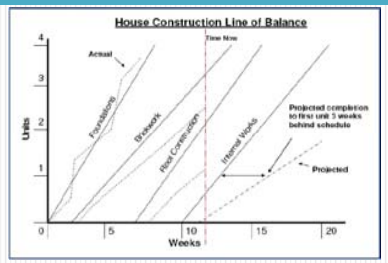
Line of Balance (LOB)



Chapter 2

Linear Projects

- Linear projects are projects involving repetitive activities.
  - several uniform units of work : multiple houses or typical floors;
  - geometrically linear such as highway, pipeline, and utility projects
- Assume the project is comprised of (n) typical units, with the activities in each unit having average quantity of the work in all units (non-typical units)
- As number of units increases, the project becomes more complex

Line of Balance (LOB)

- The Line of -Balance Scheduling Technique (LOB) is a linear scheduling method
- It allows the balancing of the operations such that each activity is continuously and efficiently performed in each consecutive unit.
- LOB technique, developed by US. Navy in the early 1950s
- First applied to industrial manufacturing and production control

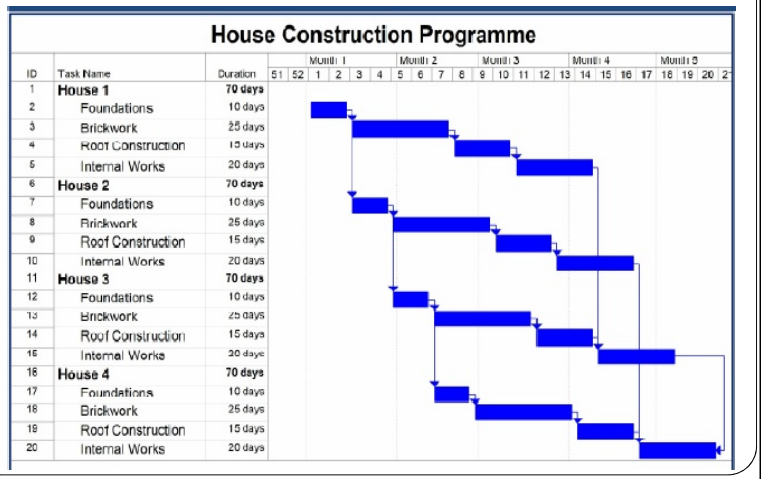
Characteristics of LoB

- Shows repetitive nature of the construction
- Progress of work can be seen easily
- Sequence of different work activities can be easily understood
- Can be developed and prepared in a shorter time period than other formats

Example

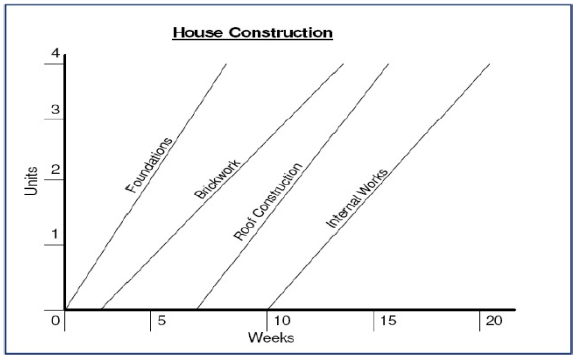
- Consider the construction of several houses (say 100)
- Each typical house involves four inter-related activities
  - A- Foundations,
  - B- Brickwork,
  - C- Roof construction
  - D- Internal works
- If programmed using a conventional bar chart , complex!
- CPM network also complex!

Bar chart



LoB Representation

- A schedule representation that suits projects with repetitive activities



Line of Balance Chart

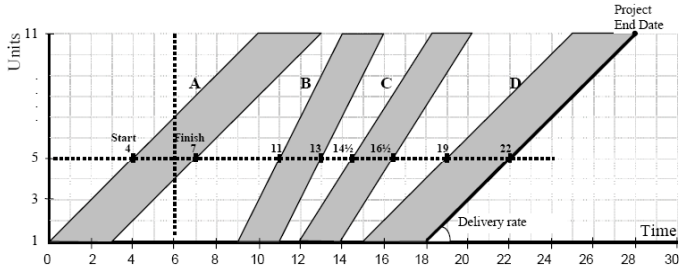
- Line of Balance Chart :
  - can summarize a group of similar activities on one line
  - shows the rate at which the work that makes up all of the activities has to be undertaken to stay on schedule
  - does not show direct relationships between individual activities;
  - shows an output relationship between the different activities in that one activity must be completed at a particular rate for the subsequent relationship to proceed at the required rate

Example

- Consider a high-rise building with 40 typical floors
- The construction of each typical floor involves four interrelated activities (A, B, C, D)
- CPM for the whole project : complex, composed of copies of the activities in a single floor
- Bar-chart also complex
- LoB schedule

LoB Representation

- A schedule representation that suits projects with repetitive activities



LoB representation

- LoB shows the following information:
  1. Each sloping bar represents one activity and the width of the bar is the activity duration, which is uniform along all units;
  2. A horizontal line at any unit intersects with the activity bars at the planned start and finish times of the work in that unit;
  3. A vertical line at any date (time) shows the planned work that should be completed/started before and on that date;

LoB representation

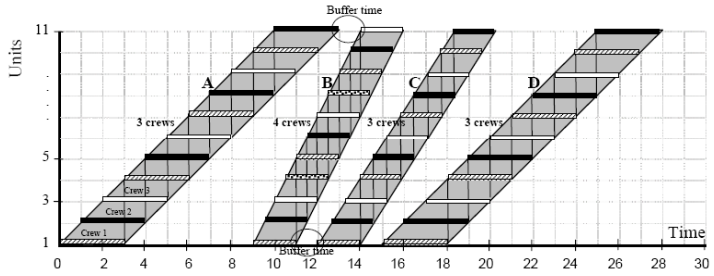
4. The slope of each activity represents its planned rate of progress and this is direct function of the number of crews involved in the activity.

   The slope of the last activity is the rate of delivery of the various units;

5. The finish time of the last unit in last activity represents the end date of the project.

LOB schedule

- Add more details to the basic LOB schedule. Example: number of crews (‘team” or “gang” employed in each task)



LoB schedule

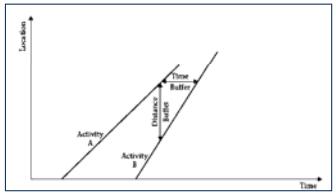
- LoB representation with crew details
  - To prevent interference among the sequential activities in case an activity is delayed, a **buffer time** may be introduced, to act as a float time
  - When a faster activity is to follow a slower activity (B follows A), the activity B needs to be scheduled starting at the top unit. If buffer time is to be added, it will be added at top.
  - When a slower activity is to follow a faster activity (C follows B), the activity C can be scheduled starting from unit 1, immediately following the predecessor B.
    - Since interference can happen at unit 1, buffer time can added to the start of unit 1

LoB schedule

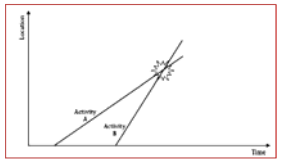
- LoB representation with crew details
  - Changing the production rate (slope) of any activity changes the project duration
  - If speeding an activity or relaxing it may result in a delay in the project, a good scheduling strategy is to schedule the activities as parallel as possible to each other and also parallel to a desired project delivery.

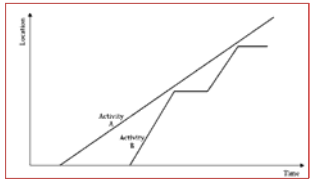
More on buffer

- Buffer is necessary if the rate of the successor is faster than the rate of the predecessor



- Lines are not allowed to intersect
- intersection means that the successor has gotten ahead of the predecessor, *which is impossible*



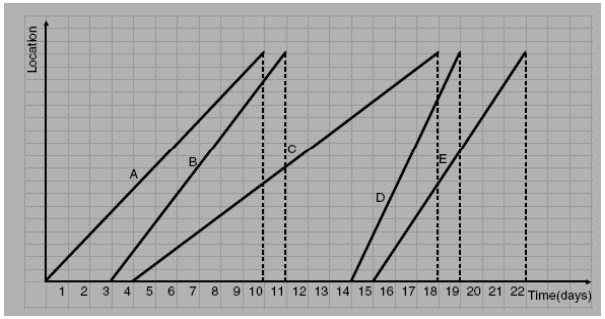


Example

- A project consists of five activities:
  - A. Excavating a trench
  - B. Laying a subbase of gravel
  - C. Laying a concrete pipe
  - D. Backfilling
  - E. Compacting
- Assume that the length of the pipe is 1,000 m and the productivity rates for the five activities are 100, 125, 75, 200, and 150 m per day, respectively.
- Draw the project diagram, using the LoB
- Leave a minimum 1-day time buffer

Solution

- Activity durations = total quantity (1,000)/ production rate for each activity
- 10, 8, 14, 5, and 7 days (for activities A through E)



LoB calculations

- The objective of using LOB is to achieve a resource-balanced schedule by determining the suitable crew size and number of crews to employ in each repetitive activity.
- This is done such that:
  (1) the units are delivered with a rate that meets a pre-specified deadline;
  (2) the logical CPM network of each unit is respected; and
  (3) crews' work continuity is maintained.
- The analysis also involves determining the start and finish times of all activities in all units and the crews' assignments.

CPM-LOB formulation

- The CPM-LOB formulation that achieves the above objective involves four main issues

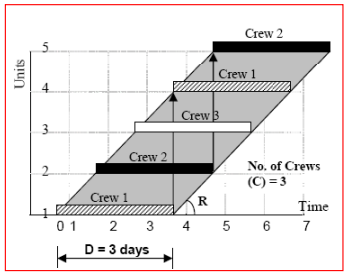
1. - Crew synchronization and work continuity equation
2. - Computation of a project delivery rate that meets a given deadline duration
3. - Calculating resource needs for critical and non-critical activities
4. - Drawing the LOB schedule

Crew synchronization

- D: duration taken by a crew in one unit
- C : the number of crews
- R : work progress rate
- Work synchronization to happen

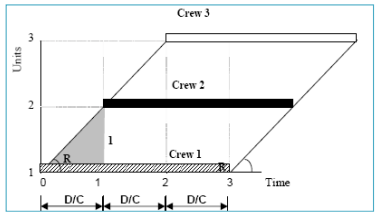
Number of Crews (C) = D x R

- If 4 crews become available,
- a faster progress rate of R 1.25 units/day. (to achieve work continuity)



R is 1 unit/day

Crew synchronization



R= 1/ (D/C) or

(D/C) = 1/R

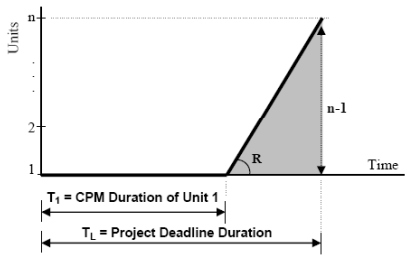
The above eqn. means that work continuity is achieved by shifting the start of each unit from its previous one by a time *D/C or 1/R*

Meeting a deadline duration

- A basic objective in CPM-LOB calculation is to meet a given deadline for finishing a number of (*n)* repetitive units
- Each has its own CPM network of component activities
- Desired rate of delivery (*Rd*)

$$R_d = \frac{(n-1)}{(T_L - T_1)}$$

Rd is the minimum rate required to meet the desired deadline.



Calculating resource needs

- R_d to be particularly applied to critical activities
- Non-critical activities have float (TF) times and can be relaxed
- a desired rate (R_i) for any repetitive activity (i):

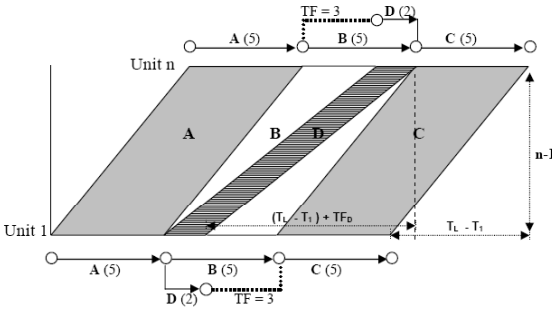
$$R_i = \frac{(n-1)}{(T_L - T_i) + TF_i}$$

Example

- A 5-unit project with each unit consisting of a simple four-activity network
  - A, B, and C are sequential and each has 5-days duration
  - D runs parallel to B and has a duration of 2 days only.
  - Thus, A, B, and C are critical activities while activity D is non-critical with Total Float (TF) of 3 days.

Example

- Floats in LoB calculations



slopes of activities A, B, and C are the same

Slope for Activity D : starting unit 1 of D as early as possible while starting the last unit as late as possible

Example

- Relaxation of non-critical activities can be performed without violating any logical relationships or crew work continuity requirement
- desired rates calculated for activities
- necessary number of crews (Ci) to use in each activity (i), as :
- $C_i = D_i \times R_i$
- $C_{ai} = Round\ Up\ (C_i)$ (a fraction of a crew not possible)
- $R_{ai} = Ca_i / D_i$ *(actual rate)*

Drawing the LoB Schedule

- LoB schedule becomes simple to draw when activities run parallel to each other
- activities' actual rates (R_{ai})s calculated may not be parallel
- draw the LoB schedule using the activities actual rates, using a forward path, following the logical relationships in the CPM network.
- Drawing schedule by hand is simple when the network is small, with varying levels of detail

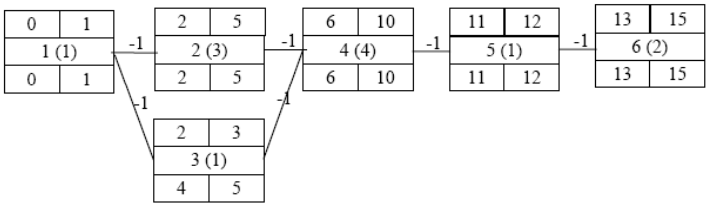
LoB Example

- Construction of 1 KM of a pipeline are given below. The project consists of 10 similar KM.
- Calculate the number of crews needed for each activity if the deadline for completing the project is 40 days and draw the LoB schedule.
- Assume one day buffer time between activities.

Activity no.	Activity name	Duration (days)	Preceding activities
1	Locate and clear	1	-
2	Excavate	3	1
3	String pipe	1	1
4	Lay pipe	4	2,3
5	Pressure test	1	4
6	Backfill	2	5

Solution: CPM calculations

- Shows the CPM calculations for a single unit of the project to identify the critical path
- Note that the one day buffer time is set as a lag between activities.



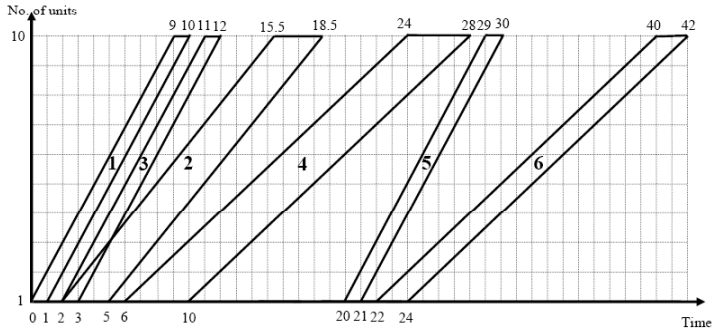
Solutions : LoB calculation

$T_1 = 15$ day $\quad T_L = 40$ day $\quad N = 10$ units

$R_i = (n\text{-}1) / T_L - T_1 + TF_i = 9 / (25 + TF_i)$

Activity	Duration D_i	Total Float	$R_i = 4 / (25+TF_i)$	$C_i = D_i \times R_i$	C_{ai} = Round up C_i	$R_{ai} = C_{ai} / D_i$
1	1	0	0.36	0.36	1	1
2	3	0	0.36	1.08	2	0.667
3	1	2	0.333	0.333	1	1
4	4	0	0.36	1.44	2	0.5
5	1	0	0.36	0.36	1	1
6	2	0	0.36	0.72	1	0.5

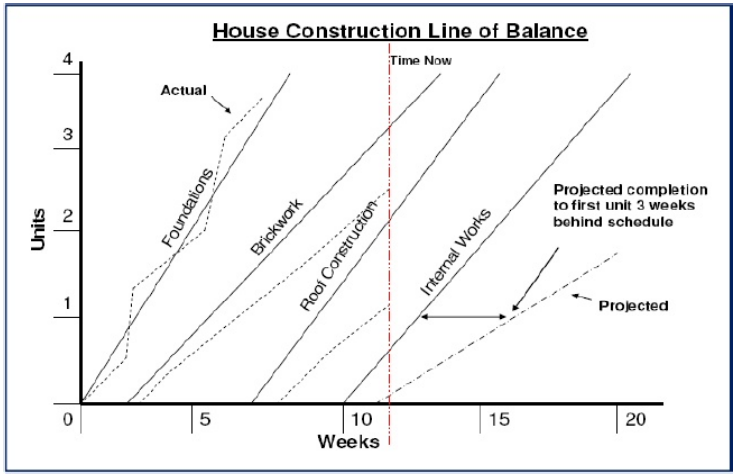
Solution : LoB drawing



LoB Progress

- A Line of Balance Chart is progressed by plotting on the chart the work achieved.
- The planned rate of completion of the various activities can then be compared with the actual
- If the rate at which the work is being achieved is lower than required, adjustments are made to increase the output.

LoB Progress



LoB Progress

- LoB Chart has been updated up to week 12
- Foundation work are on schedule but Brickwork and Roof Construction are running behind schedule.
- The Internal Works have not started
- the anticipated rate of work has been plotted on the chart and by extrapolation the first unit will be completed 3 weeks late.