PLANNING AND CONTROL
OF
REPETITIVE UNIT PROJECTS

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LIST OF ABBREVIATIONS AND SYMBOLS

ACT.	ACTUAL
C.	COMPLETION
COMP.	COMPLETION
CPM	CRITICAL PATH METHOD
CUMUL.	CUMULATIVE
d	ACTIVITY DURATION
D	TIME REQUIRED TO FINISH ONE REPETITIVE ACTIVITY
DBL	DELIVERY BOUNDARY LINE
Dur.	DURATION
E	END
ES	EARLY START
EXC.	EXCAVATION
FIG.	FIGURE
G.	GROUP
hr.	HOUR
LOB	LINE OF BALANCE
LS	LATE START
N	TOTAL NUMBER OF REPETITIVE UNITS

LIST OF ABBREVIATIONS AND SYMBOLS

n	NUMBER OF UNITS
Q.	QUANTITY
r	TIME INTERVAL BETWEEN STARTS / FINISH OF TWO SUCCESSIVE REPETITIVE ACTIVITIES
R	HAND OVER RATE
R.C.	REINFORCED CONCRETE FOUNDATION
S	START
SBL	STARTING BOUNDARY LINE
T	TOTAL PROJECT TIME
T.F	ACTIVITY TOTAL FLOAT
T.t	TOTAL TIME CONSUMED BY AN ACTIVITY
U.	UNIT
W.	WEEK

PLANNING & CONTROL OF REPETITIVE UNIT PROJECTS

INTRODUCTION

Since the network method has been used as a planning technique , project managers have had the opportunity to gain much more confidence in their decision making . They are able to improve project planning and control for their projects because of the great advantages which the network technique has added to the field of construction management .

Network Analysis as a planning technique is best used for non-repetitive projects such as power plants , petro-chemical projects, factories , etc. But when planning for projects which have the property of repetition as in housing projects , towers for power transmission lines , pipe lines , highways , reclamation and cultivation of land , etc., the network analysis as a planning technique becomes a matter of repeating a certain number of activities several times .

Methods for planning and controlling highly repetitive unit projects have been investigated in the last 10 - 15 years . The use of the line of balance (LOB) technique for linear planning and scheduling has been used principally on large production jobs for industrial production problems . The use of LOB by the construction industry has been limited .

The objective of this paper is to introduce the LOB concept for planning and control of highly repetitive unit projects in the construction industry . This method had been implemented in three different pilot projects .

The effect of the contractor's limited resources , the owner's request for minimum or limited project duration , and the effect of constrained conditions on the planning procedure will be highlighted .

The contractor's decision to bid for an advertised contract and his efficient performance during the construction period will be discussed through the repetitive units' Hand Over Rate and the factors affecting it .

The success of implementing the LOB concept in planning for the highly repetitive unit projects in the construction field requires an integrated system of resource scheduling and project progress tracking . A resource scheduling method and a proposed progress tracking sheet which were successfully used on the pilot projects will be presented and discussed .

The paper will conclude by presenting the main benefits of using the LOB in planning for the highly repetitive unit projects in the construction field .It will also highlight the main problems which might face the implementation of the LOB and the proposed solutions.

II- LINE OF BALANCE PROCEDURE

The purpose of Line Of Balance (LOB) is to provide the project manager with a simple integrated system for evaluation of his critical activities on projects with repetitive work items . The output of this technique will act as a target for the project team to assist in completion of the project within the budgeted cost and the estimated time . Each activity will be checked against some target to allow the project manager to find where each activity is with respect to where it should be . Activities that fall short of the target are denoted for further analysis .

The planning procedure for the LOB technique involves five major steps :

(1) Determination of the critical activities of a repetitive unit , their expected durations , their interelationships , and their interdependencies .

(2) Determination of the objective chart, i.e., LOB chart.

(3) Derivation of the program chart, i.e., the target chart.

(4) Progress and cost tracking .

(5) Analysis and decision making .

Similar to all construction projects , repetitive unit projects have the following main characteristics :

(1) Request of the owner to deliver the project in the minimum time .

(2) The contractors' limited resources and their wishes for having the maximum time .

(3) Complexity of activities .

(4) Activity constraints .

(5) Any combination of the above .

The LOB has the ability to deal with all the privious situations through simple modification in the determination of the objective chart to suit the conditions available in each case.

The most important step in the LOB technique is the determination of the objective chart . Once this is obtained and agreed upon by the contractor's organization or by the owner or by both , the other main steps are easily achieved .

DATA REQUIRED FOR USING LOB TECHNIQUE

To use the LOB effectively there are certain data which should be prepared . The following is a list of the information needed :

(1) If time is restricted, the project total duration should be decided upon .

(2) If resources are limited , the available resources for each activity ; their output rates , specifications , special requirements etc. , are tabulated .

(3) Constrained activities having fixed delivery dates , special dependency or requirements , contractual conditions etc. ,should be recorded .

(4) The number of the repetitive units under construction should be available .

(5) The method of construction proposed for executing the repetitive unit and a bar chart , showing the critical activities , should be determined (PERT or CPM

is used to obtain the critical activities) .

III - PLANNING PROCEDURE

It is best to present a simplified case study from an actual project to illustrate the planning procedure and the usage of the LOB technique . Below is an example case study .

CASE STUDY

A contractor was awarded a contract to construct one hundred isolated reinforced concrete footings , for support of electrical transformers .

As mentioned before there are three main considerations :

CONSIDERATION I : Projects with limited duration .

CONSIDERATION II : Projects with limited resources .

CONSIDERATION III: Projects with constrained activities.

CONSIDERATION I : PROJECTS WITH LIMITED DURATION

In this type of project the owner requires the contractor to finish the project within a specified time .

Information available in this case :

(1) Project duration ....12 months .

(2) Resources available...........should be provided by the contractor to finish the required work in 12 months .

(3) Number of project repetitive units ....100 units.

(4) Activities have no constraints .

(5) Method of construction and bar chart providing the critical activities of a repetitive unit (based on CPM) are shown in Figures 1 and 2 .

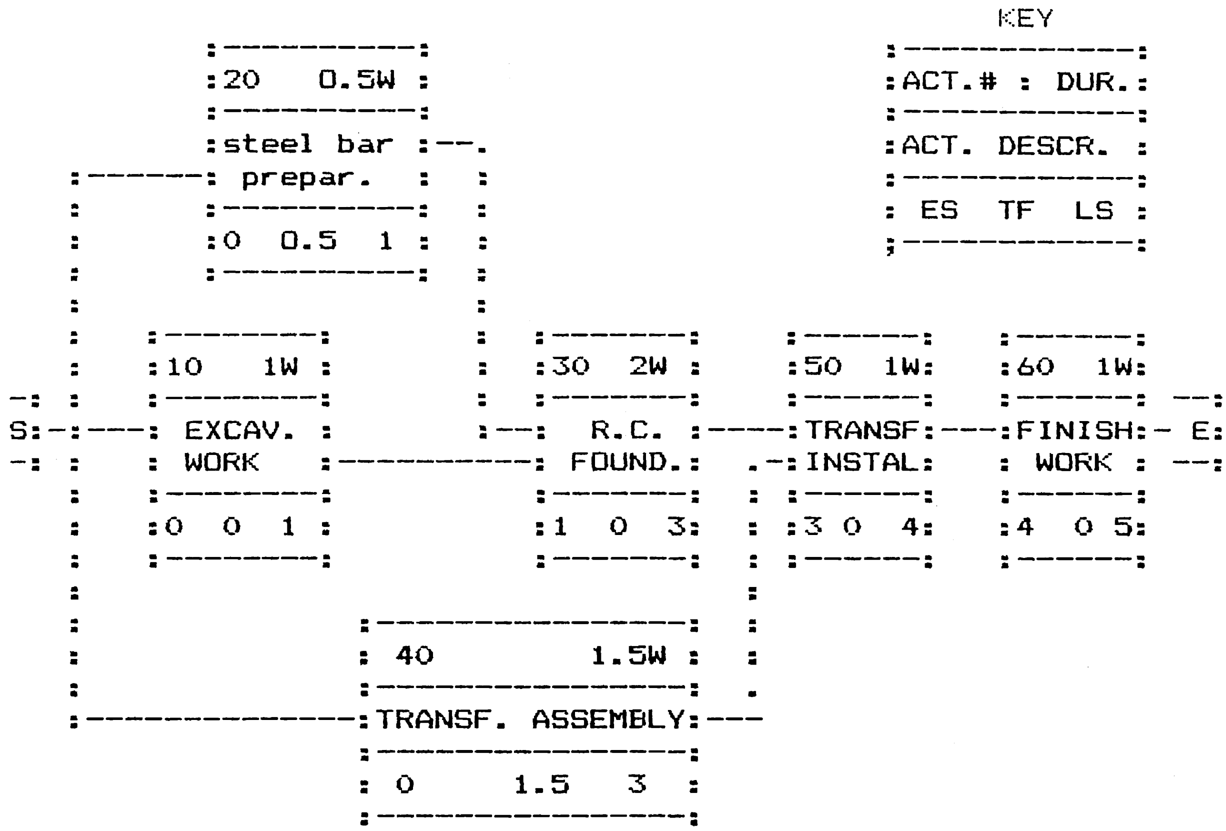

FIGURE 1 REPETITIVE UNIT CPM NETWORK

ACT#	DESCRIPTION	DUR.	1	2	3	4	5
10	EXCAVATION W.	1 W	=======				
20	STEEL BAR PREP	0.5W	....---				
30	R.C FOOTING W.	2 W		=======	=======		
40	TRANSF. ASSEMB	1.5W	....	...----	-------		
50	TRANSF. INSTAL	1 W				=======	
60	FINISHING W.	1 W					======

====== CRITICAL DUR. ..... FLOAT TIME ------- ACT. DUR.

FIGURE 2 REPETITIVE UNIT MASTER PROGRAM

Only the critical activities are considered since they determine the project duration . This also simplifies the LOB and add clarity to the analysis .

DETERMINATION OF THE OBJECTIVE CHART (LOB Chart)

The LOB is presented on a two dimensional chart , with the x-axis representing the time scale (12 months ,i.e., 52 weeks) and the vertical axis representing the number of repetitive units in the project (100 units), see Figure 3 .

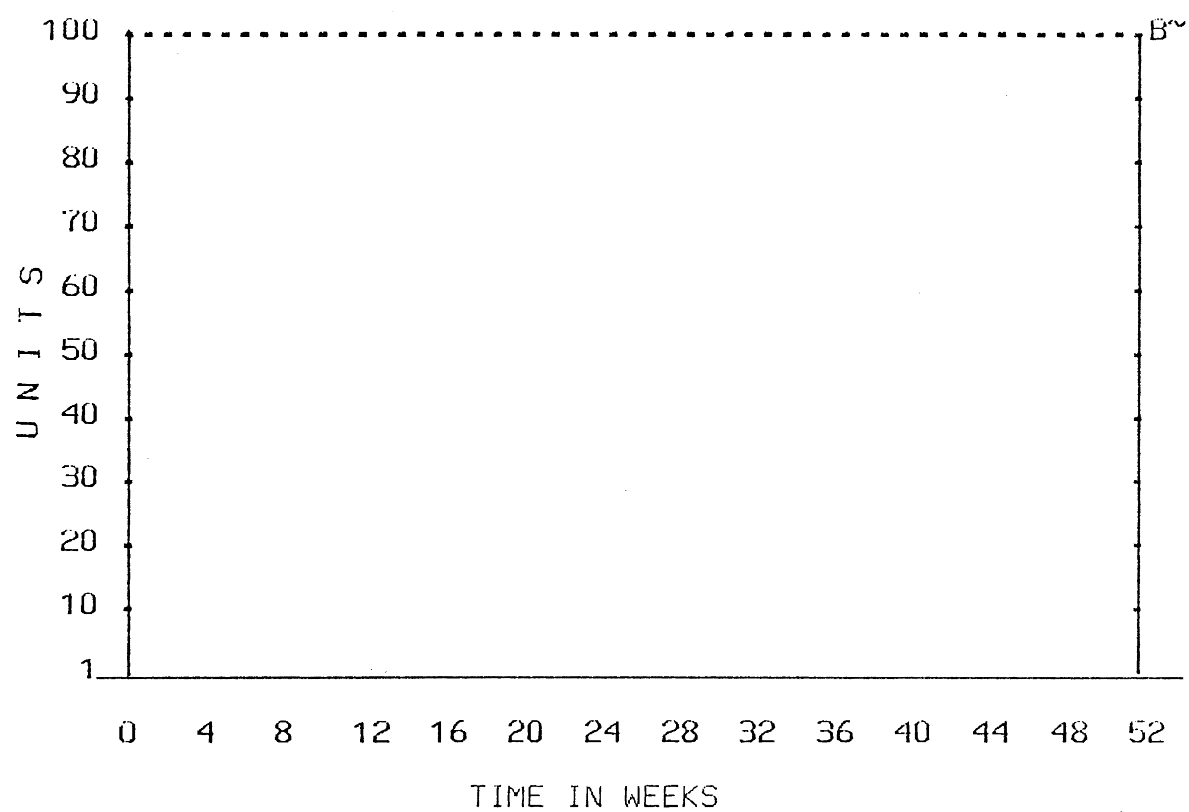

FIGURE 3 LOB MAIN TWO AXES

Point B~ should be located , and it is the intersection of the vertical line drawn from the end of the project duration (52 nd week) and the horizontal line drawn from the last unit of the project (100 th unit) .

It is assumed that any footing , under the same working conditions, will require five weeks of time to be completed according to the contract's drawings and specifications .

Utilizing the previous fact we can establish two boundary lines governing the start and the finish of all the repetitive units in the project . To achieve this the following steps are considered , see Figure 4 :

(1) Draw " AB " representing the total time consumed by the first footing (5 weeks) on the time axis starting from zero time

(2) Draw " B~A~ " starting from point " B~ " , this represents the total time consumed by the last footing (5 weeks) .

(3) By joining the two starting points of the first footing " A " and the last footing " A~ " ,we obtain the first boundary line "Start's Boundary Line (SBL) " . Similarly by joining points " B " and "B~" ,the finishing points of the first and the last footing , we obtain the second boundary line " Delivery Boundary Line (DBL) " .

By establishing these two boundaries we could determine the project situation at any time. The two points " C and D " in Figure 4, resulting from the intersection of the vertical line drawn from any required date and the two boundary lines , when projected to the vertical axis provides the planned number of the units starting and finishing at that date (points " C~ and D~) . We can also determine the starting and the finishing dates of any unit, e.g., the 40 th unit in Figure 4. This is done by drawing a horizontal line from that unit to intersect the boundary lines at two points " E and F " , projecting these two points on the time axis - points " E~ and F~ " - we can obtain the starting and the finishing dates of the 40 th unit .

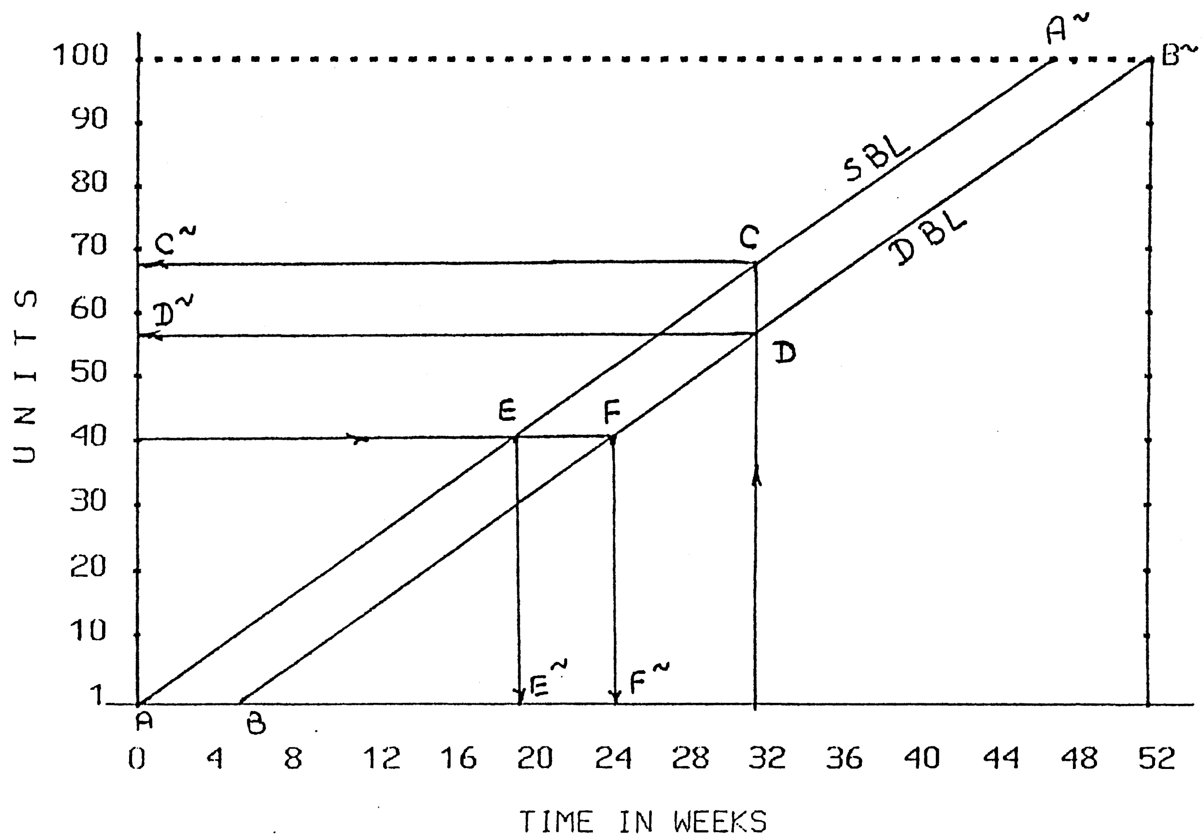

FIGURE 4 LOB EXTERNAL BOUNDARY LINES

From Figure 4 we can observe the following :

<u>week 32</u>	<u>chedule of the 40 th. unit</u>
67 units started	starts at week 20 .
56 units finished	ends at week 25 .

Going into more detail between the two boundary lines to establish the final view of the LOB chart, the durations "AB" and " A~B~ " are divided according to their critical activity durations, thus giving points " C,D,E " and " C~,D~,E~ " FIG.(5). Joining each two corresponding points " C C~ , D D~ , E E~ " we obtain further limitations between the two main boundary lines.

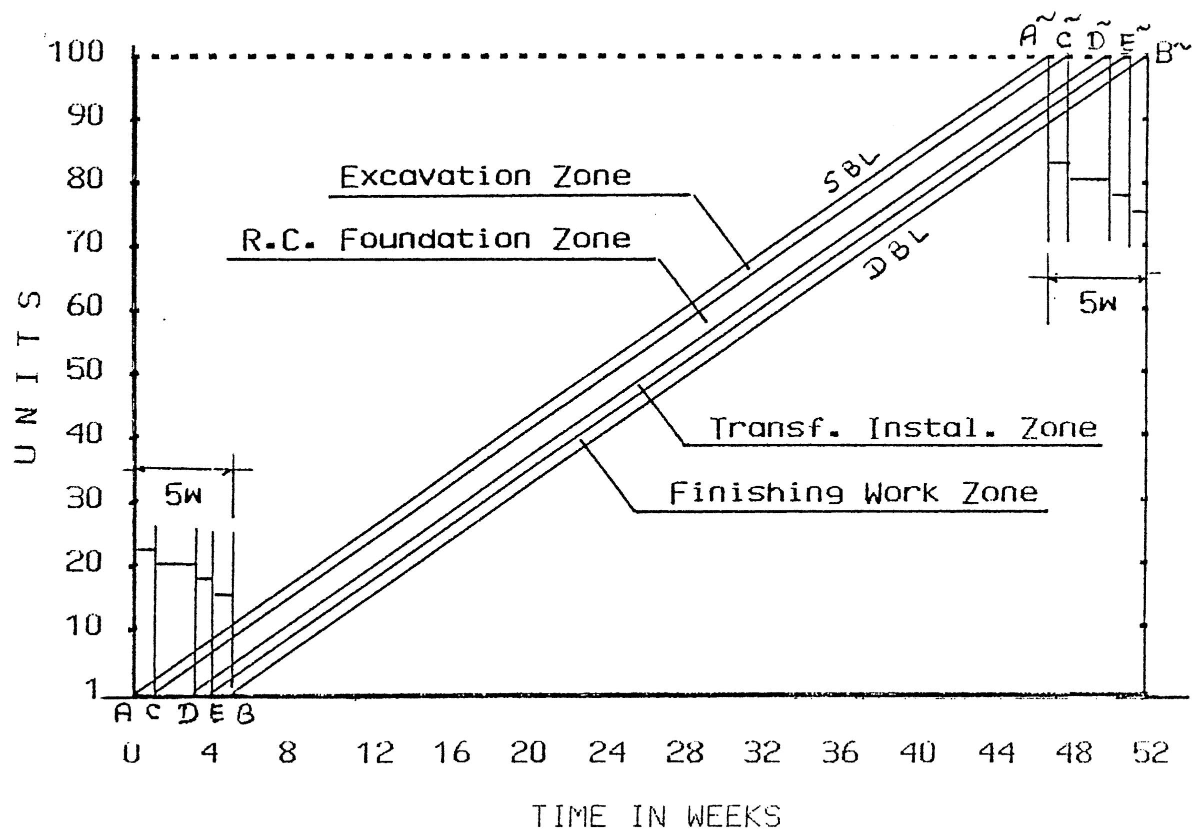

FIGURE 5 LOB CHART FOR LIMITED DURATION PROJECTS

Each line, e.g. " D D~ ", represents the finishing limit of the reinforced concrete (the preceding activity) and the starting time line of transformer installations (the following activity). Figure 5 represents the final view of LOB of projects with limite durations .

Note the following :

(1) All main and secondary boundary lines are parallel .

(2) The units delivery line " B B~ " starts after a duration

equal to the duration of the first repetitive unit , and ends at point " B~ ".

(3) The Starting Boundary line " A A~ " starts at zero time and ends at a point " A " which is before point " B~ " by a time equal to the duration of one repetitive unit .

(4) The zone between any two parallel lines represents an area in which the starting and the finishing points of the activity could fluctuate .

(5) Most of the activities in actual projects are overlapping . In this situation the starts and the ends of each activity are joined together to give the LOB chart , Figure 6 .

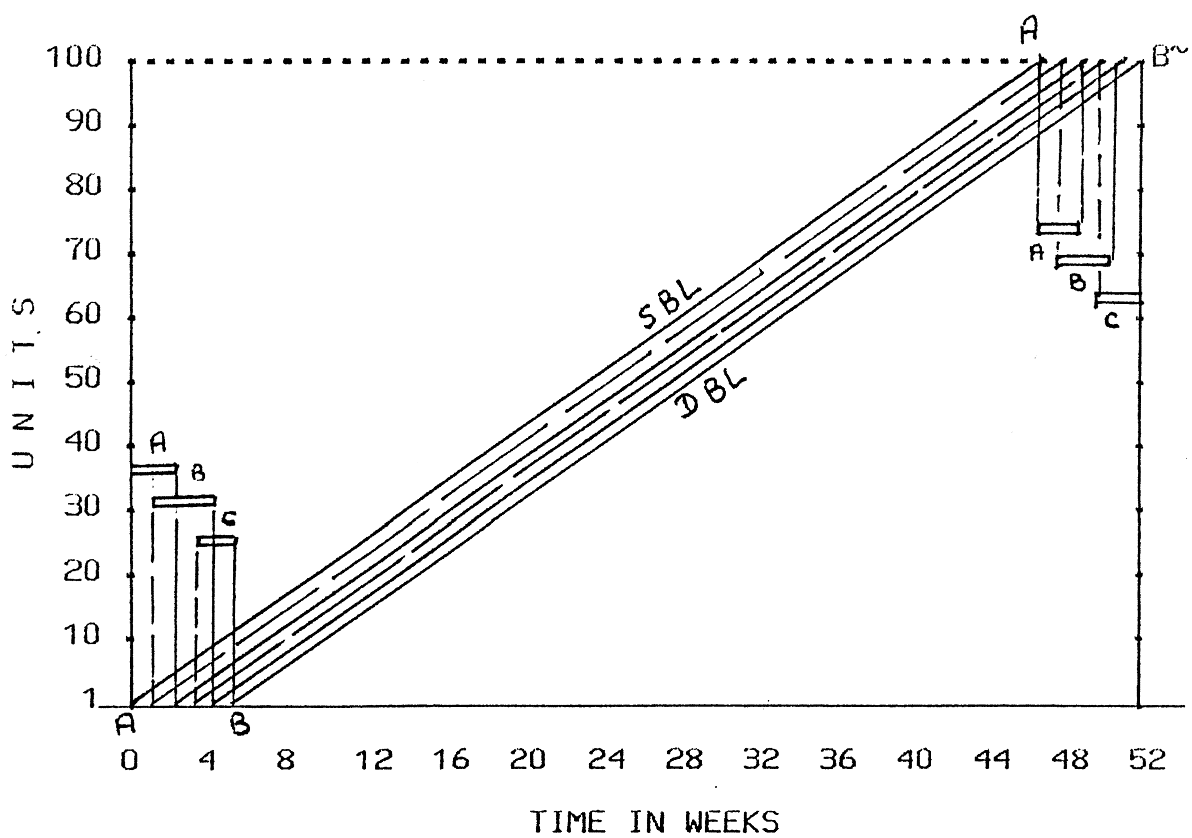

FIGURE 6 LOB CHART WITH OVERLAPPING ACTIVITIES

It is recommended to track only the end events of the repetitive activities to minimize the number of lines in the LOB chart .

(6) To present an actual field situation , it is recommended to start at point " A " after a logical period of time which could be used for project mobilization , and plan to finish the last repetitive unit (point B~) before the final project completion date by a period of time which could be reserved for unexpected delays. Figure 7.

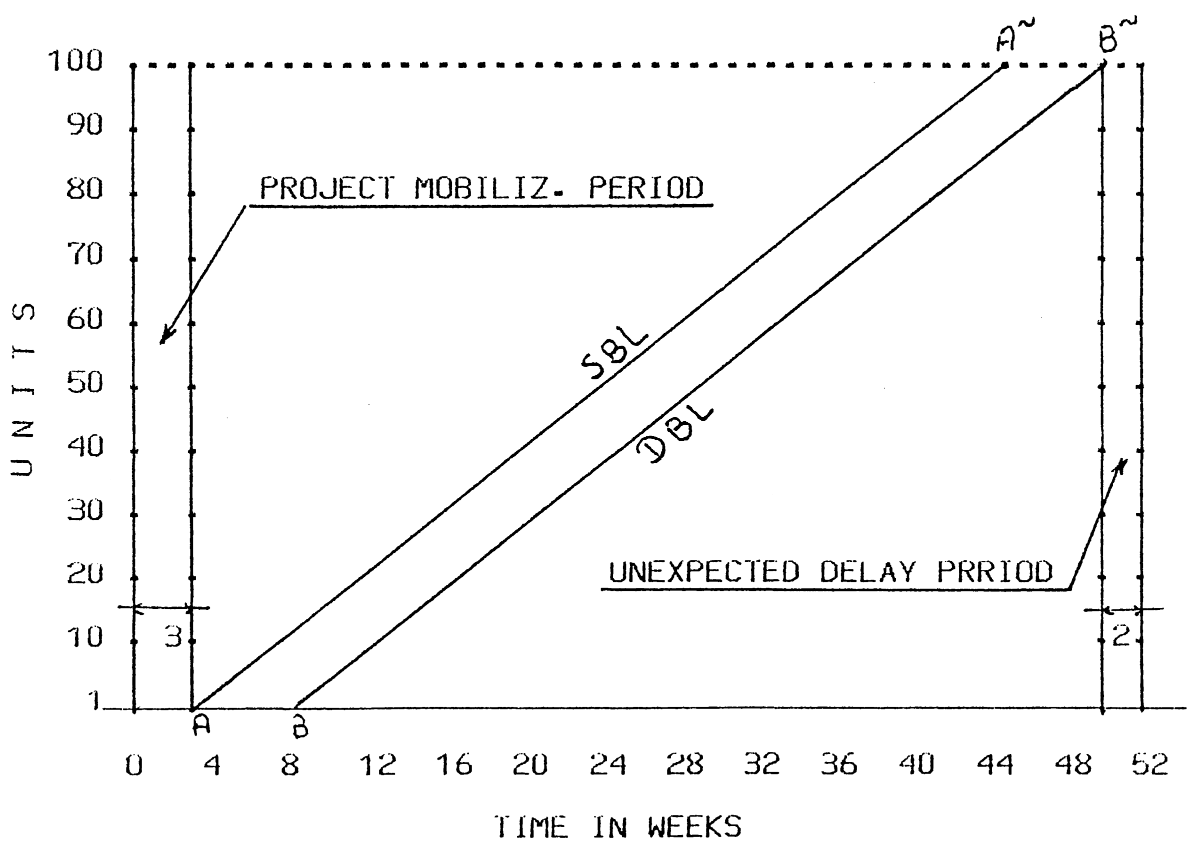

FIGURE 7 LOB CHART WITH MOBILIZATION AND DELAY TIME

(7) Holidays and expected stop time will be discussed later under the topic " Projects with constrained activities " .

CONSIDERATION II : PROJECTS WITH LIMITED RESOURCES

The availability of resources is a consideration in the LOB planning procedure. The quantity of work and availability of resources determine the total project duration .

Assume in the previous case study that the contractor can provide the following limited resources :

(1) Two excavation crews (can work on two units at a time).

(2) Carpenters, iron workers, and concrete workers are available for 10 footings at a time .

(3) One 80 ton mobile crane which can serve three footings at a time .

(4) The contractor can furnish the necessary groups to handle the finishing work for four units at a time .

Using these limited resources the contractor can determine the project total duration required to finish all the repetitive units of the contract .

The total time required to finish one repetitive activity for all the units is obtained from the following relation :

$$T.t\ (activity) = (N/n) * d$$

Where :

T.t = Total time required to finish a repetitive activity for all the units .

N = Total number of repetitive units in the project .

n = Number of units covered by the resource available at a time .

d = Duration of activity in question .

Using this relation the total duration required to finish all excavation work for all the repetitive units in the project can be determined as follows :

$$T.t\ (excav.) = (N/n) * d$$

N (number of repetitive units)	= 100	units
n (number of units covered at a time by the resource available for excavation)	= 2	units
d (duration required to finish the excav. work of one repetitive unit (FIG. 2)	= 1	week

T.t(excav.) (total duration required to finish the excavation work for all the repetitive units)= (100 u./2 u.)* 1 W.
= 50 weeks

Tabulating all work :

T.t (Excavation)	= (100 u./ 2 u.) * 1 w.	= 50	weeks
T.t (R.C. Footing)	= (100 u./ 10 u.) * 2 w.	= 20	weeks
T.t (Transf. Inst.)	= (100 u./ 3 u.) * 1 w.	= 34	weeks
T.t (Finishing Work)	= (100 u./ 4 u.) * 1 w.	= 25	weeks

To represent these results on the LOB chart the following facts should be noticed :

(1) The dependency of activities should be represented according to the network Figure 1 .

(2) The boundary lines of different activities should never cross each other .

(3) Always start by representing the boundary lines of the critical activities according to their logical sequence.

(4) Usually when representing any two boundary lines, only the first and the last units are used as follows :

(a) Locate the duration of the activity in question for the first unit .

(b) Locate the duration of the activity in question for the last unit . The late finish of this activity will be at a distance equal to "T.t" from the early start of the activity of the first unit.

(c) Joining the starting dates and the finishing dates of the activity in question for the first and the last unit , we obtain the two boundary lines required , see Figure 8.

(5) If the " T.t " of the following activity is shorter than " T.t " of the preceding one ;following the procedure given in step (4) will give crossing boundary lines, Figure 9, which means that at a time the R.C. activity is executed before the excavation activity is finished .

(6) If such a case exists the activity having the shorter "T.t" should be moved in the direction of positive time until the crossing is completely removed, see Figure 10.

Thus, if the following activity has a " T.t " less than the preceding one , the procedure for drawing the two boundary lines is a reverse of that described in step (4) .

Following the previous rules it is possible to present the results of the case study and obtain the LOB for the second consideration (Projects With Limited Resources) ,see Figure 11.

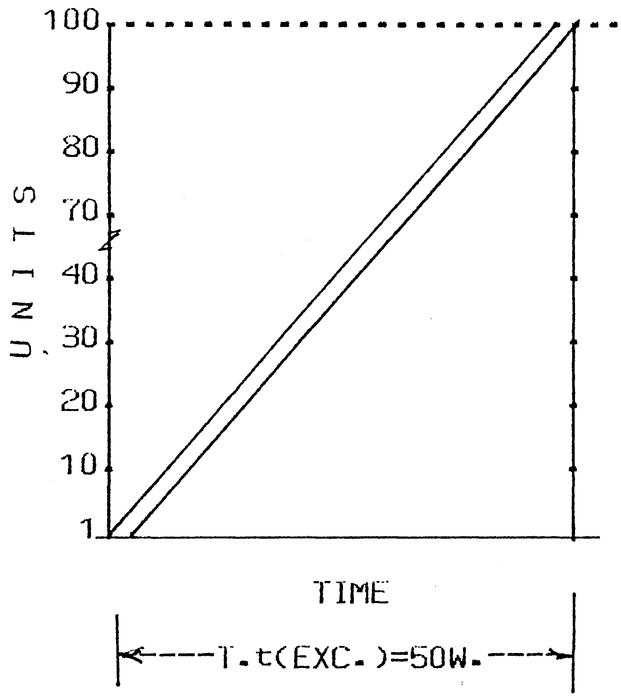

FIG. 8 EXCAVAVATIN BOUNDARY LINES

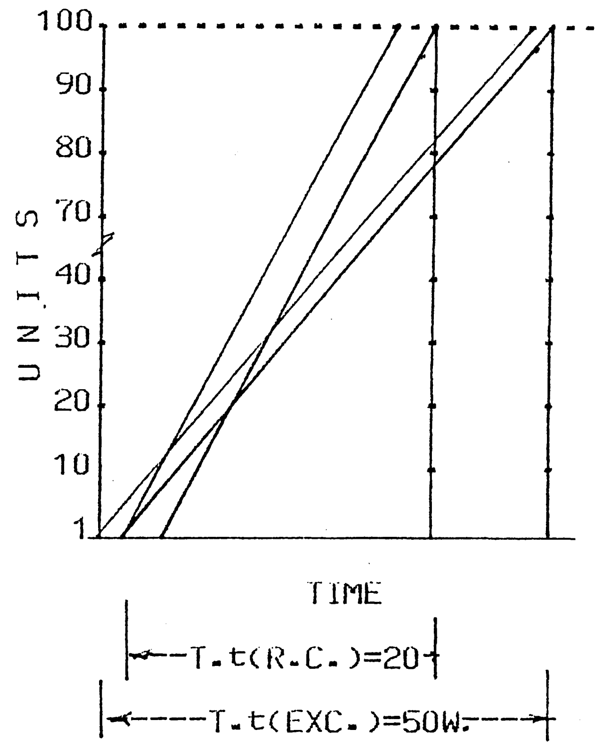

FIG. 9 CROSS BOUNDARY LINES

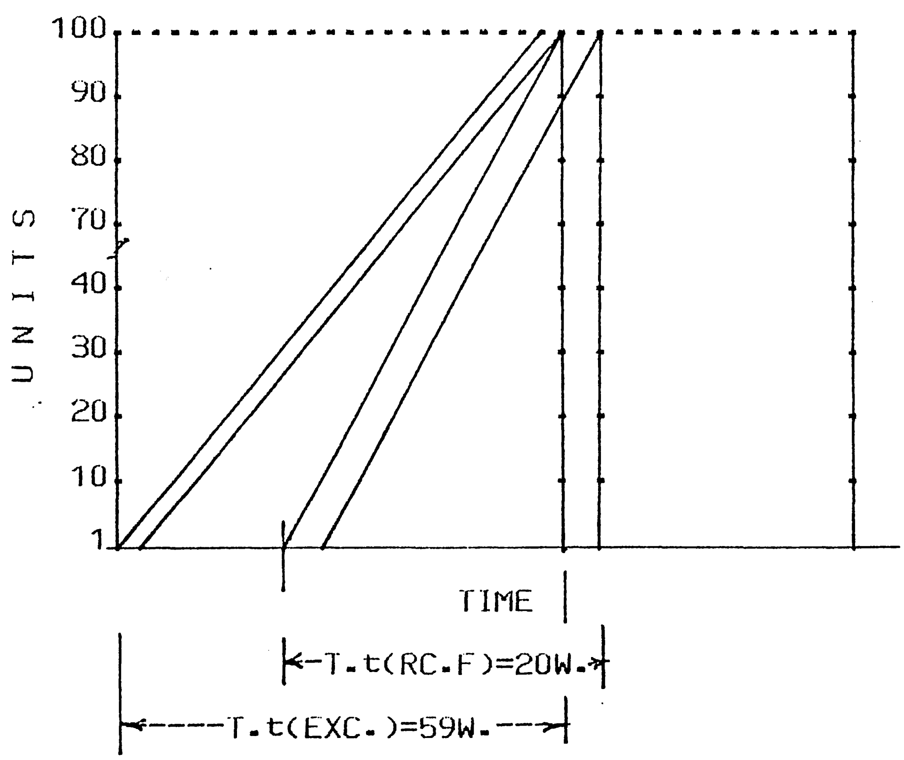

FIG. 10 CORRECTED BOUNDARY LINES

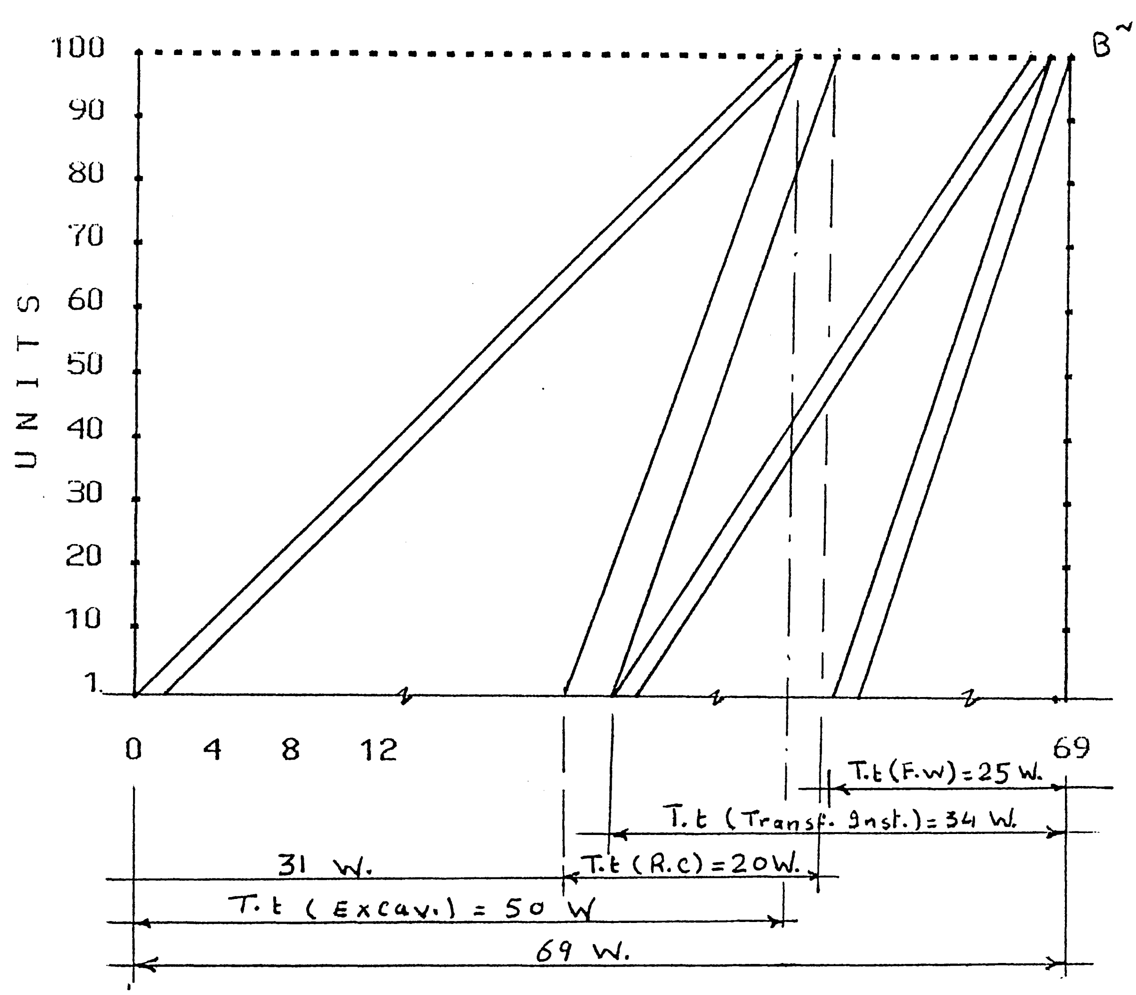

FIGURE 11 LOB FOR PROJECTS WITH LIMITED RESOURCES

Notice the following :

(1) The activity boundary lines are not parallel due to the difference in the " T.t (activities) " as a result of limited resources .

(2) There is no continuation between the activities of the same unit which might cause problems if some of these activities are left without being covered by their following ones ,e.g., excavation in the first unit is left for 31 weeks without being completed by the R.C Footing .

To overcome this problem three solutions might be considered:

SOLUTION I

R.C. footing group is called for whenever any footing is completely excavated . This might take place if the contractor has another nearby project from which he could obtain the required group necessary to finish the R.C. work.

SOLUTION II

The contractor could reduce the resources available for the activities having small " T.t ", i.e., reduce the number of units covered at a time by that group , which means making all the activities parallel using the activity having the largest " T.t " as a guide .

Applying this solution to the results in Figure 11 we can reduce the delay of the project from 17 weeks (69 W - 52 W) to only 2 weeks , see Figure 12 .

Resources required for the corrected activities will be covered under Resource Scheduling .

SOLUTION III

Working in two shifts could be a decision to bring the activities with large " T.t " parallel to the activities having small " T.t " , which is the same as adding more resources to the job . The cost associated with this solution must be considered . Benefits may be achieved by using this solution if the contractor is able to reduce the total project duration to obtain the bonus of an early finish. A comparison between benefits and losses should be considered .

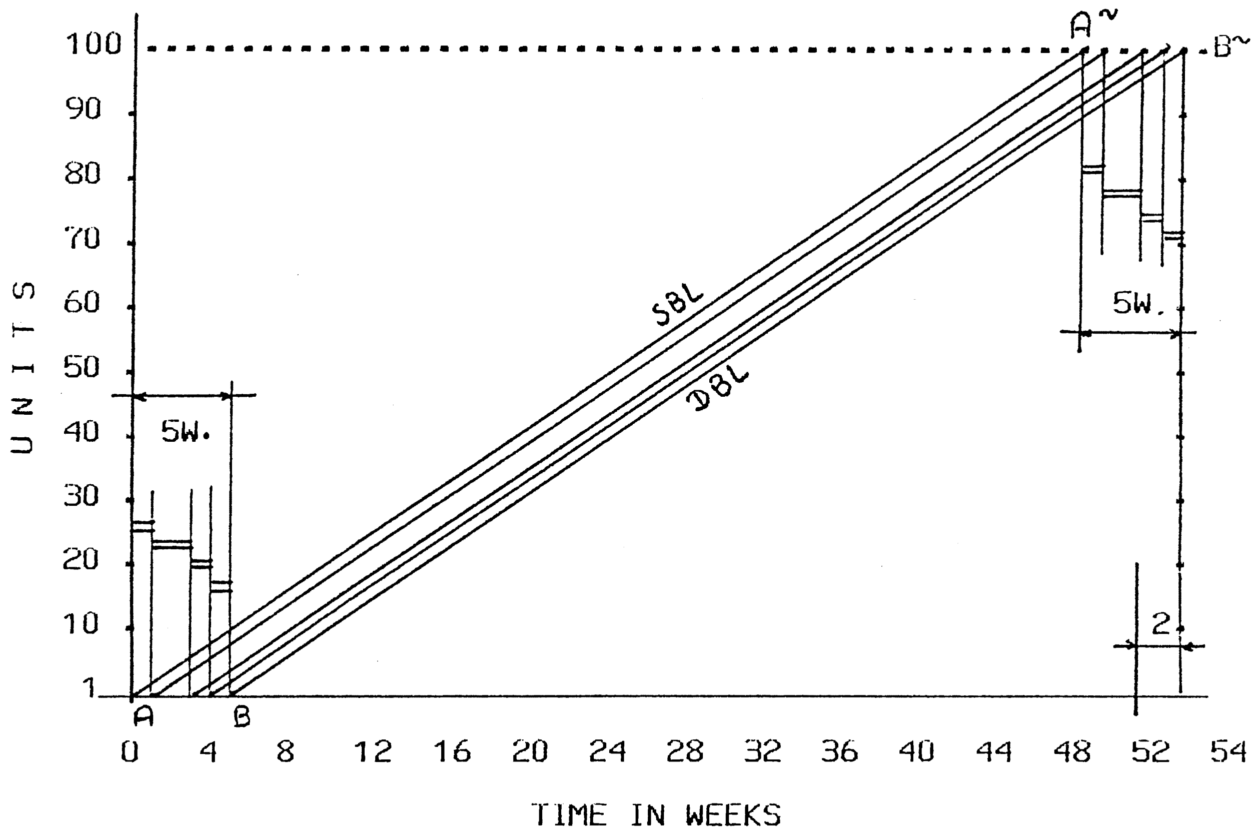

FIGURE 12 CONSIDERATION II AFTER TIME REDUCTION

(3) To obtain parallel activity boundary lines the resources of activities with large " T.t " should be increased to cover more units at a time until the inclination of the boundary lines of these activities are the same as those having small " T.t " . Determining the resources required for activities with large " T.t " will be discussed under Resource Scheduling .

(4) It is difficult to deliver limited duration projects in time since their activities depends on the availability of resources .

(5) In actual projects, time and resources are often limited

and the contractor has to balance between his limited resources and the owner's request for a limited time contract, i.e., he has to balance between time and cost.

CONSIDERATION III : PROJECTS WITH CONSTRAINED ACTIVITIES

Constrained activities have a great effect on the LOB shape. This effect should be studied and considered at an early stage in the planning process .

Examples of constrained activities are :

* Special delivery dates of certain materials
* Special starting dates of activities
* Special arrival dates of equipment
* Delay requirements between activities
* Financial restrictions , etc.

When considering any constrained activity in the LOB chart , the same procedure described before in Consideration I and II (limited duration and limited resources) is followed plus the study of the change which the constraint might cause to the activity boundary lines .

Referring to the previous case study and assuming that the Transformer Installation activity has the following conditions :

(1) The first 50 transformers will arrive at the site during week 15 , and will be available for use by the start of week 16 .

(2) The second 50 transformers will arrive at the site during week 39 and will be available for use by the start of week 40 .

To obtain the Objective Chart under these conditions , and considering a fixed project duration, excavation and R.C. footing boundary lines are located as discussed before in the case of limited duration . The following two facts should be considered when locating the boundary lines of the Transformer Installation activity :

(1) The installation of the transformers of the first unit can not start after its R.C. footing which is completed since the transformers (of the first 50 units) will not be available until the start of week 20 .

(2) For units 51 to 100 the start will be in week 40 .

Presenting this on the LOB chart the following alternatives could be presented :

FIRST ALTERNATIVE

The objective in this case is to have minimum delay between the activities of the same unit and to cover the work available and ready for the constrained activity and the activities following it . Since 50 units of transformers are available by week 20 , the early start of the transformer installation activity of the first unit could be at the beginning of that week. Checking the late finish of the R.C. footing of unit number 50 (as discussed before) it is found to be in week 27 which is after week 20 , this gives us the opportunity to achieve minimum delay between the activities of the 50 th unit and to schedule the transformer installation activity of that unit directly after the R.C. footing giving zero delay, see Figure 13.

Similarly , as soon as the next 50 transformers are available at the beginning of week 40 the boundary lines are located so that the 100 th unit does not suffer any delay . Figure 13 illustrates this case .

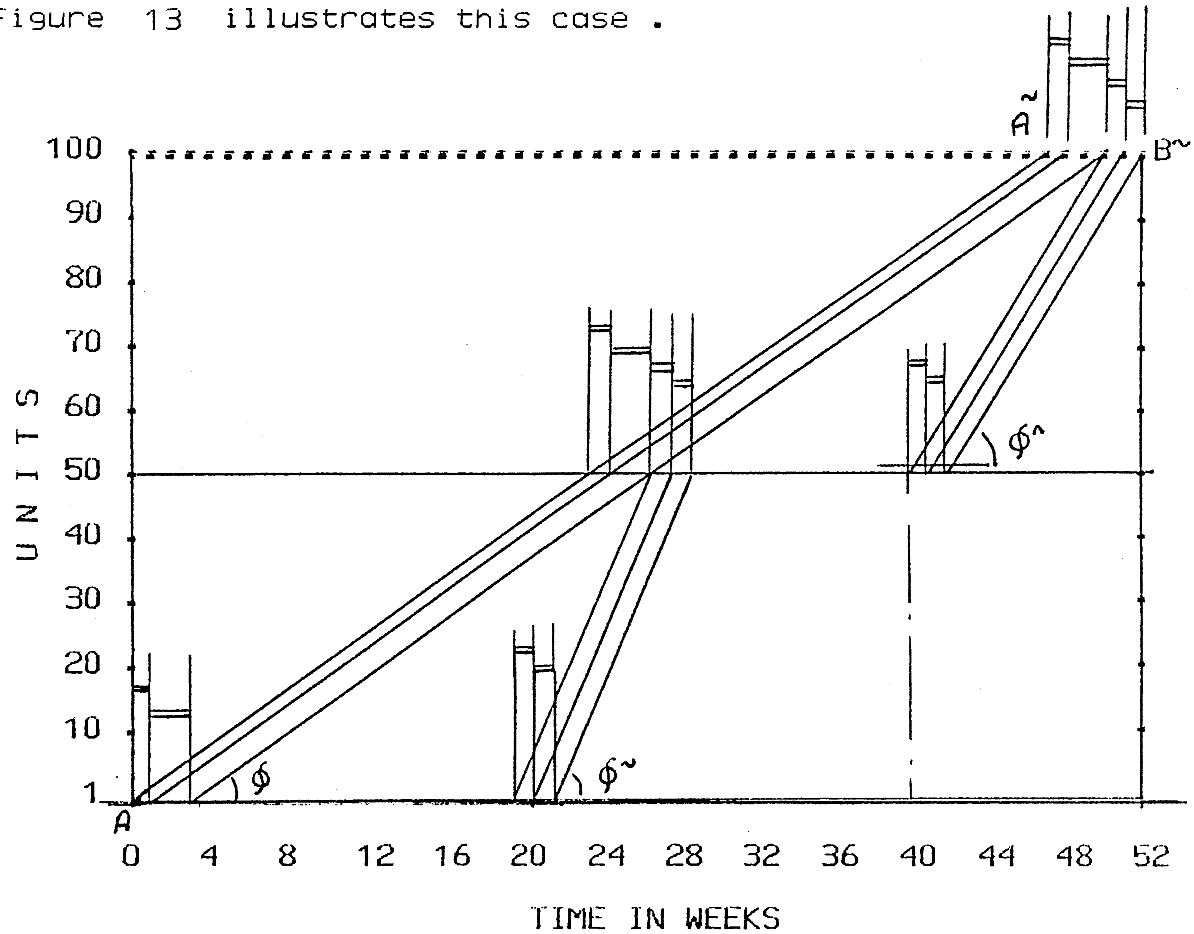

FIGURE 13 LOB CHART WITH MINIMUM DELAY BETWEEN ACTIVIVTIES

SECOND ALTERNATIVE

In this case the objective is to achieve a continuous work for the group installing the transformers through the 100 units . To achieve this , the two different arrivals of the transformers are joined together by the external boundary lines and then connected with the activities of the last unit so that no delay occurs between its activities as shown in Figure 14 .

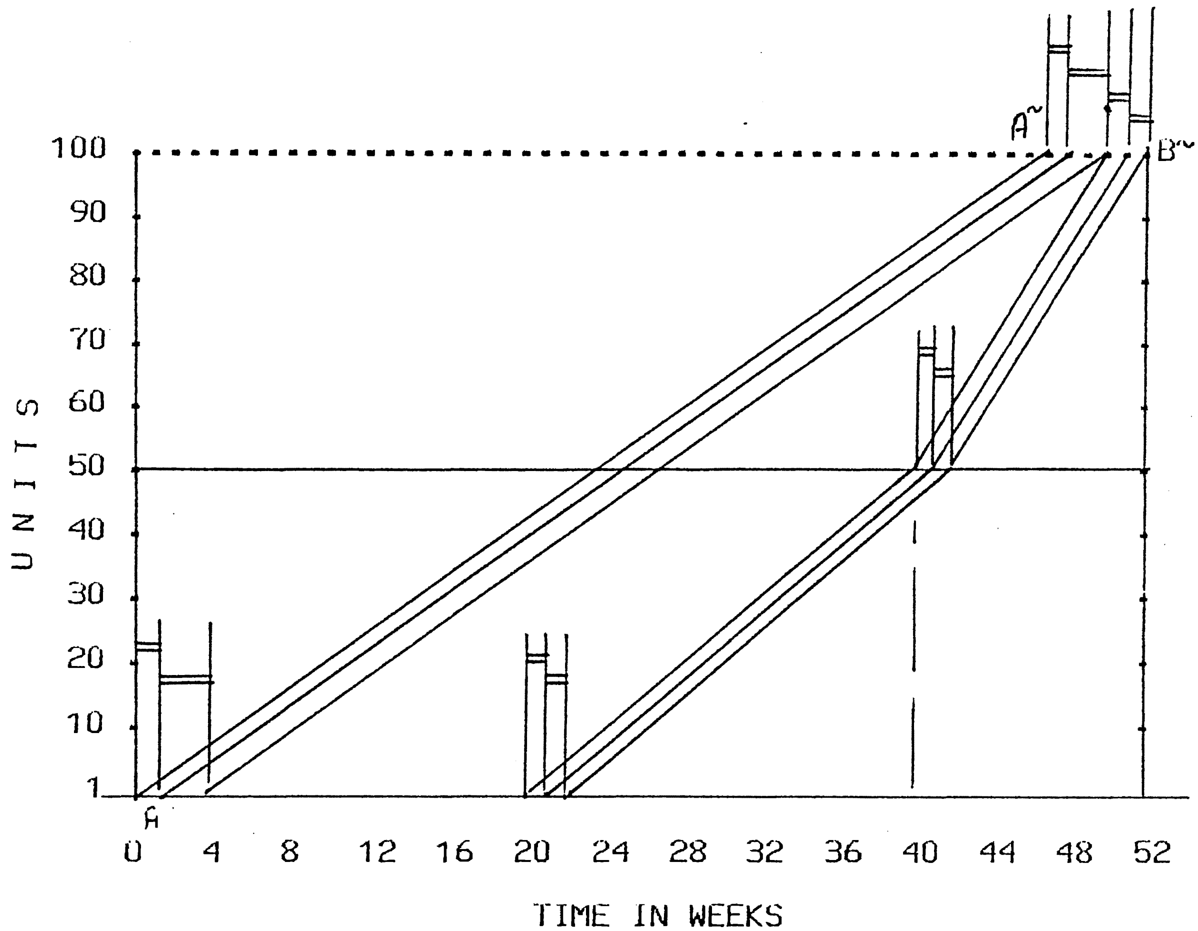

FIGURE 14 LOB CHART FOR CONTINUOUS WORK

THIRD ALTERNATIVE

The objective of using this plan is to make use of the project duration to minimize the resources needed to cover the delay of the constrained activities . The units of the project are divided into two parts according to the availability of the constrained activities . Each constrained activity and its successors are assumed as two separate project progressing at the same time with different resources . The boundary lines of these activities are drawn so that their starting and finishing point of the first unit are connected to their correspionding ones of the last unit but at the end date of the project, see Figure 15 .

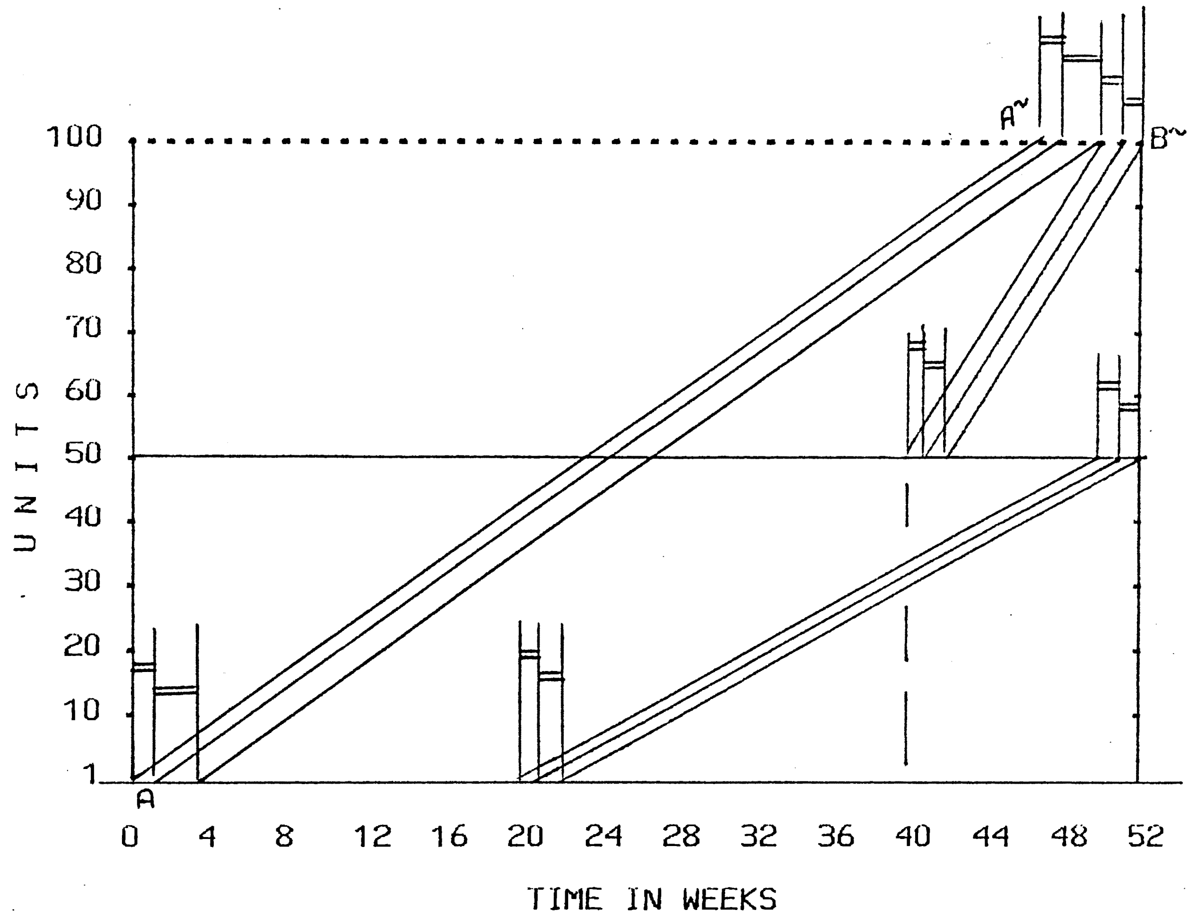

FIGURE 15 LOB CHART FOR MINIMUM RESOURCES USAGE

The choice between these three alternatives depends upon the resources availability which will be covered under Resource Scheduling .

NOTICE THE FOLLOWING

(1) Activities following the transformer installation will be obliged to have the same delay .

(2) Although this is a limited time project , the boundary lines of the constrained activities and those that follow them will not be parallel to the preceding activities .

(3) Large non-working periods usually appears between the

constrained activities and their successors and between their predecessors. This might cause problems and waste of time and money .

(4) All activities could be scheduled parallel to the least T.t(activity) . This might lead to a decrease in project duration and an increase in total cost due to the increase of resources used to achieve this condition

IV - HAND OVER RATE (R)

Hand over rate (R) is the rate the repetitive units of the project are delivered or finished . By knowing this rate the contractor can decide whether or not he could bid for the contract . This decision depends on his previous experience with hand over rates , his capabilities , and his available resources.

Deciding on a logical hand over rate and allowing for some time for mobilization and unexpected delays , the owner could announce and include in his contract documents a reasonable project duration for bidding purposes .

Hand over rate (R) depends on the following factors :

(1) Relation between number of units under construction and the project duration .

(2) Duration required to finish one repetitive unit .

(3) Resources available .

RELATION BETWEEN NUMBER OF REPETITIVE UNITS AND PROJECT DURATION

Consider the Delivery Boundary Line "BB`", and assume that its inclination on the time axis is angle " ψ " , see Figure 16 .

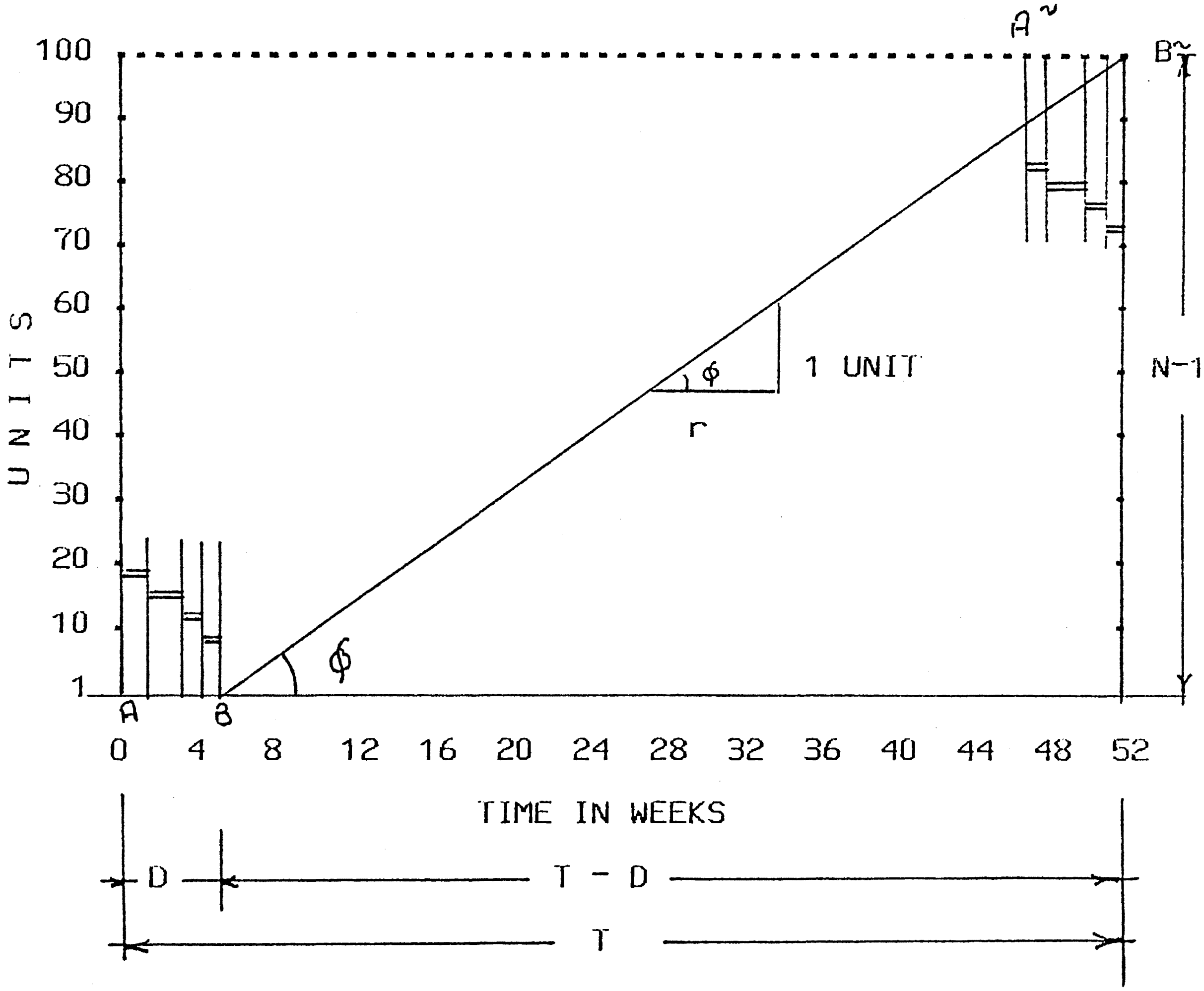

FIGURE 16 INCLINATION OF ACTIVITY BOUNDARY LINE

From similarity of triangles

$$r / (T - D) = 1 / (N - 1)$$

$$r = (T - D) / (N - 1) = \cot \phi$$

Where

- r = Time interval between the finishing dates of two successive repetitive units .
- T = Total project time .
- N = Total number of repetitive units .
- ϕ = Angle of inclination of the boundary line with respect to the time axis .

D = Time required to finish one repetitive unit .

Referring to the previous case study , the interval between the finishing dates of any two successive repetitive units can be calculated as follows :

T = 52 weeks .

D = 5 weeks .

N = 100 UNITS .

Hence $r = (52 - 5) / (100 - 1) = 0.45$

$= 0.5$ weeks

i.e., every 0.5 week a unit has to be finished . This corresponds to a hand over rate of 2 units / week.

From which we can derive the following relation :

$$\text{HAND OVER RATE } (R) = 1 / r = \tan \phi$$

If the contractor handling the project has the ability to work on two units at the same time , the LOB Chart would look like that in Figure 7 , the unit increment will be two units instead of one .

In this case the hand over rate will be :

$$R = 2 \tan \phi = 2 (100 - 1) / (52 - 5)$$

$$= 4 \text{ UNITS / WEEK}$$

Hence the general relation would be as follows :

$$\text{HAND OVER RATE } (R) = n \tan \phi \quad \text{UNITS / UNIT TIME}$$

Where n = Number of units planned to be working in parallel at the same time .

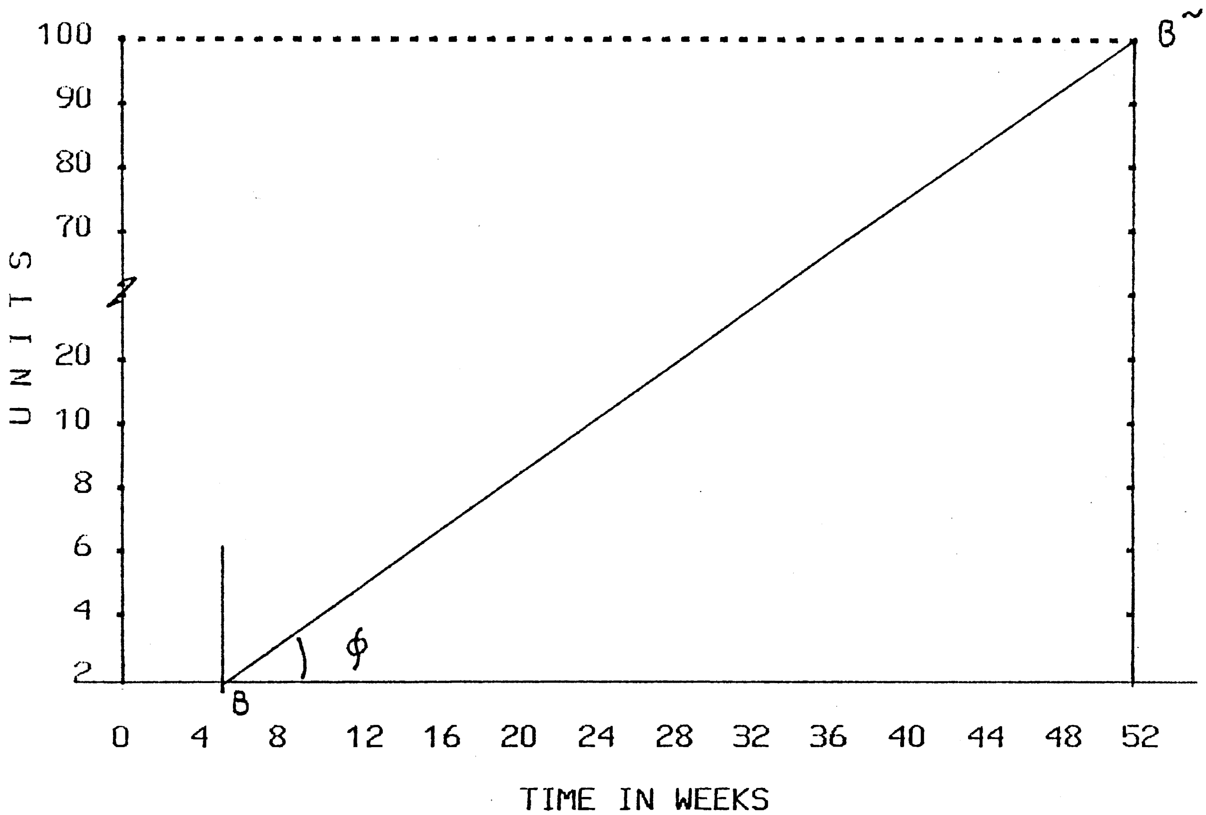

FIGURE 17 LOB CHART WITH 2 UNITS EXCAVATED AT A TIME

EFFECT OF REPETITIVE UNIT DURATION ON HAND OVER RATE (R) .

It is preferable to keep the duration required to finish the repetitive unit as short as possible . This is achieved by giving more attention to the method of construction used for the repetitive unit, and the resources assigned to the critical activities .

The longer the unit duration " D " the greater the angle "ϕ" between the boundary lines and the time axis , which in turn increases the number of units required to be completed or delivered during the project time (T) . Hence, the hand over rate "R" is directly proportional to the activity duration "D".

To clarify this relation , assume that the duration of one repetitive unit is equal to 12 weeks instead of 5 weeks .

Since HAND OVER RATE (R) = n TAN. ϕ

and n = one unit at a time = 1

TAN. ϕ = (N - 1) / (T - D)

therefore HAND OVER RATE (R) = (100 - 1) / (52 - 12)

= 2.5 UNITS / WEEK

= 5.0 UNITS / 2 WEEKS

Therefore when " D " increased from 5 weeks to 12 weeks

" R " increased from 4 units/W to 5 units/W

As a matter of fact if the total project duration is too short , for example 25 weeks instead of 52 weeks , and the duration of the repetitive unit is 12 weeks , the hand over rate will be as follows :

R = (100 _ 1) / (25 _ 12) = 8 UNITS / WEEK

which is a high hand over rate . The contractor might face difficulties in achieving this hand over rate .

EFFECT OF RESOURCES AVAILABLE ON THE HAND OVER RATE (R)

Limited resources have a great impact on the inclination of the activity boundary lines , i.e., angle ϕ which in turn affect the hand over rate (R). Affect of limited resources on the LOB chart will be discussed in the resource scheduling section .

Note the following :

(1) Hand over rate could be calculated for any repetitive activity .

(2) Since the starting boundary line (SBL) is parallel to the delivery boundary line (DBL) the rate of finishing and starting the activity will be the same rate .

V - RESOURCES SCHEDULING

One of the main objectives of planning is to determine the optimum resources required to complete the contracted work with the desired quality , at the agreed time , for the agreed cost .

Deriving the resource schedules from the LOB chart is different from other planning techniques due to the overlapping between the repetitive units and their activities . The number of resources used to finish the work depends on the total project duration and the required hand orer rate .

To determine the resources needed for any repetitive activity in the LOB chart the following information should be available :

(1) The duration " d " required to execute the activity in question . This can be obtained from the project network or the bar chart , Figures 1 and 2 .

(2) The number of units executed in parallel at a time," n ".

(3) The time interval between the start of two successive repetitive activities, " r " .

(4) Constituents of the group needed for a particular job , i.e., labor , equipment , etc.

In the case study described before , the excavation activity has the following information :

d = 1 week

n = 1 unit

r = 0.5 week

Since every 0.5 week excavation starts in a new unit , and since 1.0 week is required to finish the excavation we need two excavation groups for the whole job . Figure 18 is the graphical representation for this situation .

The following relation can be derived from the previous discussion :

Number of groups required = (Duration of activity in question)/ (Time interval between two successive starts)

= (d) / (r)

This could be put in the general form as follows :

G. (activity) = n * d * R

Where R = 1 / r = Hand Over Rate of activity in question .

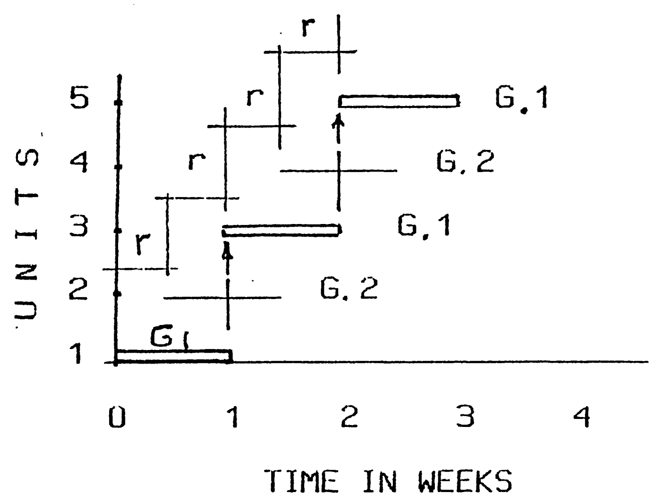

FIGURE 18 ASSIGNMENT OF EXCAVATION CREWS

To determine the resources required for the LOB chart in Fig. 13 the following procedure is followed :

(1) Resources required for Excavation

n	=	1	unit at a time
d	=	1	week / excavation / unit
N	=	100	units
D	=	5	weeks

T = 52 weeks

since R = 1 / r = tan. ϕ

Therefore R = (100 - 1) / (52 - 5) = 0.5 units / week

And since # G. (activity) = n * d * R

Therefore # G. (excavation) = 1 * 1 * 2 = 2 groups .

The following schedule, Table 1, is formed using the previous result .

Activity : EXCAVATION # G. Assigned = 2 G.

Group contents :

type	Code	Q.	Cost
Excavator	6415	2	$ 30 / hr.
....	....	...	....

Group assignment: Area 4

G.1	UNITS	1	3	5	7	9	11	
	E S .							
G.2	UNITS	2	4	6	8	10	12	
	E S .							

TABLE 1 RESOURCES NEEDED FOR EXCAVATION

(2) Resources required for R.C. foundation

n = 1 unit at a time

d = 2 weeks / activity / unit

R = 2 units / week (the same as in excav. since the boundary lines are parallel .

Therfore # G. (R.C found.) = 1 * 2 * 2 = 4 groups .

The units assigned for each group and their starting dates are scheduled in the Table 2.

Figure 19 is used to determine assignment of the R.C. crew

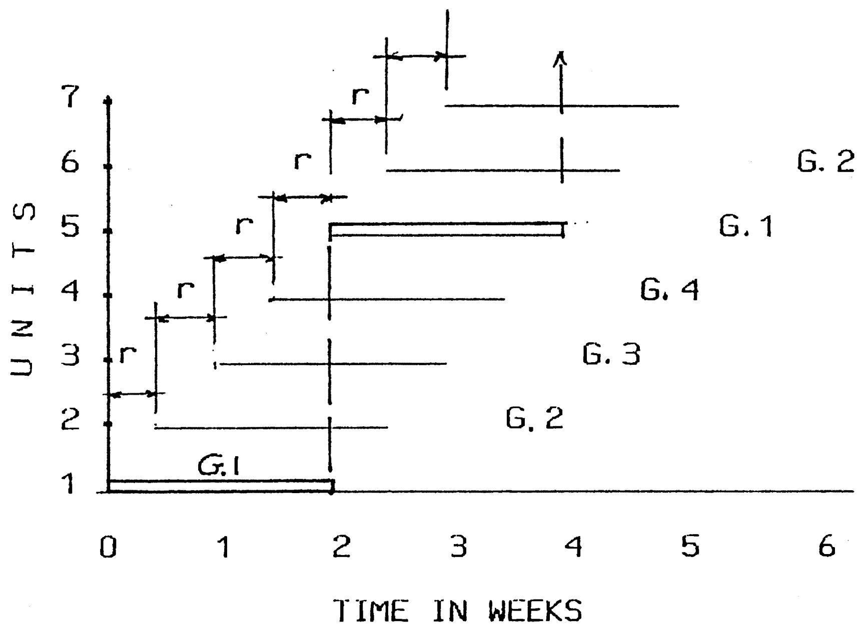

FIGURE 19 ASSIGNMENT OF R.C. FOOTINGS CREWS

(3) Resources required for the transformer installation

n = 1 unit at a time

d = 1 week / act. / unit

r = cot ϕ ~ Figure 13

= ((LF of R.C. foudation unit 50) -

(ES of transformer installation unit 1)) /

(# of units under consideration)

Activity : R.C.FOUND. # G. Assigned = 4 G.

Group contents :

type	Code	Q.	Cost
Carpenters	4208	5	$ 18 / hr.
....	....	...	....

Group assignment: Area 4

G.1	UNITS	1	5	9	13	17		
	E S							
G.2	UNITS	2	6	10	14	18		
	E S							
G,3	UNITS	3	7	11	15	19		
	E S							
G,4	UNITS	4	8	12	16	20		
	E S							

TABLE 2 RESOURCES NEEDED FOR R.C. FOOTINGS

Where LS = Activity late finish date

ES = Activity early start date

= (27 - 20) / 50 = 0.14 weeks

R = 1 / r = 1 / 50 = 7 units / week

# of G. (T.Install.) = 1 * 1 * 7 = 7 groups .

which means that seven groups are needed to finish all transformer installation work through the whole project in the required duration . A schedule for the units assigned to each group could be formed .

(4) Resources required for the finishing work

Since the boundary lines of the finishing work are parallel to those of the transformer installation , seven groups are also required to fulfill this work .

(5)Resources required for transformer installation (units 51-100)

n = 1 unit at a time

d = 1 week / act. / unit

r = cot ϕ^ Figure 13

= (50 - 40) / 50 = 0.2 week

R = 1 / r = 5.0 units / week

G.(T. Install. 50 TO 100) = 1 * 1 * 5 = 5 groups

As discussed previously in Consideration III (projects with constrained activities) there are three alternatives for the execution of the transformer installation activities for units 1 to 50 . Resources for the First Alternative had been discussed . Similarly the resources required for the Second and Third Alternatives could be obtained .

In order to determine the optimum number of groups required for an activity , the planner should go into more details when analyzing the resources needed for that activity .

To discuss this statement , consider the R.C. foundation activities from the previous calculations. It was recommended to use four groups to finish all the activities through the project. By breaking the R.C. foundation into its components Table 3 , the following facts are observed :

(1) Each group should contain the following sub-groups:

* Carpenters ,
* Iron workers ,
* Concrete sub-group ,
* back-fill sub-group

(2) Each sub-group is only utilized a few days according to the sequence of work and not a full time of two weeks .

R.C. Components	DAYS									
	1	2	3	4	5	6	7	8	9	10
Formwork	----	----	----	----						
Steel reinf.				----	----	----	----			
Concrete work								----		
Dismantle forms									----	
Back-fill										----

Table 3 R.C. FOUNDATION COMPONENTS

The optimum number of groups could be obtained by allowing the R.C. foundation activities to overlap, see Table 4.

As a result of this analysis , One group is required to cover all the repetitive R.C. foundation work for all the units , thus saving the cost and time of three groups .

This procedure should be considered for every activity before a final decision on the resources needed at the job site .

From the previous discussion we can conclude the following:

(1) The number of groups required for any activity is affected by the following :

(a) Number of units executed at a time , " n " .

(b) Duration of the activity in question , " d " .

(c) The hand over rate of the activity in question, "R"

(2) The contractor has to choose the alternative which minimizes his total cost .

(3) The required number of groups should be checked for redundancy before scheduling .

(4) Since these are the project critical activities , the scheduled resources should be provided by the contractor without any delay .

(5) Resources required for the other non-critical activities should also be determined and balanced utilizing the activity float to obtain the best resources allocation .

VI - PROJECT PROGRESS TRACKING

The purpose of effective planning and scheduling is to develop a continuous comparison between the actual achievements

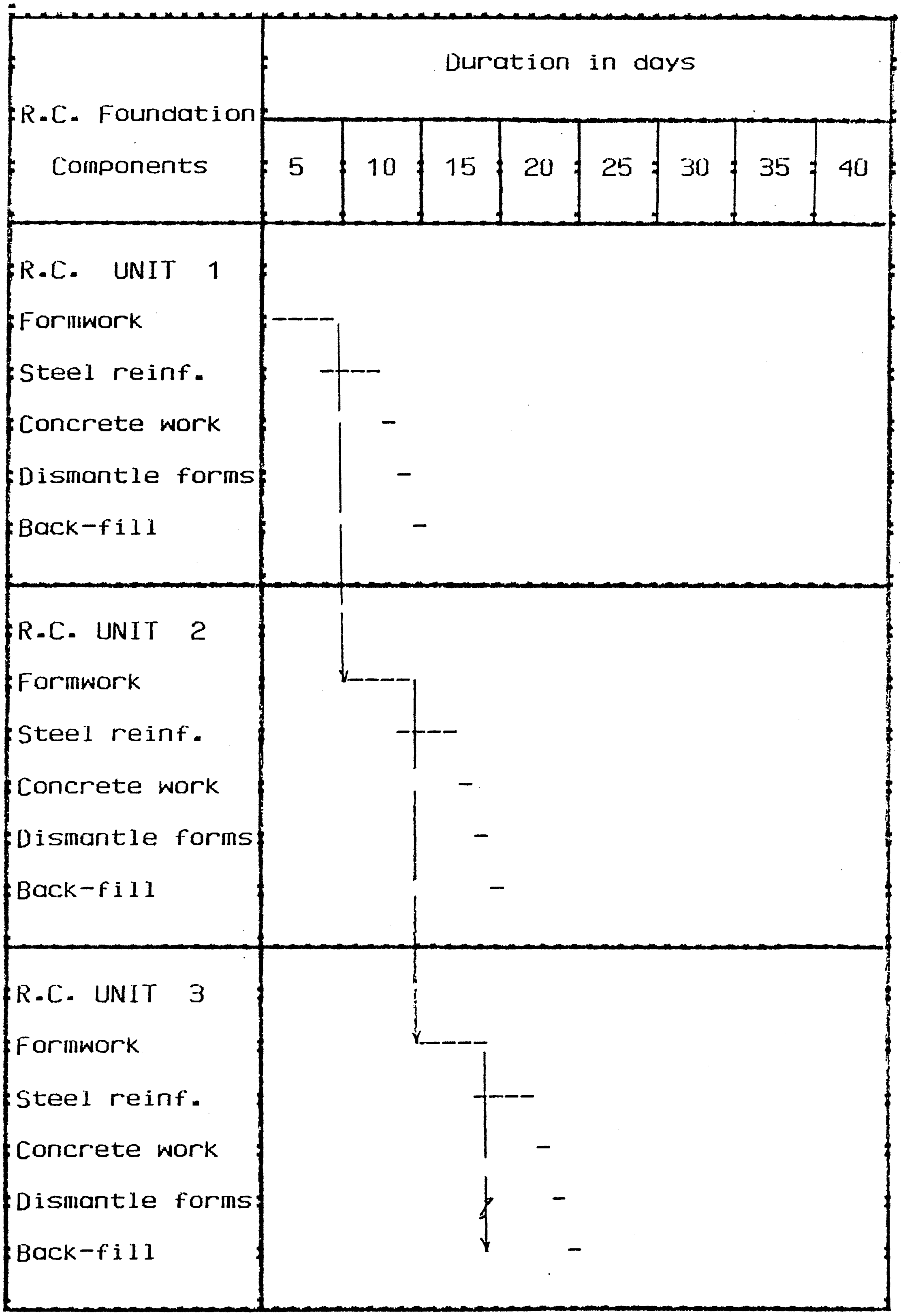

TABLE 4 R.C. FOUNDATION COMPONENTS OVERLAP

at the job site and the previously planned achievement . This is to ensure that the contractor will fulfill his time and cost obligations .

Actions should be considered by the project manager , whether in the plan or in the execution phase, to correct any deviation. Figure 20 is a schematic diagram of the planning cycle

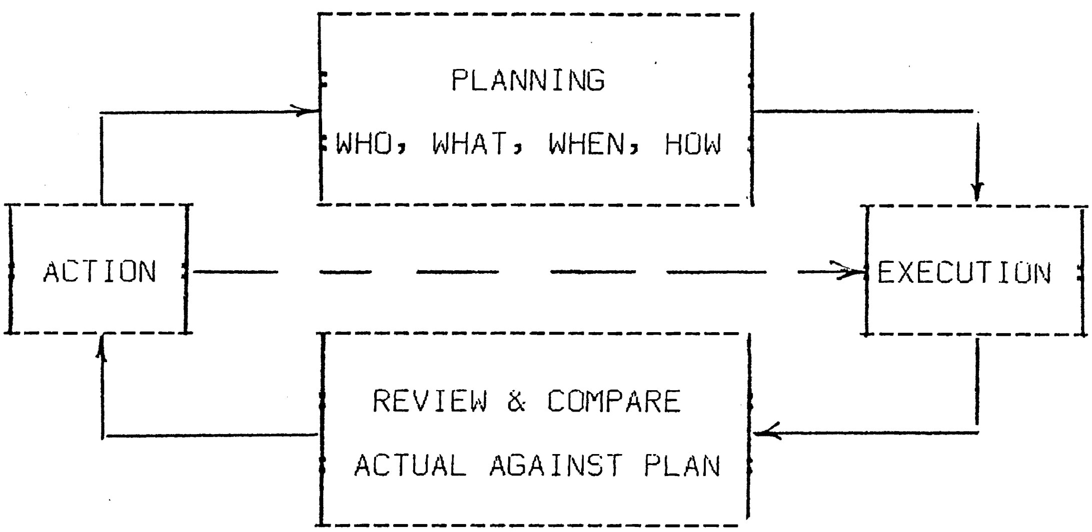

FIGURE 20 PROJECT PLANNING CYCLE

Since controlling is the process of making events confirm to schedules , it is essential to put the objective chart (LOB chart) in a simple and readable form for the purpose of easy and quick progress tracking . This is achieved by THE PROGRAM or TARGET CHART which is derived from the LOB chart .

The contents of this chart are :

(1) A horizontal dimension is the time scale in the form of the project calendar .

(2) A vertical dimension is the list of LOB critical activities .

(3) The number of units obtained from the LOB chart and planned to be covered within the other two dimensions .

PROCEDURE TO OBTAIN THE PROGRAM CHART

There are two methods to derive the program chart ,graphical and analytical. The following is a discussion of each .

(1) THE GRAPHICAL METHOD

First a vertical line is drawn from any point along the time axis until it intersects the boundary lines of the repetitive activities on the LOB chart . The intersection points are then projected horizontally to the ordinate scale to obtain the number of units required for completion at that date , see Figure 21 .

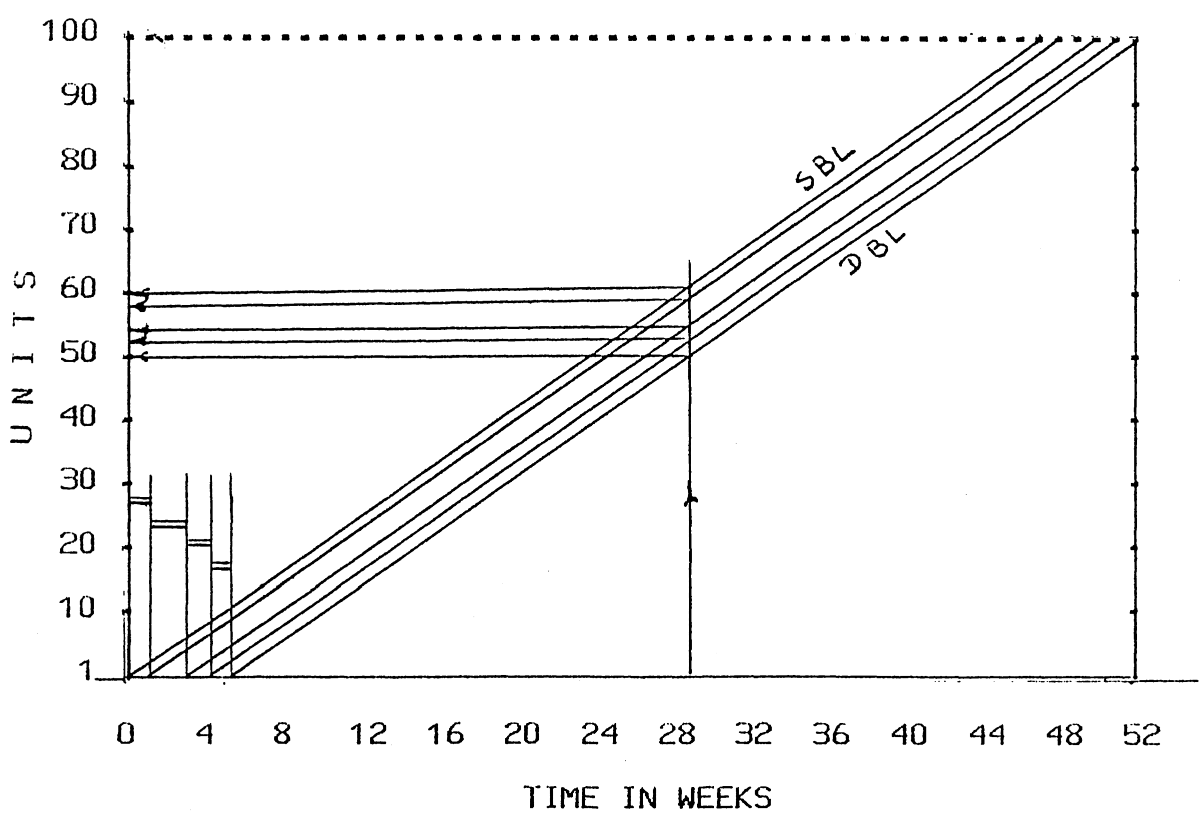

FIGURE 21 RESOURCES SCHEDULING USING GRAPHICAL METHOD

Hence , by drawing vertical lines from every week through the project duration and following the previous concept , the corresponding number of units required to be finished at that date are obtained . These are then tabulated to give the desired program or target chart shown in Table 5.

(2) ANALYTICAL METHOD

In this method, the Hand Over Rate , " R ", is used to determine the number of units which should be finished at a certain date for a certain activity .

Since R = number of activities handed over or finished in a certain unit of time = 1 / r = Tan. ϕ

By calculating the value of " R " for the activity under consideration, the constant increase of the units for each unit of time is obtained . The program chart is then filled horizontally for the activity by increasing the units each unit of time by the " R " value obtained .

For example to fill the program chart for excavation in the case study presented , the following steps are considered :

(1) R (excav.) = Tan. ϕ = (100 - 1) / (52 - 5) = 2.11 U/W

Fractions of a unit should be neglected when calculating " R " , for example , if " R " = 3.8 units / week

then consider " R " = 3 units / week

This will give some advantages to the project team on the job .

A correction should be made while scheduling the number of units to cover the neglected cumulative unit fractions , i.e. for the excavation activity a unit should be added every 10 weeks to cover the 0.11 unit neglected weekly .

Proj. Name:............. PROGRAM CHART

WORK AREA :.............

ACTIVITY.													
	year												
	date												
	cumu	1	2	3	4	5	...	28	..	49	50	51	52
Excavation	PLAN.							60					
	ACTUAL												
	% COMP.												
R.C Found.	PLAN.							56					
	ACTUAL												
	% COMP.												
Trans.Inst	PLAN.							52					
	ACTUAL												
	% COMP.												
Finish W.	PLAN.							50					
	ACTUAL												
	% COMP.												

TABLE 5 PROGRAM CHART FOR THE GRAPHICAL METHOD WEEK 28

(2) The activity Delivery Boundary Line is considered from the first date it starts , i.e., week ONE in this case .

(3) The following weeks are calculated as follows :

At end of week one = 1 unit is excavated

At end of week two = 1 + 2 = 3 units are excavated

At end of week three = 3 + 2 = 5 units are excavated. This procedure is continued until all the project units are finished . Table 6 is then filled .

	YEAR											
	DATE											
ACTIVITY	CUMUL.	1	2	3		46	47	48	49	50	51	52
EXCAV.	PLAN	1	3	5		95	97	100				
	ACT.											
	% C.											
R-C. FOUN.	PLAN											
	ACT.											
	% C.											

TABLE 6 PROGRAM CHART FOR THE ANALYTICAL METHOD

Similarly this is done for the rest of the LOB critical activities . The final program chart for Consideration I (Projects with limited duration) is shown in Table 7 .

PROJECT PROGRAM CHART

e:.........................

:.........................

year																																																				
date																																																				
cumu	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	20	1	2	3	4	5	6	7	8	9	30	1	2	3	4	5	6	7	8	9	40	1	2	3	4	5	6	7	8	9	50	1	2
PLAN.	1	3	5	7	9	11	13	15	17	20	22	24	26	28	30	32	34	36	38	41	43	45	47	49	51	53	55	57	59	62	64	66	68	70	72	74	76	78	80	83	85	87	89	91	93	95	97	100	—	—	—	—
ACTUAL																																																				
% COMP																																																				
PLAN.	—	—	1	3	5	7	9	11	13	15	17	20	22	24	26	28	30	32	34	36	38	41	43	45	47	49	51	53	55	57	59	62	64	66	68	70	72	74	76	78	80	83	85	87	89	91	93	95	97	100		
ACTUAL																																																				
% COMP																																																				
PLAN.	—	—	—	1	3	5	7	9	11	13	15	17	20	22	24	26	28	30	32	34	36	38	41	43	45	47	49	51	53	55	57	59	62	64	66	68	70	72	74	76	78	80	83	85	87	89	91	93	95	97	100	
ACTUAL																																																				
% COMP																																																				
PLAN.	—	—	—	—	1	3	5	7	9	11	13	15	17	20	22	24	26	28	30	32	34	36	38	41	43	45	47	49	51	53	55	57	59	62	64	66	68	70	72	74	76	78	80	83	85	87	89	91	93	95	97	100
ACTUAL																																																				
% COMP																																																				

TABLE 7

The following should be noted regarding the program chart :

(1) At any week the project manager could easily observe the planned work that should be finished by his team .

(2) The actual progress of work is recorded on the program chart every week . The percentage of work completed for each activity is obtained by dividing the its actual achievement by the planned one.

(3) Activities falling behind schedule, i.e., those with low percentage of completion , are analyzed and suitable actions taken to overcome the delay .

(4) Determining the program chart using the analytical method is easier and more accurate than using the graphical method .

SUMMARY AND CONCLUSION

The LOB technique provides project managers with a simple integrated system to assist in the planning and monitoring of complex repetitive type projects .

As described in this paper and determined from the work done in the pilot projects where this technique was used , the LOB scheduling can handle three different project situations :

Projects with limited duration	Consideration I
Projects with limited resources	Consideration II
Projects with constrained activities	Consideration III

From the discusion of the Hand Over Rate in this paper it is clear that the contractor can make a decision whether or not he can bid for the job .

Resource scheduling in highly repetitive unit projects depends on the hand over rate. Economical resource allocation requires extensive analysis before a final decision is made on the number of groups which should be ordered for an activity .

This paper presents a project progress tracking method which converts the LOB chart to a simple readable form . This solved the major LOB tracking problem and gave the project manager the opportunity to determine the job's present and future situation and to calculate the percentage of work completed .

The following are the main LOB benefits when it is used for planning and scheduling of repetitive unit projects :

(1) It is an easy technique to construct and implement .

(2) It integrates the LOB concept with the PERT / CPM .

(3) Information input are collected at the selected lowest levels of management .

(4) It provides periodic updating of progress and cost, plus a measurement of the relationship between actual units accomplished with those planned . Thus, the manager is continually apprised of the status of current work as well as the forecast of the future schedules .

(5) Provides management with an easy progress control method

(6) Potential problems are highlighted in time through a simple tracking procedure that aids effective corrective actions .

(7) It is a flexible technique for handling constrained activities subjected to special considerations .

The success of the LOB as a planning and scheduling technique depends on resources assigned to each activity and estimates of the rates of production of each group . Since errors in estimates are magnified with the increasing repetition of the units , the LOB resources scheduling should be handled with great care to prevent project time or cost overrun .

Records from previous projects should be considered in determining the output rates , production and group sizes . At the same time these records should be updated and sent to the estimating and planning departments for future usage .

Lack of training of the project planners , executives and managers in constructing and implementing the LOB technique might be one of the main problems which faces the achievement of the project objectives . Training courses and seminars should be scheduled for the line staff to furnish them with the necessary construction management techniques needed for their work .

Their is no doubt that computers should be used in constructing and implementing the LOB, especially in projects involving many critical activities and very frequent tracking . Computer outputs may be configured to help management in analyzing problems and reaching better decisions

Using computers will lead to the following improvement :

(1) Computers will substantially reduce the time required to prepare and maintain the LOB and program charts .

(2) The accuracy will increase .

(3) The program charts are reproducible and can be used in reports and proposals .

(4) The effectiveness of corrective action can readily be

evaluated though simulation .

(5) The actual project status can be evaluated .

(6) Computerized LOB can also be used as a method of transmitting accurate information between the sub-contractor and the main contractor or between the main contractor and the owner .

(7) Project documentation is enhanced by using a computerized program . This will help in creating a data base for the project which could be used in future estimates and future planning .

Research work in the area of constructing and implementing the LOB as a planning , scheduling and control tool for highly repetitive unit projects should be encouraged to identify the shortcomings , eliminate hidden implementation problems , and make this method more attractive to constructors for this type of project .

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