Calculations for Line-of-Balance Diagrams

Chapter 3 of the Handbook introduces the Line-of-Balance planning technique. (see Page 71). Here we show a structured approach to calculating and plotting a Line-of-Balance Schedule. Whilst software exists for producing Line-of-Balance schedules, the investment required (in time and money) to produce computer-based diagrams may not be justified. The approach shown below allows the planner to fully understand the basis of the resulting diagram and explore opportunities to optimise production. The way of working and the individual example selected for demonstration purposes are taken from Harris and McCaffer, 1996.

Example

Consider the calculation of the time taken to construct 30 houses. The target rate for completion of these houses is four houses per week. A working week comprises five 8-h days.

The construction plan for each individual house is shown in Figure 1. These construction activities have been simplified for demonstration purposes. In practice the activities and their inter-relationship will be more complicated.

A Handbook for Construction Planning and Scheduling, First Edition. Andrew Baldwin and David Bordoli.

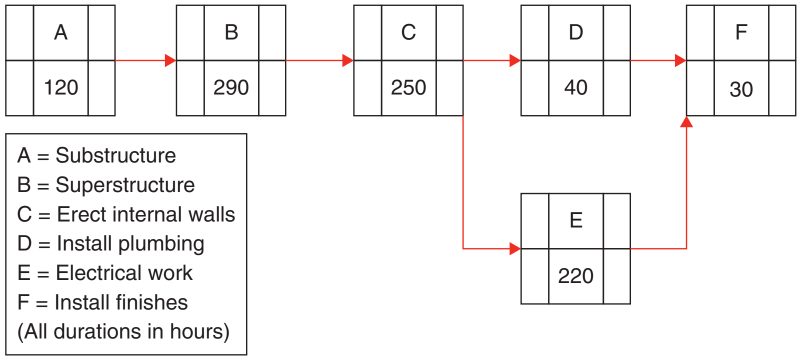

Figure 1 The construction plan for each house.

The activities within the plan are as follows:

Activity A – Construction of the sub-structure
Activity B – Construction of the super-structure
Activity C – Internal partitions and walling
Activity D – Plumbing
Activity E – Electrical work
Activity F – Finishes

It is assumed that there is a minimum buffer time of 5 days between each operation.

Calculations

The calculations required to draw the Line-of-Balance schedule for the construction of the houses are shown in Table 1.

Each of the activities involved in the construction of a single house is listed. For each activity, it is necessary to determine the time taken in days to complete this activity for one house, (T). It is also required to calculate the time between the start of the first house and the finish of the last house, (S). (This represents the gradient of the line-of-balance for the activity and is useful in drawing the schedule.) With this information and details of the required rate of completion, it is then possible to draft the diagram.

The Table shows seven calculations for each activity. Work from left to right across the table completing the calculations for each activity in turn. (No attempt should be made at this stage to balance the output of the different trades. This is made when the complete diagram has been drawn.)

The calculations for the first activity, the Substructure, are as follows. The estimated time in man-hours per house (M) is 120 h. (This initial data comes from the planner's estimate of the time required after considerations of the drawings and specifications for the construction work.)

The theoretical gang size (G) required to complete the target rate of build (R), 4 houses per week equals (R x M)/H where H is the hours worked per week. (In this contract, H equals 8 x 5 = 40 h per week. This may be different on other contracts.)

Table 1 Calculation of gang sizes and rates of build for Line of Balance Schedule.

Activities	Man-hours per house (M)	Theoretical Gang Size (G)	Men Per House (Q)	Actual Gang size (multiples of Q) (g)	Actual rate per week (U)	Time in days for one house (T)	Time between start of first house and the last house (S)
Substructure	120	12	3	12	4.0	5.00 = 5 R	36.25 = 37 R
Superstructure	290	29	6	30	4.14	6.04 = 6 R	35.02 = 35 R
Erect internal walls	250	25	4	24	3.84	7.81 = 8 R	37.76 = 38 R
Install Plumbing	40	4	3	3	3.0	1.67 = 2 R	48.33 = 49 R
Electrical Work	30	3	2	2	2.67	1.87 = 2 R	54.31 = 55 R
Install Finishes	220	22	5	20	3.64	5.50 = 6 R	39.84 = 40 R

Additional Data

d = the number of working days per week = 5

B = the buffer time between activities = 5

n = the number of units to be constructed = 104

R = the Target Rate of Build = 4 houses per week

H = the hours worked per week = 8 × 5 = 40

h = the hours worked per day

Notes:

1. R means rounded number. (Because the data will be used to plot the lines on the schedule, it is necessary to work with integers.)
2. The Man hours per House (M) is the required number of hours work required in the Activity in each house.
3. The Theoretical Gang Size (G) is the theoretical gang size required to produce the required output $G = (R \times M)/H$.
4. The Men per House (Q) is the total number of men to work on each Activity in each house.
5. g = The Actual Gang size selected (Q) must be a multiple of G selected as close as possible to the theoretical gang size.
6. The Actual rate per week $(U) = (g/G) \times R$.
7. The Time in Days for one house = $T = (M/h) \times (1/Q)$ is the time to complete the activity in one house based on the Actual Gang Size.
8. The Time between the start of first house and the finish of the last house = $S = ((n-1) \times d)/U$.

The Men per house (Q) is the usual gang size for the type of construction work. The planner compares this figure with the theoretical gang size to meet production requirements on this house and decides on the actual gang size (g) to be used on this contract. (g must be a multiple of Q) In this calculation, the actual gang size is determined as 12, that is four gangs of 3 will be used. This gives the actual rate of production per week as 4.0 the output required.

(Compare this calculation with the calculation for the Superstructure. For the Superstructure, the theoretical gang size (G) is 29. The planner decides to use five gangs of six workers per house. The actual rate of production is therefore 4.14, greater than that required.)

Given this actual rate of production per week, the time in days for one house (T) can be calculated. (For practical purposes, when drawing the schedule, this figure needs to be rounded to a whole number.) The time between the start of the first house and the finish of the last house (S) needs to be calculated. To do this, multiply the number of houses to be constructed minus 1, by the number of working days (d) and divide the total by the actual rate per week (U). Again for practical purposes, this figure needs to be rounded up or down into an integer.

When the calculations for each activity have been completed the schedule may be drawn.

Drawing the schedule

Figure 2 is the completed schedule for the project.

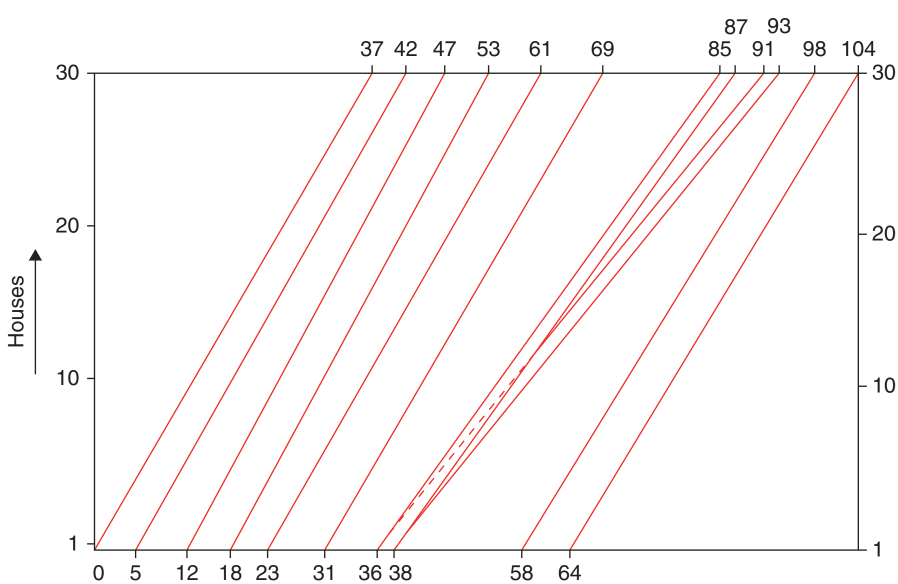

Figure 2 The Line-of-Balance Schedule for the construction of the houses.

The vertical axis shows the number of units to be constructed, in this example the house numbers from 1 to 30. The horizontal axis shows the number of working days. The schedule is drawn from left to right considering each activity in turn.

The first activity, A, the Substructure commences on house 1 at time zero, that is the start of the first working day. Construction work on the last of the houses, house 30, commences on day 37. (This is the calculated figure S taken from the table.) Work on the Substructure of the first house is completed at the end of day 5. Work on the Substructure of the last house commences on day 37 and is completed on day 42. Drawing the two lines, 0–37 and 5–42 presents an 'envelope' of time representing the construction of the Substructure for all the houses. By reading horizontally across the schedule, it is possible to forecast when substructure work is scheduled to commence on each of the houses.

Having drawn the schedule for the Substructure the schedule for the Superstructure can be drawn. It is known that there is to be a scheduled buffer time of 5 days between the two activities. (This was decided as part of the basic data for preparing the schedule.) Having completed the Substructure at the end of day 5, it is therefore possible to start the Superstructure after the buffer ends. If we assume this then the Superstructure on house 1 commences on day 11. Work on the Superstructure of the last house is then scheduled to start on day 11 + 35 equals day 46. This will not provide sufficient buffer time for the last house. It is therefore decided to delay the start of the Superstructure on House 1 until day 12. This then gives the working day number for the start of the superstructure on the last house to be day 47. The time taken for the Superstructure on each house is 6 days and therefore the work is completed on house 1 on day 18. It is completed on house 30 on day 53.

In this way, the schedule of activities for all the construction work can be completed. As shown care must be taken when drawing the schedule to ensure that sufficient buffer time is allowed between the activities. This may require the commencement of work on the first house to be delayed form its earliest possible start date to avoid a possible clash with work on the preceding activity (or insufficient buffer time) as construction proceeds. When two or more activities take place in parallel, these are shown commencing on the same day. If the production rate for these activities varies, the 'envelopes' of work in the schedule will be different. The day number for completion of the last activity is the completion date for construction. In this example, this is working day 104.

Summary

The production of a Line-of-Balance Schedule is always an iterative process. Having produced a schedule there will, inevitably, be the need to revisit the assumptions and the production decisions to improve productivity and reduce construction time.

The aim with producing a Line-of-Balance schedule is to find a balanced schedule where all the activities are in parallel and the construction time is the minimum practical time.

To achieve this, it is necessary to adjust gang sizes, (where possible), carry out activities in parallel (where possible) and reduce buffer times to the minimum. The level of buffer size (5 days) used in the example calculation is purely for demonstration purposes in this example. In practice, buffer sizes are much reduced, and apart from those determined by the specification (e.g. concrete curing times), the time taken between activities only becomes significant where there are complex temporary works to dismantle. Buffer sizes may even be eliminated completely.

The schedule as drawn assumes that the gang sizes at the start of the construction work will remain constant throughout the contract. In practice there will be opportunities to increase (or decrease) gang sizes as the work progresses. The calculations make no allowance for the learning curve in repetitive construction; this will influence actual production as the gangs move from one unit to the next. Despite the limitations of producing a schedule to reflect the influences of practical construction, there are considerable benefits in preparing a line-of-balance schedule for repetitive construction activities. The discipline of calculating and drawing out the schedule brings benefits in understanding both the basics of the construction and the alternatives as the work proceeds.