we need zero hours (21:25) plus two hours (25:27) plus one hour (27:29) or a total of three hours. Therefore the latest we can possibly finish at node 21 and still complete the patio in twelve hours is the tenth hour which is the lower of the two computed LF times at node 21.



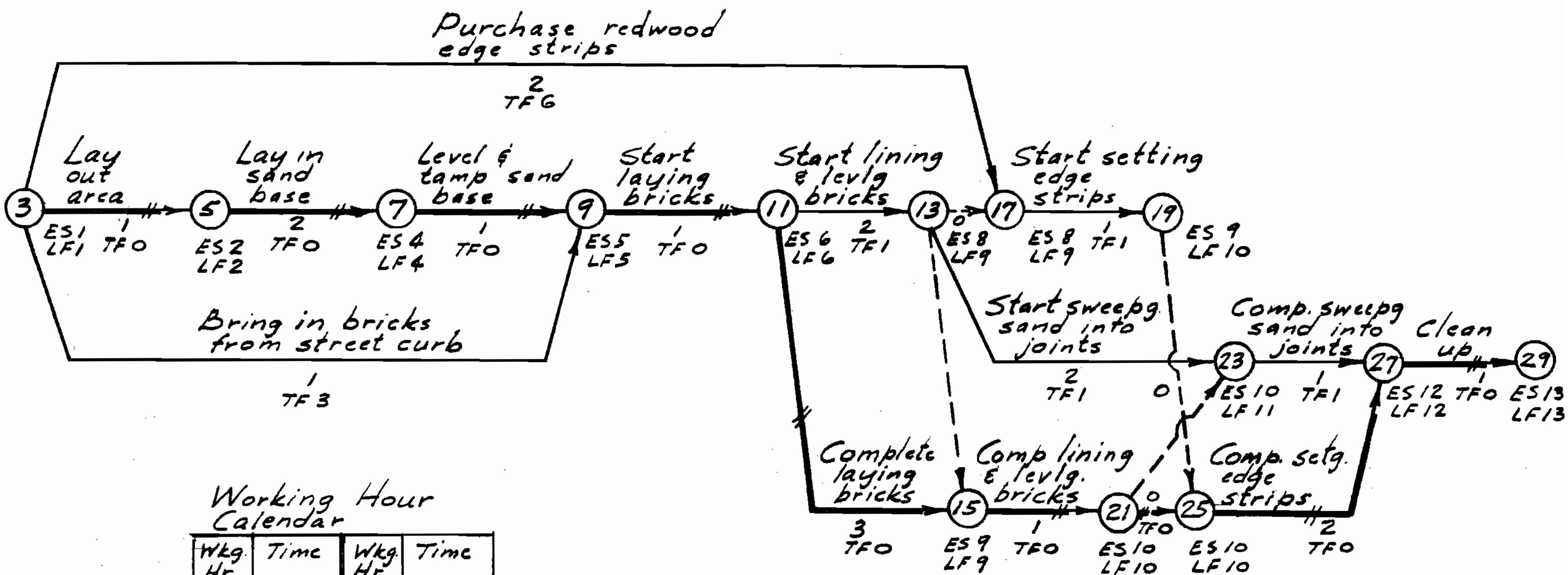


Method of Computation

Early start times (ES) are computed by adding the task duration to the ES time at the beginning node of the task. Where two or more arrow heads enter a node the ES time at that node is the latest of the computed early start times.

Latest finish times (LF) are computed by subtracting the task duration from the LF time at the end node of the task. Where two or more arrow tails leave a node the LF time at that node is the earliest of the computed latest finish times.

Figure 8



Working Hour Calendar

Wkg. Hr	Time	Wkg. Hr.	Time
1	8 A.M.	9	5:00
2	9:00	10	7:00
3	10:00	11	8:00
4	11:00	12	9:00
5	1 P.M.	13	10:00
6	2:00	14	11:00
7	3:00	15	12:00
8	4:00	16	1 A.M.

Figure 10

path an excellent picture is gained of exactly what actions are going on at any given time during the project.

3. What happens if we decide to mix some cement in with the sand that is swept into the brick joints? At what point must we make our decision to do this if it will take one hour to get adequate cement at the lumber yard?
   Analysis - We can start sweeping the sand into the brick joints as early as 4:00 P.M. or as late as 5:00 P.M. It will take about one hour to pick up the cement from the lumber yard and a half hour to mix enough sand and cement to get started. Therefore, the latest we can start for the lumber yard is 5 o'clock minus an hour and one half or 3:30 P.M. However unless other conditions interpose it is best to consider that we will start sweeping the sand into the brick joints at the early start time of 4:00 P.M. Therefore the recommended starting time for getting cement would be 2:30 P.M. This permits any float time available to be taken up and used in the actual operation itself.

Although these are simple situations to analyze, it can be seen that there is a pattern of interpretation with the network that makes situations crystal clear. In more complicated networks the analysis is helped immeasurably by having the entire job laid out graphically with all information directly at hand.

In the example assume the work shown requires two trades - electricians (E) and pipefitters (P). The estimated durations from Figure 12 are entered on the corresponding task arrows on the network plan (Figure 13).

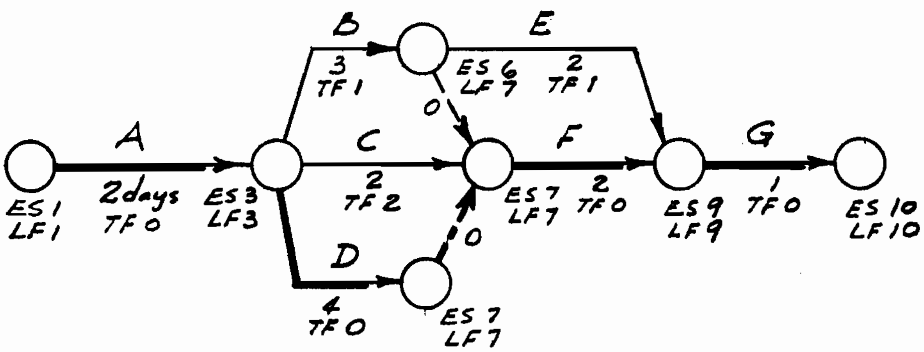


Figure 13

Dummy arrows are, of course, assigned zero duration. The earliest start (ES) and the latest finish (LS) time limitations are then computed for each task. In our example the longest time sequence of tasks is through A, D, F and G - a path which takes nine working days to traverse.

At this point we have realized many advantages from the network:

1. Everybody on the project knows the work sequence and how many days are allocated to every task.
2. Management knows how long the project will take and when it can expect each task to start and finish if the job is to be on time.
3. Management has an advance look at where trouble might develop by analyzing the critical path tasks.
4. Purchasing can be scheduled at times when buying conditions are best.
5. The effect of changes upon completion dates can be easily seen.
6. Replanning of the project (for example, because of anticipated strikes or material shortages) can be accomplished with full knowledge of the impact of the change in plan upon the rest of the work.

But there are still other uses for the network. By using the data table and the network plan we can inject the concept of scheduling and resource allocation into the program. Look at Figure 13. Only four of the tasks - A, D, F and G are actually scheduled with definite starting and completion dates - these are critical tasks which have no float time available. The other three tasks B, C and E have some leeway or float available. The question is - when are the best times to start and complete the non-critical tasks?

WORKING DAY

	1	2	3	4	5	6	7	8	9	TOTAL MAN DAYS
A*	E 1 P 2	E 1 P 2								E 2 P 4
B			E 2 P 1	E 2 P 1	E 2 P 1					E 6 P 3
C			E 1 P 0	E 2 P 0						E 3 P 0
D*			E 4 P 4	E 4 P 4	E 4 P 4	E 4 P 4				E 16 P 16
E						E 3 P 2	E 3 P 2			E 6 P 4
F*							E 2 P 1	E 2 P 1		E 4 P 2
G*									E 1 P 1	E 1 P 1
TOTAL	E 1 P 2	E 1 P 2	E 7 P 5	E 8 P 5	E 6 P 5	E 7 P 6	E 5 P 3	E 2 P 1	E 1 P 1	E 38 P 30

*** CRITICAL TASKS**

Figure 14

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WORKING DAY

	1	2	3	4	5	6	7	8	9	TOTAL MAN DAYS
A	E 2 P 4									E 2 P 4
B		E 2 P 1	E 2 P 1	E 0 P 0	E 2 P 1					E 6 P 3
C				E 2 P 0	E 1 P 0					E 3 P 0
D		E 4 P 4	E 4 P 4	E 4 P 4	E 4 P 4					E 16 P 16
E						E 3 P 2	E 3 P 2			E 6 P 4
F						E 2 P 1	E 2 P 1			E 4 P 2
G								E 1 P 1		E 1 P 1
TOTAL	E 2 P 4	E 6 P 5	E 6 P 5	E 6 P 4	E 7 P 5	E 5 P 3	E 5 P 3	E 1 P 1		E 38 P 30

Figure 16

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CHAPTER SEVEN

ADVANTAGES AND ADDITIONAL APPLICATIONS OF CPM

As we discuss, learn and use network planning and critical path method, certain advantages of the system become very apparent. Other benefits are subtle in nature and appear only after extensive experience with the technique. It might be remembered in evaluating the use of network planning that the tool can become a powerful two edged sword. Those who are prepared to engage in the use and application of NP must realize that it reveals not only to the user, but to the owner and all interested parties the entire plan of work for the project. As such, it lays bare the inner secrets and prevents the fudging, hedging and burying of time that is saved to hedge against prospects of bad weather, strikes, material shortages, delays and in some cases incompetency.

However, let us be positive about our approach to this matter and look at the direct advantages gained by the use of NP.

1. Makes one think about a project in more than usual detail and tends to prevent omission of tasks.
2. Tells accurately how long the project will take and what jobs must be kept on time to meet the schedule.
3. Simplifies advance work assignments and helps improve communications between those responsible for the project.
4. Assists to evaluate and forecast the outcome of alternate plans of action.
5. Focuses attention on potentially troublesome tasks and allows pinpointing of corrective action rather than wasteful scatter-shooting.
6. Fixes responsibility and provides a permanent record of assignments.
7. Insures continuity of action even with changes in personnel.
8. Encourages personnel at all management levels to contribute to effective job planning.
9. Simplifies periodic re-evaluation and rescheduling.
10. Provides a uniform system of planning, scheduling and reporting.
11. Measures proposed changes against time, money, manpower and equipment yardsticks.
12. Provides a measure of individual performance.
13. Shows proper relationships between all tasks.
14. Provides a graphic picture of the work to be done and encourages making accurate and prompt field decisions where needed.
15. Shows what to expedite, when.
16. Encourages accurate and continuous control of buying operations and sub-contractor performance.
17. Separates planning of the task sequence from the assignment of time values to each task and makes the entire project scheduling less susceptible to time distortion.

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CHAPTER EIGHT

MANUAL RECORD KEEPING CONTROL AND UPDATING WITH NETWORK PLANNING

A decision to use NP without adequate control of its execution is neither effective nor complete. Therefore, concurrently with preparation of a plan, policies should be established to insure control of the plan. These controls are generally of two types - secondary and primary.

Secondary control involves routine progress reviews and minor changes in the plan/time/resource allocation that do not substantially affect the final completion date or final project cost.

Primary control concerns major progress and policy reviews that impose changes upon the completion time, costs or resource allocation of the project.

Secondary control of a design or construction program is normally the responsibility of the staff member directly in charge. This might be the project manager, the squad boss, the field superintendent or a department head. The man exerting secondary control normally has direct contact with the job on a day to day basis.

Responsibilities of those making secondary control reviews include:

1. Maintaining short term (once or twice weekly) color coding of individual tasks on the graphic network showing the exact status of that task at that time.
2. Making minor alterations to the plan, time and resource assignments so long as they do not materially affect other major groups in the organization or contribute to changing the time of completion or cost of the overall project.
3. Providing brief, narrative statements or reminders to other departments or individuals when they are to play a part in maintaining the plan and schedule. Examples are memos to the reproduction department when a large printing is to be made; to purchasing when a certain key trade is to be bought; to accounting when a billing is to be made; or to consultants when important information must be provided by them.
4. Review of progress with the owner to show at what point his decisions must be made. For example, a secondary control function would be to inform the owner that according to the network plan (a copy of which he should have and understand) he will be required to review and approve sash samples by a certain date if the project is to remain on schedule.

Primary control is that exerted by management in conjunction with line personnel to assure that policy decisions of a major nature are not left untended.

The letters i, j and d stand for starting node number, finish node number and duration. The card is a permanent record and can be used to keep notes of any pertinent matters of current or historic interest. These might include reasons for delays, names of sub-contractors, delivery dates, scope of work, details of manpower assignments or other items which always tend to get mislaid in the jumble of paperwork. The above card technique is one suggested form of many that might be adopted. Undoubtedly, as one works with NP one will find other ways of using the system which are uniquely suited to his own company function.

In addition to the record card, it is necessary to provide a daily reporting form to be used in conjunction with the control system. By this technique the field can tell the office exactly where the job stands at any given time. With NP, reporting is very simple. The daily field report consists of a brief narrative statement describing the days to complete or percentage completion of each task in the network. This narrative allows records to be kept up to date and gives management all the routine information they need concerning the project.

Look at Figure 19.

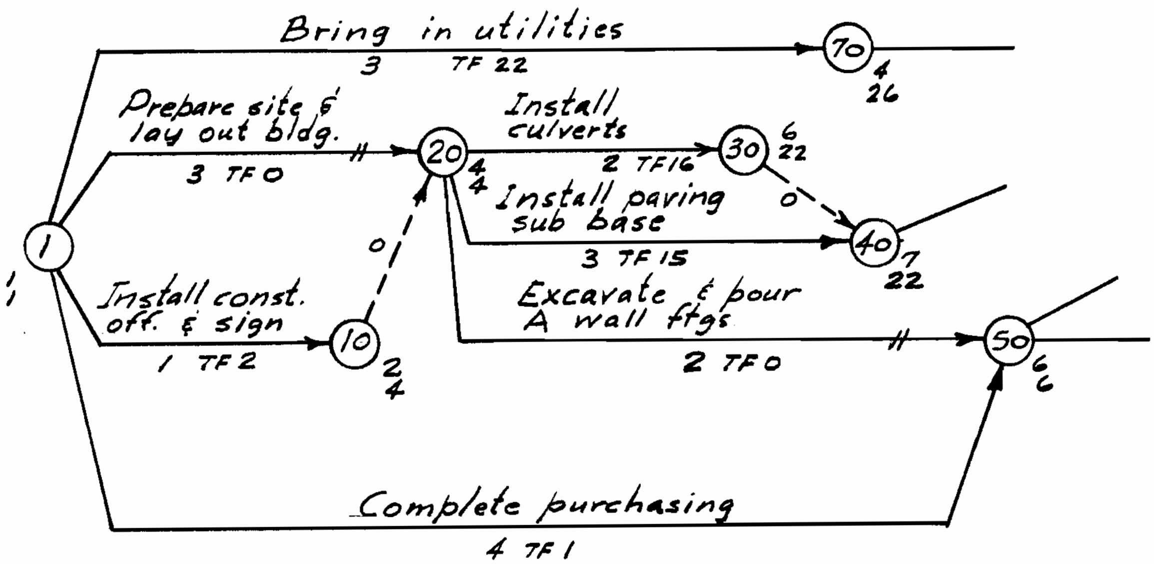

Figure 19

It shows a partial network for a small construction project. Suppose we are in the third day after the start of construction. The superintendent's daily report for the third day might look like this:

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Three major items of information are needed about a job by the planner and management. Is the job on time? Is it behind time? Is it complete? Each of these conditions can be shown on the network plan by color coding the task as the information comes from the job. One suggested code system uses four project status situations each keyed to a color. The colors can be any combination that provide contrast but they should be easily read for quick reference. A recommended code is:

Green	-	Task on Time	-	currently not past early finish date
Orange	-	Task on time	-	currently past early finish date
Blue	-	Task behind	-	currently not past late finish date
Yellow	-	Task behind	-	currently past late finish date

To update the network using the color code, each task is evaluated according to the latest field report. A decision is made as to which of the four categories applies, and a partial line is drawn from the last status color end. At the end of this new color line a slash is placed with the date of the review (Figure 21).

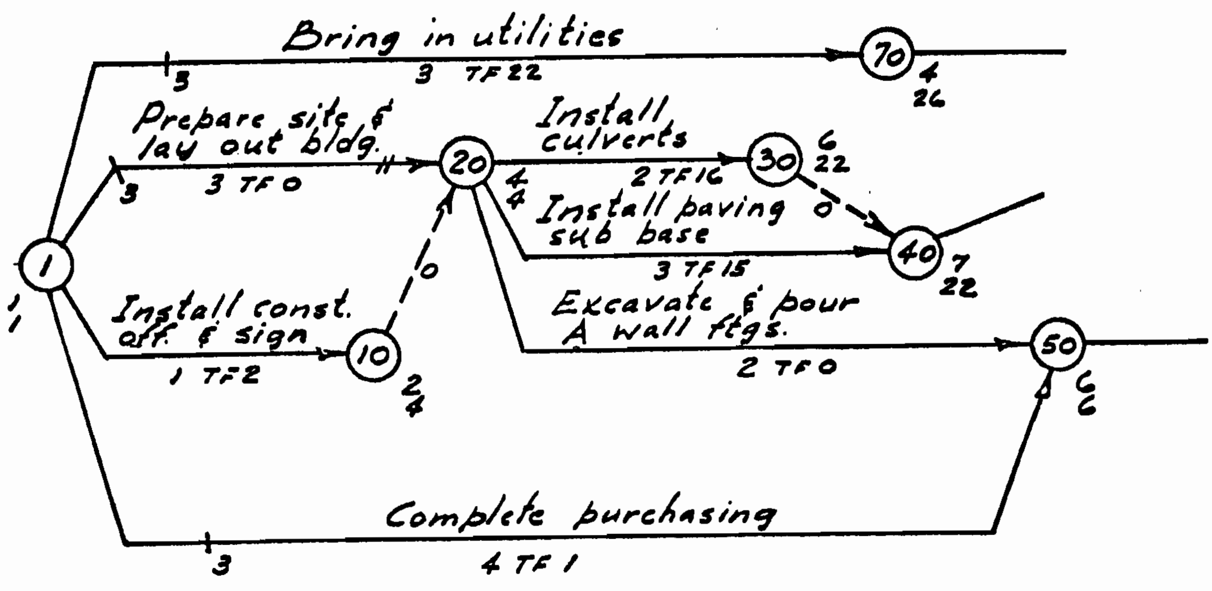

Figure 21

Thus, at any point in the project a glance at the network plan will show exactly where the job stands, what tasks have started and the status of all jobs in progress. As each task is finished, the last color code is

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CHAPTER NINE

USE OF ELECTRONIC DATA PROCESSING EQUIPMENT FOR COMPUTING NETWORK PLANS

The practice of network planning was spawned in a computer environment. However to this point in our text, we have seen that NP can be effectively utilized without having any computer equipment available whatsoever. In fact, networks with as many as 200 tasks can be computed readily without equipment. The computer starts to be valuable when the complexity of the network grows through the addition of sub networks to the primary control network or when the uses to which the network is put, such as extensions into resource allocation, manpower leveling or cost control become so sophisticated that computations cannot be made manually without strong possibility of error.

Another and perhaps more important reason for the use of electronic data processing equipment is to expedite evaluation of alternate plans of action. When we utilize the computer in this manner we normally refer to the process as a simulation run. Suppose one has prepared four different plans of action for a project upon which he is working. Suppose, further, that each of these four different plans of action contain 150 distinct and separate tasks. Computing each network, selecting the best one and then refining it so as to be acceptable could conceivably involve 5 to 10 computation sequences. Done by hand this might take as long as a full day or two while with most computers the time would be reduced to minutes. Thus, many alternate plans of action involving not only time, but cost and resources can be prepared and analyzed much more quickly with the use of computers than by hand.

However, the computer, like a network plan, is only a tool in the hands of the user. The computer will merely tell you what the data one has given it means when arranged in a certain manner. With NP the computer is told the duration of each task, the starting node number and the finish node number. From this raw data, fed into the equipment with a set of key punched cards, the machine does the same thing electronically that we did in our hand computations of ES, LF and TF. The end result is a print-out of the data as shown in Figure 22.

CP Print-out for
Patio Project

Sept. 1, 1964

* Zero TF

This listing is in node number sequence

i	j	d	Description	ES	EF	LS	LF	TF	FF
3	5	1	Lay out area	1	2	1	2	*	0
3	9	1	Bring in bricks	1	2	4	5	3	3

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CONSULTING ENGINEER

Any use of free float time within a task, therefore, does not affect the amount of free float time available to subsequent tasks.

The preparation of input data varies depending upon the make of computing equipment used. However the basic process follows this pattern:

1. Prepare input sheet as shown in Figure 24.

Input Data - Patio Project

i - Starting node
j - Finish node
d - Duration

i	j	d	Description
3	5	1	LAY ØUT AREA
3	9	1	BRING IN BRICKS
3	17	2	PURCHASE EDGE STRIPS
5	7	2	LAY SAND BASE
7	9	1	LEVEL & TAMP SAND BASE
9	11	1	START LAYING BRICKS
11	13	2	START LNG & LVLG BRICKS
11	15	3	CØMP LAYING BRICKS
13	23	2	START SAND FILL BRICK JTS
15	21	1	CØMP LNG & LVLG BRICKS
17	19	1	START SET EDGE STRIPS
23	27	1	CØMP SAND FILL BRICK JTS
25	27	2	CØMP SET EDGE STRIPS
27	29	1	CLEAN UP
13	15	0	DUMMY
13	17	0	DUMMY
19	25	0	DUMMY
21	23	0	DUMMY
21	25	0	DUMMY

Figure 24

2. Key punch cards as required by make of equipment and type of computer program being used.
3. Feed program input to computer.
4. Feed data input to computer.
(As a result of the matching of these two decks of cards, the program input and the data input, you will receive cards or a tape that contain all of the computed ES, LS, EF, LF, TF and FF times)

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i	j	d	Description	ES	EF	LS	LF	TF	FF
15	21	1	Comp. lng. & lvlg. bricks	9	10	9	10	*	0
19	25	0	Dummy	9	9	10	10	1	1
21	23	0	Dummy	10	10	11	11	1	0
21	25	0	Dummy	10	10	10	10	*	0
23	27	1	Comp. sand fill brick jts.	10	11	11	12	1	1
25	27	2	Comp. set edge strips	10	12	10	12	*	0
27	29	1	Clean up	12	13	12	13	*	0

Figure 25

(c) Late start listing (Figure 26) - when the tasks are arrayed in ascending order of latest start possible, the listing is used to determine those jobs that must have been started by the review day. Thus, if we use the 9th day as an instance and have located in the latest start column the number 9, it shows that all tasks above that 9 mark must have been started by now or the network will have to be revised to maintain the schedule.

Late Start Listing
for Patio Project

Sept. 1, 1964
* Zero TF

i	j	d	Description	ES	EF	LS	LF	TF	FF
3	5	1	Lay out area	1	2	1	2	*	0
5	7	2	Lay sand base	2	4	2	4	*	0
3	9	1	Bring in bricks	1	2	4	5	3	3
7	9	1	Level & tamp sand base	4	5	4	5	*	0
9	11	1	Start laying bricks	5	6	5	6	*	0
11	15	3	Comp. laying bricks	6	9	6	9	*	0
3	17	2	Purchase edge strips	1	3	7	9	6	5
11	13	2	Start lng. & lvlg. bricks	6	8	7	9	1	0
13	15	0	Dummy	8	8	9	9	1	1
13	17	0	Dummy	8	8	9	9	1	0
13	23	2	Start sand fill brick jts.	8	10	9	11	1	0
15	21	1	Comp. lng. & lvlg. bricks	9	10	9	10	*	0
17	19	1	Start set edge strips	8	9	9	10	1	0
19	25	0	Dummy	9	9	10	10	1	1
21	25	0	Dummy	10	10	10	10	*	0
25	27	2	Comp. set edge strips	10	12	10	12	*	0
21	23	0	Dummy	10	10	11	11	1	0
23	27	1	Comp. sand fill brick jts.	10	11	11	12	1	1
27	29	1	Clean up	12	13	12	13	*	0

Figure 26

(d) Late finish listing (Figure 27) - the late finish listing is an array of the latest finish times in ascending order. By using the late finish listing, a complete picture of those jobs that must have been finished by the review day is obtained. Using 9 as our example once again, all jobs above 9 in the late finish column must have been finished by that review day. If there are tasks not finished above the 9 mark, the network must be reviewed and changes made to bring the project back in line.

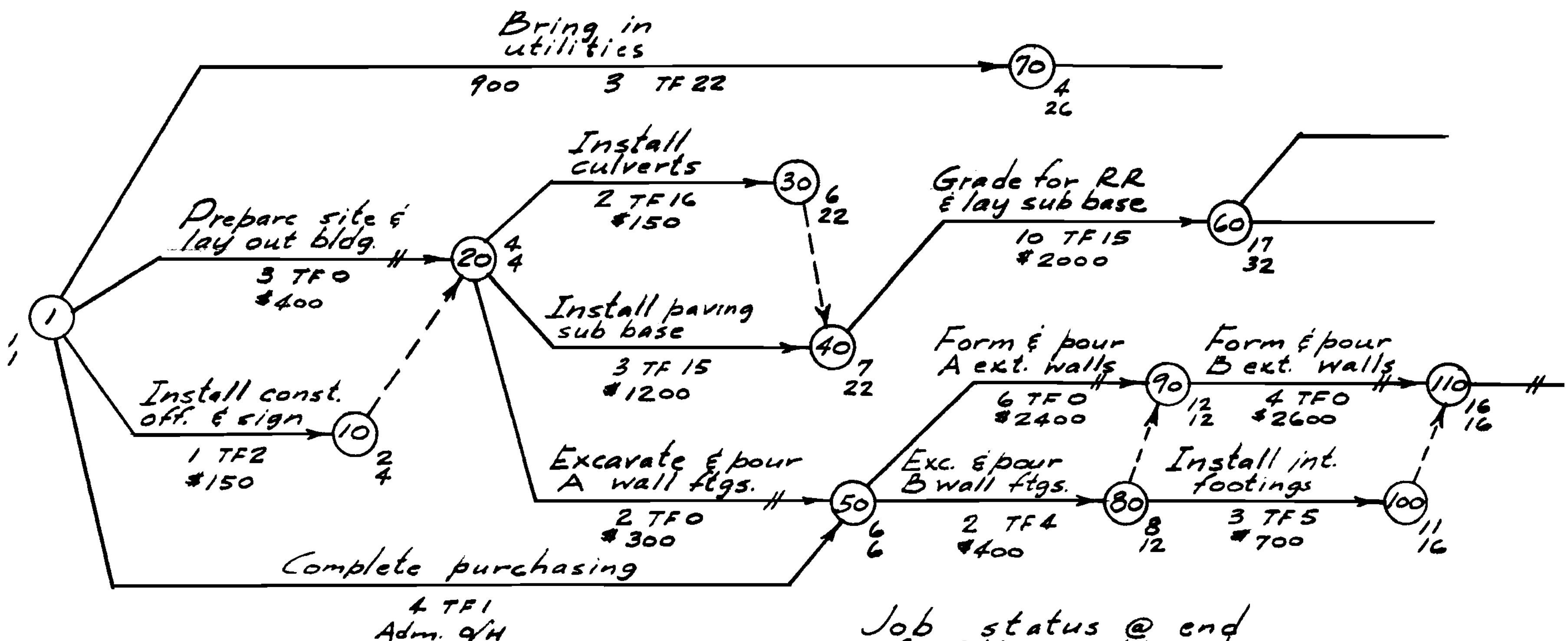
i	j	d	Description	ES	EF	LS	LF	TF	FF
25	27	2	Comp. set edge strips	10	12	10	12	*	0
27	29	1	Clean up	12	13	12	13	*	0
11	13	2	Start lng. & lvlg. bricks	6	8	7	9	1	0
13	15	0	Dummy	8	8	9	9	1	1
13	17	0	Dummy	8	8	9	9	1	0
13	23	2	Start sand fill brick jts.	8	10	9	11	1	0
17	19	1	Start set edge strips	8	9	9	10	1	0
19	25	0	Dummy	9	9	10	10	1	1
21	23	0	Dummy	10	10	11	11	1	0
23	27	1	Comp. sand fill brick jts.	10	11	11	12	1	1
3	9	1	Bring in bricks	1	2	4	5	3	3
3	17	2	Purchase edge strips	1	3	7	9	6	5

Figure 28

Whether or not the additional data on different arrays can be effectively utilized is a function of each organization's method of control through the network plan. Some organizations have found that the print-out of a properly prepared network is all that must be furnished to the field to properly run the job. If it is desired to provide only the information in certain columns of the print-out for various business reasons, then the remaining columns of data (for instance LS, LF, TF & FF) can be supressed when the printing is made. The speed of printing the lists ranges from 100 lines per minute to 1200 lines per minute. Thus, listings are quickly prepared and can be done inexpensively with a minimum of attention by trained personnel.

The use of electronic data processing has many advantages and it is generally found by those organizations which enter into a full blown network planning program that over a period of time the use of computer equipment, either within the organization or rented on an hourly basis from a service bureau is a wise and prudent investment.

In this chapter we have only scratched the surface in the use of EDP equipment, however, since the subject is so broad and of such great magnitude the interested reader would do well to absorb further detailed information from the authoritative manuals and literature published by all reputable computer manufacturers.



Job status @ end of 5th working day

Task	% Comp.	Total Cost	Incurred Cost
1:10	100%	$150	$150
1:20	100%	$400	$400
1:70	100%	$900	$900
20:30	50%	$150	$75
20:40	30%	$1200	$360
20:50	70%	$300	$210
		$3100	$2095

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Figure 29

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CHAPTER ELEVEN

APPLICATION OF NETWORK PLAN INFORMATION TO PURCHASING

The use of NP to plan purchasing procedures is one of the most little understood and underrated applications of NP. It can be seen by only a cursory inspection of any network plan or computer print-out of a network plan that the system can be of great assistance in buying for maximum economy and efficiency. Network planning should be applied to purchasing in conjunction with the various task arrays discussed in Chapter Nine. For each task in the network the purchasing department, the project manager or the field superintendent should determine which trades must be bought. Then by a careful examination of the listings, lead times for buying can be established for each of these trades.

The lead times can be shown directly on the network as a purchasing operation if desired. However, it is sometimes better to translate the lead times into a narrative day by day purchasing check list giving the date, job, items to be bought and required delivery times.

Normally purchasing tries to buy out a project as soon as the job starts in the field. This is not necessarily the most efficient way to purchase the trades, labor and material for a project. If definitive milestones in the job are well established and a consistently good record of accomplishment is maintained by the field forces, then the purchasing department can plan to buy at the best times according to the market. A good example is asphalt paving. In the spring and in the late fall when the plants are either just opening or just closing, the demand for blacktop is great. If a job has been let and construction is starting in March, there may be a tendency for the purchasing department to put the blacktop under contract immediately. However if a reliable pattern of action has been demonstrated through the use of network planning in the past and it is seen that black topping is not going to be required until sometime late in August, then it would be far better to wait until the market drops in the warmer weather - say in July or early August and to order at that time to take advantage of a lowered demand to get a better price.

Although this is a simple example, it is illustrative of how the alert business man and aggresive purchasing agent can apply the network technique in various related areas of his operation.

It is highly recommended that when any project is being planned by critical path method that the purchasing department be allowed to participate at an early point in evaluating the various plans under consideration and in the selection of the one to be used.