

A REPETITIVE PROJECT SCHEDULING BY INTEGRATING CRITICAL PATH METHOD AND LINE OF BALANCE METHOD

MOHAMMED ZEESHAN 1* , SUEBHA KHATOON 2*

1. M.Tech Student, Dept of Civil engineering, LORDS INSTITUTE OF ENGG &
TECHNOLOGY

2. Asst. Prof, Dept of Civil engineering, LORDS INSTITUTE OF ENGG &
TECHNOLOGY

ABSTRACT

construction projects often involve projects that consists of repetitive activities like multiple houses, typical floors in a high rise building(repetitive projects) or highways and pipelines(linear projects) are some typical examples. these projects have activities which are repetitive from one unit to other, but there is a lot of problem practically. the scheduling problem posed by multi unit projects with repeating activities in akin to the minimization of the project duration subject to resource continuity constraints as well as technical precedence constraints. the uninterrupted movement of resources is not a problem addressed by the critical path method (CPM), and also there is a method used in construction of repetitive projects that focuses strongly on the time and location aspects of the project its known to be as line-of-balance method, it's a graphical method, showing the developments in activities from one unit to other.

CPM nor the graphical scheduling methods have proven to be adequate on their own, in addressing the scheduling needs of repetitive projects. in scheduling repetitive projects, it is necessary to pay attention to the repetitive nature of tasks and the need for an uninterrupted movement of crew from one unit to the next. so repetitive project scheduling integrating critical path method and line-of-balance method is developed to combine project repetitive scheduling method that takes the view that a repetitive construction project consists of repetitive activities. Instead of repetitive production units. The benefits of both CPM and LOB methods adds more flexibility to the planning and scheduling of repetitive construction projects and enhances the effectiveness of repetitive scheduling. through this study we can develop a integrated LOB and CPM model for planning and scheduling repetitive project, it helps to optimize the resources for work continuity and availability constraints and most importantly to calculate the mathematical execution of crews without the need of graphical aids. and a working procedure is adopted as shown in methodology and it does gives best results

INTRODUCTION

1.1 General

Construction projects that involve repetitive activities are usually designated as repetitive or linear projects. Multiple houses and typical floors in a high-rise building (repetitive projects) or highways and pipelines (linear projects) are typical examples. Both repetitive and linear projects will be designated in this paper as repetitive projects. Repetitive projects represent a large portion of the construction industry and, consequently, efficient planning and scheduling of this type of project is crucial.

Construction contractors are often faced with projects containing multiple units wherein activities that repeat from unit to unit create a very important need for a construction schedule that facilitates the uninterrupted flow of resources (i.e., work crews) from one unit to the next, since it is often this requirement that establishes activity starting times and determines the overall project duration. Hence, uninterrupted resource utilization becomes an extremely important issue. The scheduling problem posed by multiunit projects with repeating activities is akin to the minimization of the project duration subject to resource continuity constraints as well as technical precedence constraints. The uninterrupted deployment of resources is not a problem addressed by the critical path method (CPM), nor by its resource-oriented extensions, such as time-cost trade-off, limited resource allocation, and resource leveling.

1.2 Repetitive Scheduling

The idea of repetitive scheduling originated in the manufacturing industry, in connection with the use of mass production line units. These production line units are identical. Many of the constructions repetitive

scheduling methods formulated so far also maintain the premise that a repetitive project consists of number of identical production units. A unit network is employed to represent production activities and is repeated for production units. generally a crew(group of workers) is assigned to each of the repetitive activities in the unit network. The crew performs the same production unit activity consecutively and continuously. Each repeated activity is performed with the same sequential order of production units.

In practice, however, the production units in many repetitive construction projects may not be identical. For instance, the depth and the soil conditions encountered when placing each pile will not be exactly the same in a piling project; the number of manholes and the number of pipe sections will not normally be the same in a pipeline-laying project, so they cannot be classified as traditionally defined repetitive production units; the interior design of each house may differ in a multi-housing project, and therefore the required workload, as well as the time duration and cost, will differ. Furthermore, even a typical repetitive construction project with many identical production units is very likely to contain portions of work of a non-repetitive nature

1.3 Line of Balance

Line-of-Balance (LOB) method is a project planning and control method which in projects with repetitive nature has proved to be more efficient than the network techniques like CPM. Much of the reason for superiority of LOB to other planning methods is because it considers an additional dimension (unit of production) in the representation of the activities. Planning and scheduling techniques applicable to construction management can be classified into two basic categories: duration driven methods, such as the critical path method (CPM), and resource-driven techniques, such as line of balance (LOB). In CPM, activity durations are assumed functions of the resources required (rather than available) to complete each activity. Despite the wide application of CPM in construction management, it fails on a practical basis to schedule repetitive projects. CPM-based techniques have been criticized widely in the literature for their inability to model repetitive projects. CPM formulation accounts for neither resource availability nor work continuity.

Using CPM, the same activities are repeated and hence the resultant CPM schedule is cluttered with the repetition of information. The inability of CPM are (1) model work continuity constraints, (2) handle the large number of activities needed to represent repetitive projects, and (3) accurately reflect actual conditions. In contrast, resource-driven techniques have been used to schedule repetitive activities such that a project deadline is met.

Being a resource-driven technique, the primary objective of LOB is to determine a balanced mix of resources and synchronize their work such that they are fully employed. The major benefit of LOB methodology is that it presents production rate and duration information in an easily interpreted graphical format. The LOB plot can present at a glance the progress rate of activities and allows the possibility to adjust the rates to meet project deadlines, while maintaining work continuity of resources. Because LOB assumes essentially sequential activities, work has been done to link the benefits of CPM and LOB techniques. Microsoft Project Professional (MSP) is used in this study to schedule the project.

1.4 Objectives of the Study

The objectives of the study are as follows:

- To develop a integrated LOB and CPM model for planning and scheduling repetitive project.
- To determine a balanced mix of resources and synchronize their work such that they are fully employed.
- To optimize the resource for work continuity and availability constraints.
- To calculate the mathematical execution of crews without the need of graphical aids.

1.5 Organization of the Report

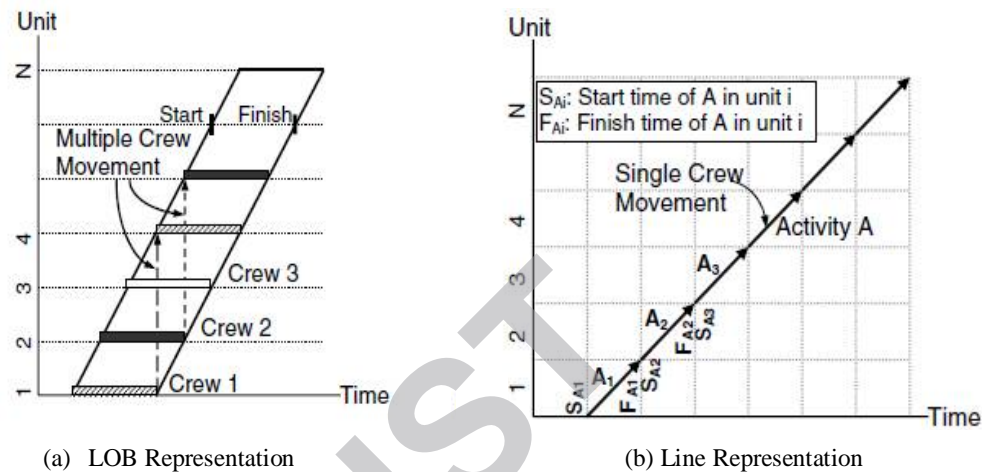
After a brief introduction, pertinent literature has been reviewed and presented in the second chapter. Methodology of LOB and CPM integrated method of repetitive project scheduling is elaborated and discussed in the third chapter. A case study and result discussions is presented in the fourth chapter the summary and conclusions are given in the fifth chapter

2.METHODOLOGY

2.1 Basic Line of Balance Representations

The most common representation format of LOB is shown in Fig.3.1(a), in which each bar represents one activity and each repetitive unit is represented by a horizontal line. The width of the bar is the activity duration of one unit, which is assumed uniform along all units. This representation allows for multiple crew usage in the same activity, as shown in the figure. Maintaining work continuity has been recommended to minimize disruption and maximize the beneficial effect of the learning curve (Fan and Tserng 2006). Variable duration at different units of an activity can be assumed, but is too difficult to be modeled using this visualization.

Harris and Ioannou (1998) introduced another representation, in which a repetitive activity is represented by a single line instead of a bar. Two points represent each unit: the point denotes the unit start time, whereas the second denotes its finish time, as shown in Fig. 3.1(b). The horizontal difference between the two points is the activity duration for that unit. The slope of a repetitive activity line represents the activity production rate. This visualization can easily handle variable activity durations (i.e., variable work quantities) along different units. However, multiple crew usage cannot be modeled using line representation. The first representation will be adopted in this paper.



2.2 Integrated CPM-LOB Model

In developing the proposed model, shortcomings of both CPM and LOB in planning and scheduling of repetitive projects are avoided. The method integrates capabilities of CPM, as an analytical method, with those of LOB technique (use of multiple crews and maintaining work continuity). Harris and Ioannou (1998) first suggested the possibility of using overlapping precedence activities to model repetitive activities. Ammar and Elbeltagi (2001) used overlapping activities to model repetitive projects, and presented an analytical procedure for scheduling repetitive projects and to determine the controlling path. However, the previous two methods consider only one crew per activity. In real cases, most repetitive activities use multiple crews. In the proposed model, overlapping precedence activities are used to model repetitive activities with multiple crews. Two assumptions are used in developing the proposed model. First, quantity of work in each repetitive activity is assumed identical in all units. This implies that activity duration is constant along all repetitive units. This assumption is not true but is realistic, especially for projects containing large number of repetitive units. Second, the crew movement configuration shown in Fig.3.1(a) will be used. Although other configurations can be assumed, this is the most frequently used configuration in the literature. Steps of model development are described next in detail.

Step.1. LOB Calculations

The objective of LOB formulation is to achieve a resource-balanced schedule by determining the number of crews to be employed in each repetitive activity. This is conducted such that the units are delivered with a rate that meets a prespecified project deadline and crew's work continuity is maintained. Only one crew is assumed to work in a single unit and the crew spends 'd' time on the unit before moving to the next similar unit. It is possible to formulate a strategy for meeting a prespecified project deadline. A desired rate of delivery (R_d) can be calculated, with reference to Fig.3.2, by Eq. (1), in which N = number of repetitive units. Desired rate of delivery is the theoretical rate of output, which is usually expressed in terms of number of units per unit time (e.g., section/week). The total float of noncritical activities can be utilized to

reduce the number of crews employed. Eq. (1), therefore, can be generalized for all activities (critical and noncritical) to account for activity total float (Suhail and Neale 1994) using Eq. (2), in which R_{di} = desired (theoretical) rate of delivery of activity 'i' and TF_i is its total float calculated from the network of the first unit.

$$R_d = \frac{N-1}{T_p - T_1} \quad (1)$$

$$R_{di} = \frac{N-1}{T_p - T_1 + TF_i} \quad (2)$$

The duration of an activity 'i' (d_i) taken by a single crew in one unit can be calculated based on the work quantity and output rate of the crew employed, using any formula similar to that of Eq. (3). The number of crews (C_{di}) required to maintain the desired rate of delivery of activity 'i' can be calculated, with reference to Fig.3.3, by Eq. (4). In general, the number of crews calculated by Eq.(4) is not an integer value and fractional crews are not possible. Therefore the number of crews must be rounded up to determine the actual number of crews (C_{ai}), as given by Eq. (5a). Consequently, the actual progress rates (R_{ai}) for different activities must be recalculated using Eq. (6). Eq. (5b) ensures that the actual number of crews allocated to an activity does not exceed crew availability for that activity.

$$d_i(\text{days}) = \frac{\text{Work hours of activity i in one unit}}{\text{work hours/days}} \quad (3)$$

$$C_{di} = d_i \cdot R_{di} \quad (4)$$

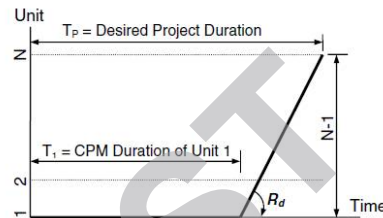


Fig.3.2. Desired Project Rate of Delivery

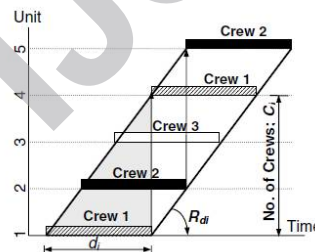


Fig.3.3.Synchronization and Work Continuity of Crews

$$C_{ai} = \text{rounded up } (C_{di}) \quad (5a)$$

$$C_{ai} \leq C_{mi} (\text{maximum available crews}) \quad (5b)$$

$$R_{ai} = C_{ai} / d_i \quad (6)$$

Step 2: Calculating Activity Duration

In this paper, overlapping activities are generalized to represent repetitive activities. For this generalized to be possible, the duration is assumed constant in all units of a repetitive activity. Having the basic LOB calculations performed, the duration of an activity 'i' over all units (D_i) can be calculated, with reference to Fig.3. 4, as the following:

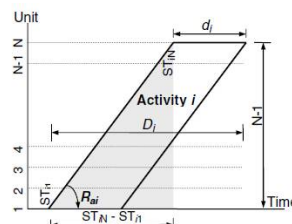


Fig.3.4. Duration of Repetitive Activity Along All Units

$$D_i = d_i + ST_{iN} - ST_{i1} = d_i + (N - 1)/R_{ai} \quad (7)$$

ST_{iN} = start time of last unit; ST_{i1} = start time of first unit; and D_i = duration along all units of activity 'i'.

Step 3: Specifying Logical Relationships using Overlapping Activities

For the specifying the relationships, the actual progress rate of each activity is compared with that of its successors. If R_{ai} and R_{as} denote actual progress rates of an activity 'i' and its succeeding activity 's', respectively, three scenarios can be encountered.

Scenario 1:

$R_{ai} > R_{as}$, this shows the case of two diverging activities, as depicted in Fig.3.5(a), In which activity 'i' is faster than its succeeding activity 's' (leading to divergence). In this scenario, the finish of the first unit of activity 'i' controls the start of the first unit of activity 's'. Therefore, a start-to-start (SS) relationship can be specified. The lag associated with the SS relationship (Lag_{SS}) can be calculated by Eq. (8). In which B_{is} = minimum buffer time between activities 'i' and 's'. Buffer time is usually used in LOB scheduling to absorb the effect of any unforeseen effects that may delay project completion. Fig.3.5(b) depicts a symbolic representation of the SS relationship with the associated lag.

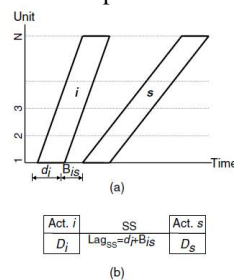


Fig.3.5. Overlapping Repetitive Activities with SS Relationship:
 (a) SS Relationship; (b) Modeling of SS Relationship

$$Lag_{SS} = d_i + B_{is} \quad (8)$$

Scenario 2:

$R_{ai} < R_{as}$, this represents the scenario of two converging activities, as shown in Fig.3.6(a). Because the 's' activity is faster than the 'i' th activity (leading to convergence), the finish of the last unit of the 'i' th activity controls the start of the last unit of the 's' activity. Therefore, a finish-to-finish (FF) relationship exists. The associated lag with FF relationship (Lag_{FF}) can be calculated by Eq.(9), in which d_s = unit duration of the succeeding activity 's'. Fig.3.6(b) depicts a symbolic representation of the FF relationship with the associated lag.

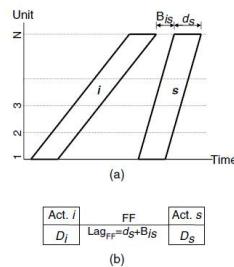


Fig.3.6. Overlapping Repetitive Activities with FF Relationship:
 (a) FF Relationship; (b) Modeling of FF Relationship

$$Lag_{FF} = d_s + B_{is} \quad (9)$$

Scenario 3:

$R_{ai} = R_{as}$, in this scenario, either an SS or FF relationship can be specified, with corresponding lag values as in scenarios 1 and 2.

Step 4: Time Scheduling

Forward pass calculations are conducted to determine early timings of activities, whereas late timings of activities are determined in the backward pass calculations.

Forward Pass :

In forward pass calculations, early timings (belong to the first and last units only) are determined for each activity 'i'. Early timings calculations can be conducted as follows:

SS relationship

$$ES_{i1} = \text{Max}(ES_{p1} + \text{Lag}_{SS(ip)}), p = 1, 2, \dots, NP_i \quad (10)$$

$$EF_{iN} = ES_{i1} + D_i \quad (11)$$

Where ES_{i1} = early start time of the first unit of activity 'i'; ES_{p1} = early start time of the first unit of its predecessor p; NP_i = number of its predecessors; and EF_{iN} = early finish time of the last unit of activity 'i'.

FF relationship

$$ES_{iN} = \text{Max}(EF_{pN} + \text{Lag}_{FF(ip)}), p = 1, 2, \dots, NP_i \quad (12)$$

$$EF_{i1} = ES_{iN} - D_i \quad (13)$$

Having the early start and finish times of the first and last units of an activity determined, the early start and finish times for all units of that activity can be easily determined using Eqs. (14) and (15).

$$ES_{in} = ES_{i1} + (n - 1)/R_{ai} \quad (14)$$

$$EF_{in} = ES_{in} + d_i \quad (15)$$

Where ES_{in} and EF_{in} denote early start and early finish times of any unit 'n' in activity 'i', respectively ($n = 1, 2, \dots, N$).

Backward Pass :

In backward pass calculations, the late timings (belong to the first and last units only) are determined for each activity 'i'. Late timings calculations can be conducted as follows:

SS relationship

$$LS_{i1} = \text{Min}(LS_{s1} - \text{Lag}_{SS(is)}), s=1, 2, \dots, NS_i \quad (16)$$

$$LF_{iN} = LS_{i1} + D_i \quad (17)$$

Where LS_{i1} = late start time of the first unit of activity 'i'; LS_{s1} = late start time of the first unit of its successor 's'; NS_i = number of its successors; and LF_{iN} = late finish time of the last unit of activity 'i'.

FF relationship

$$LS_{iN} = \text{Min}(LS_{sN} - \text{Lag}_{FF(is)}), s=1, 2, \dots, NS_i \quad (18)$$

$$LS_{i1} = LF_{iN} - D_i \quad (19)$$

Having the late start and finish times of the first and last units of an activity determined, the late start and finish times for other units can be calculated, using Eqs. (20) and (21).

$$LF_{in} = LF_{i1} + (n - 1)/R_{ai} \quad (20)$$

$$LS_{in} = LF_{in} - d_i \quad (21)$$

Where LS_{in} and LF_{in} = late start and late finish times of unit 'n' in activity 'i', respectively.

2.3 Closure

The CPM and LOB in planning and scheduling of repetitive project are avoided. CPM analysis does not suit characteristics of repetitive project, whereas LOB lacks the analytical qualities of CPM scheduling. The development of integrated CPM and LOB repetitive scheduling combines the benefits of both CPM and LOB. In the next chapter the Green valley villas case study shows how the above mentioned integrated CPM and LOB is used practically.

3. Case Study and Result Discussion

3.1 General

The idea of repetitive scheduling originated in the manufacturing industry, in connection with the use of mass production line units. Most of the construction repetitive scheduling methods developed so far also maintain the premise that a repetitive project consists of many identical production units. A unit network is employed to represent production activities and is repeated for production units. In practice, however, the production units in many repetitive construction projects may not be identical.

Repetitive projects represent a large portion of the construction industry and, consequently, efficient planning and scheduling of this type of project is crucial. Planning and scheduling techniques applicable to construction management can be classified into two basic categories that is duration-driven methods, such as the critical path method (CPM), and other is resource-driven techniques, such as line of balance (LOB). In CPM, activity durations are assumed functions of the resources required to complete each activity. CPM formulation accounts for neither resource availability nor work continuity. Using CPM, the same activities are repeated and hence the resultant CPM schedule is cluttered with the repetition of information. Green valley villa is scheduled with the help of Microsoft Project Professional software which is basically an CPM based software.

3.2 Case Study Description

The Green valley is an Exclusive Gated Community, Located in Nizampet, Hyderabad adjacent to the eco-friendly neighborhood. It comprises of Limited Edition 58 Villa's spread across 4 acres in phase-1 and High Quality designed independent villas, Children Play Areas, High Class Amenities (Club House, Gym, Party Hall etc.,) It consists of 3BHK, Plot size 180 Sq.Yds, 24West facing villas and 34East facing villas of which 24West Facing Villas are considered in the case study. It is a Ground, First floor and Second floor open terrace. Each flat is of 2635 Sq. Ft. built up area with R.C.C. framed structure to withstand Seismic Loads and Cement blocks for 9" outer walls & 4 1/2" Internal walls with Double Coat internal cement plastering and single coat cement plastering foe ceilings, Double coat plaster for external walls, RCC and masonry surfaces. Fig. 4.1 shows the top view of the site selected for case study. The Ground floor plan of west face villa is shown in the Fig. 4.2, and First and Second Floor plans of west are showed in Fig. 4.3.



Fig. 4.1 Site Selected for Case Study





Fig.4.3. First and Second Floor Plans of West

3.3 Project Work Breakdown Structure

The case study considered West face villa of 2635 Sq. Ft. It consists of 11 WBS structure, under that 8 Sub-WBS structures and 50 activities are assigned to the project. Durations and relations of all the activities are given and scheduling is done. The Scheduled total project duration, determined by MS Project Professional, is 175 days as shown in Project WBS structure Fig. 4.4.

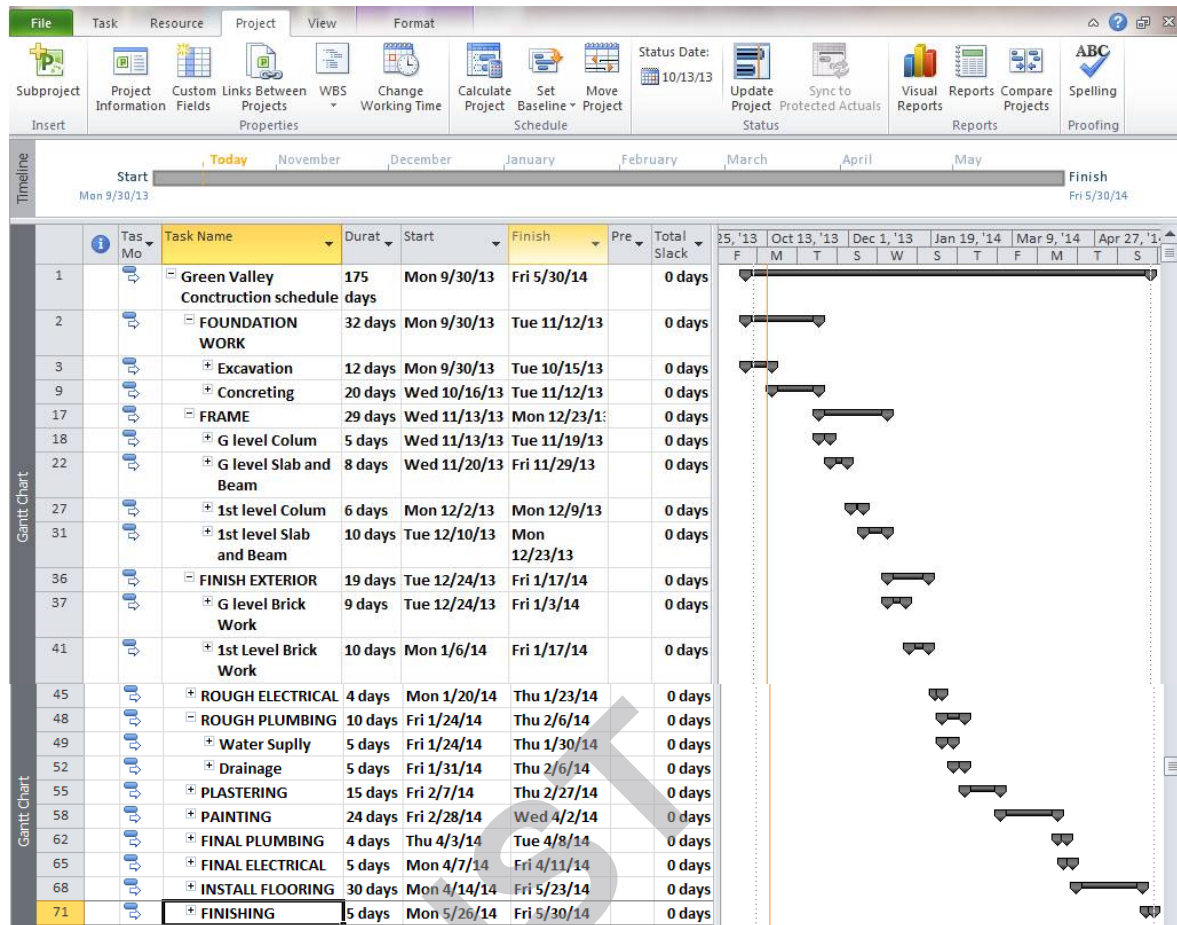
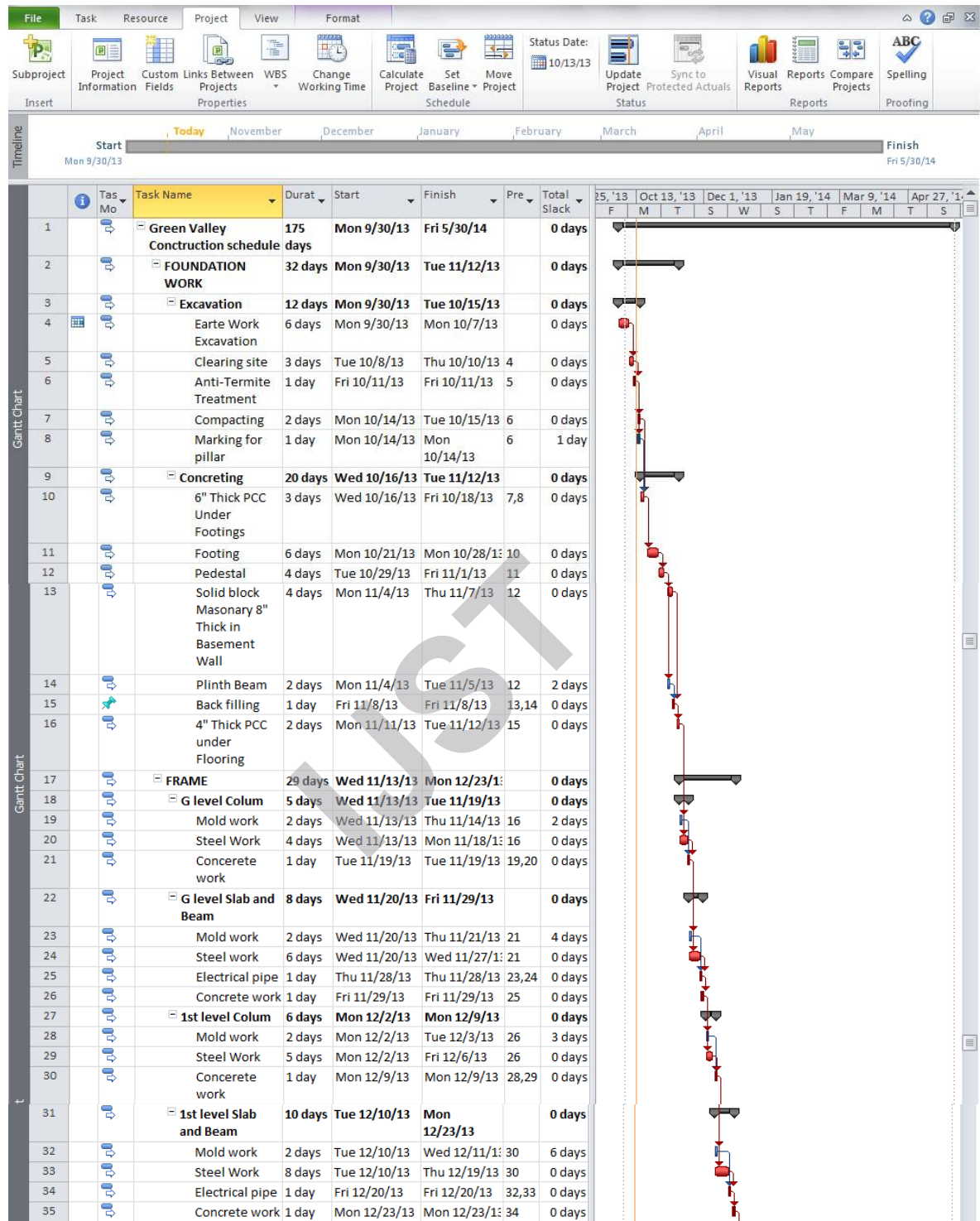


Fig.4.4 Project WBS Structure

Project WBS is made and then the activities are assigned under the WBS, total 50 activities are assigned in this project according to the requirements of the Green valley construction specifications of R.C.C. framed structure to withstand Seismic Loads and Cement blocks for 9" outer walls & 4 1/2", 12mm Thick single coat internal cement plaster for walls and 20 mm Thick two coats plaster for external walls, RCC and masonry surfaces and Acrylic Oil Bound Distemper (OBD) over one coat of primer, emulsion paint over smooth putty finish and veneered door frame and shutter with reputed hardware fittings finished with melamine finish. Total scheduled project activities are shown in Fig.4.5.



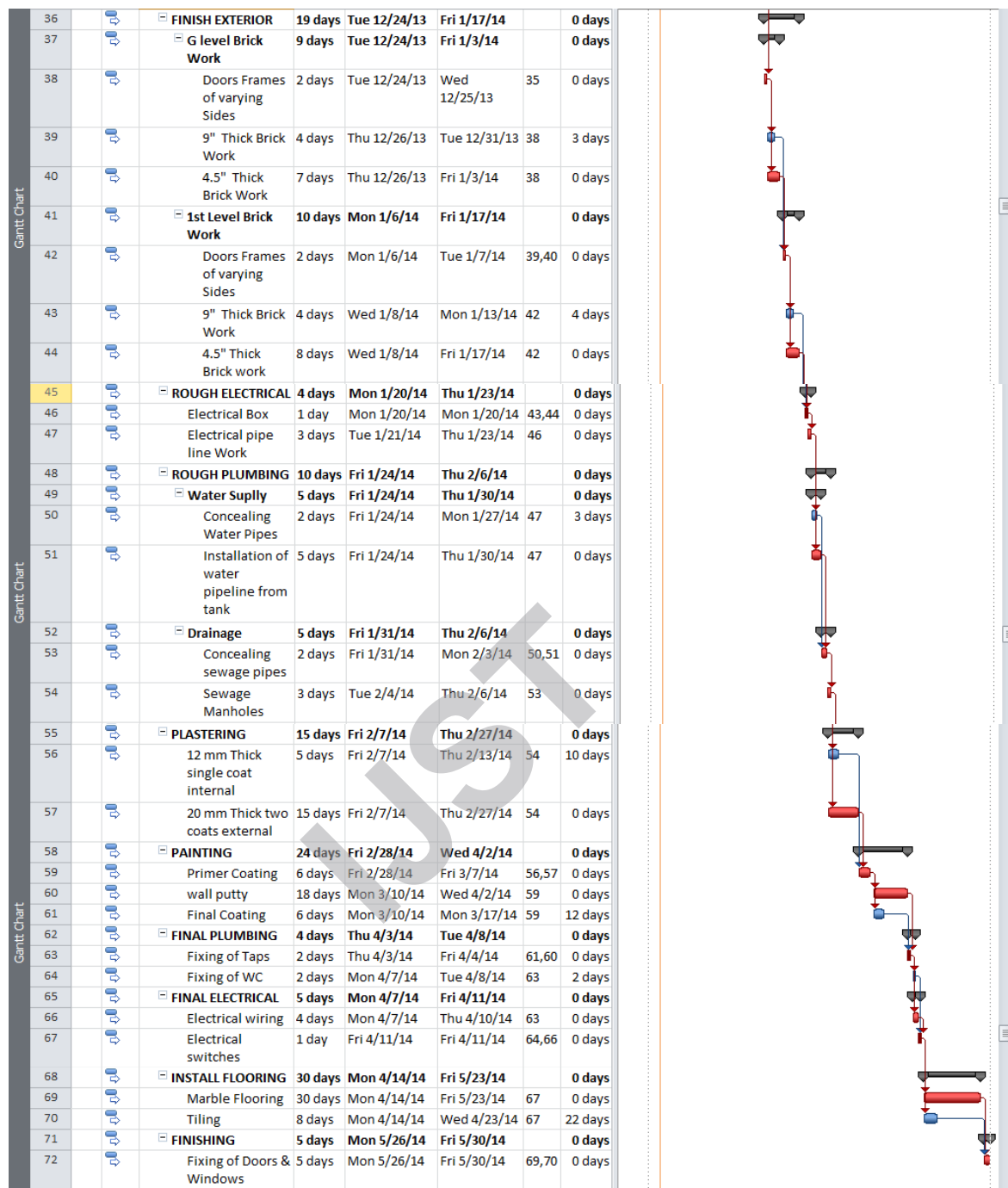


Fig.4.5 Total Project Scheduled Showing the Activities.

Steps and the developed model is applied on the Green valley villas west face application with 24 identical units. The desired total project duration (T_d) is 217days and a minimum buffer time of one day is to be maintained between consecutive activities. Activities from Work Breakdown for a single unit and estimated unit duration of activity are given in Table 4.1

Table 4.1 Planning Data of Activities of a Typical Unit

Activity	Description	Predecessors	Unit duration(Days)
A	Earth Work Excavation	-	6

B	Clearing site	A	3
C	Anti-Termite Treatment	B	1
D	Compacting	C	2
E	Marking for pillar	C	1
F	6" Thick PCC Under Footings	D,E	3
G	Footing	F	6
H	Pedestal	G	4
I	Solid block Masonry 8" Thick in Basement Wall	H	4
J	Plinth Beam	H	2
K	Back filling	I,J	1
L	4" Thick PCC under Flooring	K	2
M	Mold work(G Level Colum)	L	2
N	Steel work(G Level Colum)	L	4
O	Concrete work(G Level Colum)	M,N	1
P	Mold work(G Level Slab)	O	2
Q	Steel work(G Level Slab)	O	6
R	Electrical pipe(G Level slab)	P,Q	1
S	Concrete work(G Level Slab)	R	1
T	Mold work(1st Level Colum)	S	2
U	Steel Work(1st Level Colum)	S	5
V	Concrete work(1st Level Colum)	T,U	1
W	Mold work (1st Level Slab)	V	2
X	Steel Work(1st Level Slab)	V	8
Y	Electrical pipe(1st Level Slab)	W,X	1
Z	Concrete Work(1st Level Slab)	Y	1
AA	Doors Frames of varying Sides(G Level)	Z	2
BB	9" Thick Brick Work(G level)	AA	4
CC	4.5" Thick Brick Work(G Level)	AA	7
DD	Doors Frames of varying Sides(1st Level)	BB,CC	2
EE	9" Thick Brick Work(1st level)	DD	4
FF	4.5" Thick Brick Work(1st Level)	DD	8
GG	Electrical Box(Rough Electrical)	EE,FF	1
HH	Electrical pipe line Work(Rough Electrical)	GG	3
II	Concealing Water Pipes(Water Supply)	HH	2
JJ	Installation of water pipeline from tank(Water Supply)	HH	5
KK	Concealing sewage pipes(Drainage)	II,JJ	2
LL	Sewage Manholes(Drainage)	KK	3
MM	12 mm Thick single coat internal(Plastering)	LL	5
NN	20 mm Thick two coats external(Plastering)	LL	15
OO	Primer Coating(Painting)	MM,NN	6
PP	Wall putty(Painting)	OO	18
QQ	Final Coating (Painting)	OO	6
RR	Fixing of Taps(Final Plumbing)	PP,QQ	2
SS	Fixing of WC(Final Plumbing)	RR	2

TT	Electrical wiring (Final Electrical)	RR	4
UU	Electrical switches(Final Electrical)	SS,TT	1
VV	Marble Flooring (Insert Flooring)	UU	30
WW	Tiling (Insert Flooring)	UU	8
XX	Fixing of Doors & Windows(Finishing)	VV,WW	5

Project is scheduled in Microsoft Project Professional software where the software is CPM based it calculates the total float according to the given relationship of the activities, applying the developed model in the following steps:

- Perform CPM time analysis for the Green valley first unit considering unit duration of each activity and minimum buffer time of one day. Buffer time is considered in this as lag time between consecutive activities. The resulting CPM duration of the first unit (T_1) is 211 days and the critical path is A-B-C-D-F-G-H-I-K-L-N-O-Q-R-S-U-V-X-Y-Z-AA-CC-DD-FF-GG-HH-JJ-KK-LL-NN-OO-PP-RR-TT-UU-VV-XX. Total float (TF) values of noncritical activities are given in Table 4.2.
- Perform LOB calculations. Because the desired total project duration (T_d) is 217days, the desired project rate of delivery (R_d) can be calculated using Eq. (1) as $(24-1)/(217-211)=3.83$. The progress rate of noncritical activities is calculated considering total float using Eq. (2). The theatrical and actual number of crews as well as actual progress rate of each activity are calculated and are also given in Table 4.2.
- Calculate activities durations along all units using Eq. (7). For instance, the duration of activity A (D_A) = $6 + (24-1) / 3.83 = 12$ days. Durations of all activities are also given in Table 4.2.

Table 4.2 LOB Calculation of the Green Valley Construction Activities

Activity	d(days)	Total Float	Rd	Cd=d*Rd	Ca	Ra	STn-ST1	D(days)
A	6	0	3.83	22.98	23	3.8	6	12
B	3	0	3.83	11.49	12	4.0	6	9
C	1	0	3.83	3.83	4	4.0	6	7
D	2	0	3.83	7.66	8	4.0	6	8
E	1	0	3.83	3.83	4	4.0	6	7
F	3	0	3.83	11.49	12	4.0	6	9
G	6	0	3.83	22.98	23	3.8	6	12
H	4	0	3.83	15.32	16	4.0	6	10
I	4	0	3.83	15.32	16	4.0	6	10
J	2	1	3.28	6.56	7	3.5	7	9
K	1	0	3.83	3.83	4	4.0	6	7
L	2	0	3.83	7.66	8	4.0	6	8
M	2	0	3.83	7.66	8	4.0	6	8
N	4	0	3.83	15.32	16	4.0	6	10
O	1	0	3.83	3.83	4	4.0	6	7
P	2	3	2.55	5.1	6	3.0	8	10
Q	6	0	3.83	22.98	23	3.8	6	12
R	1	0	3.83	3.83	4	4.0	6	7
S	1	0	3.83	3.83	4	4.0	6	7
T	2	2	2.87	5.74	6	3.0	8	10
U	5	0	3.83	19.15	20	4.0	6	11
V	1	0	3.83	3.83	4	4.0	6	7
W	2	5	2.09	4.18	5	2.5	10	12
X	8	0	3.83	30.64	31	3.9	6	14

Y	1	0	3.83	3.83	4	4.0	6	7
Z	1	0	3.83	3.83	4	4.0	6	7
AA	2	0	3.83	7.66	8	4.0	6	8
BB	4	2	2.87	11.48	12	3.0	8	12
CC	7	0	3.83	26.81	27	3.9	6	13
DD	2	0	3.83	7.66	8	4.0	6	8
EE	4	3	2.55	10.2	11	2.8	9	13
FF	8	0	3.83	30.64	31	3.9	6	14
GG	1	0	3.83	3.83	4	4.0	6	7
HH	3	0	3.83	11.49	12	4.0	6	9
II	2	2	2.87	5.74	6	3.0	8	10
JJ	5	0	3.83	19.15	20	4.0	6	11
KK	2	0	3.83	7.66	8	4.0	6	8
LL	3	0	3.83	11.49	12	4.0	6	9
MM	5	9	1.5	7.5	8	1.6	15	20
NN	15	0	3.83	57.45	58	3.9	6	21
OO	6	0	3.83	22.98	23	3.8	6	12
PP	18	0	3.83	68.94	69	3.8	6	24
QQ	6	11	1.35	8.1	9	1.5	16	22
RR	2	0	3.83	7.66	8	4.0	6	8
SS	2	1	3.28	6.56	7	3.5	7	9
TT	4	0	3.83	15.32	16	4.0	6	10
UU	1	0	3.83	3.83	4	4.0	6	7
VV	30	0	3.83	114.9	115	3.8	6	36
WW	8	21	0.85	6.8	7	0.9	27	35
XX	5	0	3.83	19.15	20	4.0	6	11

Table 4.3 CPM Time Analysis for LOB calculation

Activity	D(day)	Forward pass		Backward pass	
		ES ₁	EF _N	LS ₁	LF _N
A ^c	12	0	12	0	12
B ^c	9	12	21	12	21
C ^c	7	21	28	21	28
D ^c	8	28	36	28	36
E	7	28	35	29	36
F ^c	9	36	45	36	45
G ^c	12	45	57	45	57
H ^c	10	57	67	57	67
I ^c	10	67	77	67	77
J	9	67	76	68	77
K ^c	7	77	84	77	84
L ^c	8	84	92	84	92
M	8	92	100	94	102
N ^c	10	92	102	92	102
O ^c	7	102	109	102	109
P	10	109	119	111	121
Q ^c	12	109	121	109	121
R ^c	7	121	128	121	128
S ^c	7	128	135	128	135
T	10	135	145	136	146
U ^c	11	135	146	135	146
V ^c	7	146	153	146	153
W	12	153	165	155	167
X ^c	14	153	167	153	167
Y ^c	7	167	174	167	174
Z ^c	7	174	181	174	181
AA ^c	8	181	189	181	189
BB	12	189	201	190	202
CC ^c	13	189	202	189	202
DD ^c	8	202	210	202	210
EE	13	210	223	211	224
FF ^c	14	210	224	210	224
GG ^c	7	224	231	224	231
HH ^c	9	231	240	231	240
II	10	240	250	241	251
JJ ^c	11	240	251	240	251
KK ^c	8	251	259	251	259
LL ^c	9	259	268	259	268
MM	20	268	288	269	289
NN ^c	21	268	289	268	289
OO ^c	12	289	301	289	301
PP ^c	24	301	325	301	325
QQ	22	301	323	303	325
RR ^c	8	325	333	325	333
SS	9	333	342	334	343
TT ^c	10	333	343	333	343
UU ^c	7	343	350	343	350
VV ^c	36	350	386	350	386
WW	35	350	385	351	386
XX ^c	11	386	397	386	397

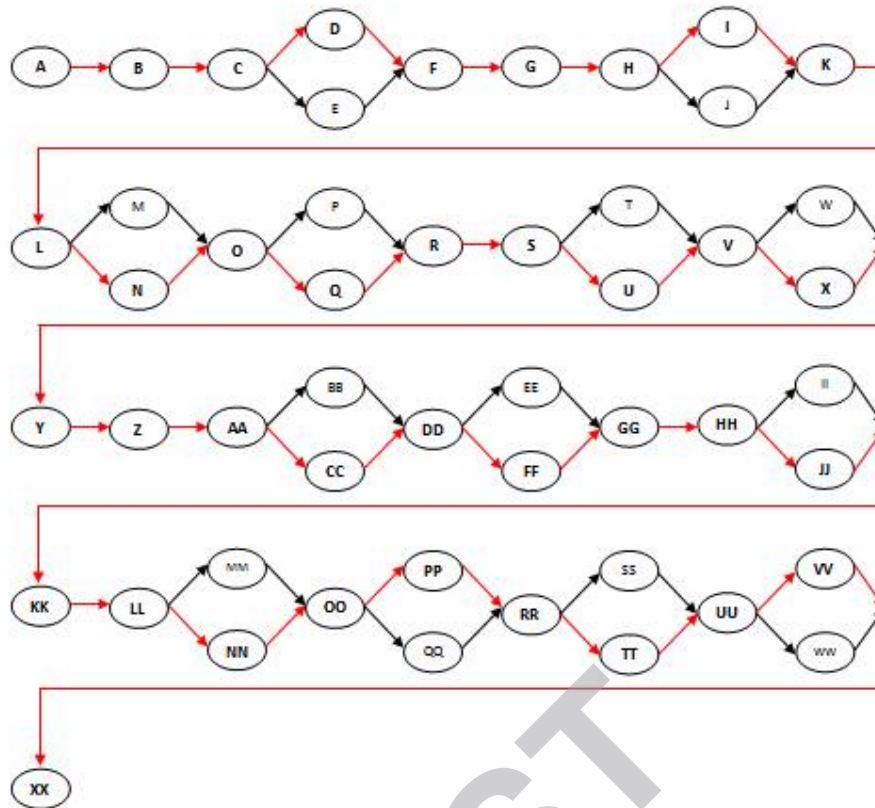


Fig. 4.6 Network Diagram of the Green Valley Villas

- Specific relationship type and associated lag values among the consecutive activities according to their actual progress rate. For example, activity B is a successor to activity A. In this scenario, $R_{aA} = 3.83$ and $R_{aB} = 4$ and therefore an SS relationship exist between activity A and B, and the corresponding $Lag_{ss(AB)} = 6+1=7$ days. Relationship type and the corresponding lag for project activity are given in Table 4.4. This information is also shown in Table 4.5, along with forward pass and backward pass of activities link connecting different activities.

Table 4.4 Relationship Type and Associated Lag

Activity	Ra(Activity)	Successor	Ra(Successor)	Relationship	Lag(days)
A	3.83	B	4	SS	6+1=7
B	4	C	4	SS	3+1=4
C	4	D	4	SS	1+1=2
		E	4	SS	1+1=2
D	4	F	4	SS	2+1=3
E	4	F	4	SS	1+1=2
F	4	G	3.83	SS	3+1=4
G	3.83	H	4	FF	4+1=5
H	4	I	4	SS	4+1=5
		J	3.5	SS	4+1=5
I	4	K	4	SS	4+1=5
J	3.5	K	4	FF	1+1=2
K	4	L	4	SS	1+1=2
L	4	M	4	SS	2+1=3
		N	4	SS	2+1=3
M	4	O	4	SS	2+1=3
N	4	O	4	SS	4+1=5
O	4	P	3	SS	1+1=2
		Q	3.83	SS	1+1=2
P	3	R	4	FF	1+1=2
Q	3.83	R	4	FF	1+1=2
R	4	S	4	SS	1+1=2
S	4	T	3	SS	1+1=2
		U	4	SS	1+1=2
T	3	V	4	FF	1+1=2
U	4	V	4	SS	5+1=6
V	4	W	2.5	SS	1+1=2
		X	3.87	SS	1+1=2
W	2.5	Y	4	FF	1+1=2
X	3.87	Y	4	FF	1+1=2
Y	4	Z	4	SS	1+1=2
Z	4	AA	4	SS	1+1=2
AA	4	BB	3	SS	2+1=3
		CC	3.85	SS	2+1=3
BB	3	DD	4	FF	2+1=3
CC	3.85	DD	4	FF	2+1=3
DD	4	EE	2.75	SS	2+1=3

		FF	3.87	SS	2+1=3
EE	2.75	GG	4	FF	1+1=2
FF	3.87	GG	4	FF	1+1=2
GG	4	HH	4	SS	1+1=2
HH	4	II	3	SS	3+1=4
		JJ	4	SS	3+1=4
II	3	KK	4	FF	2+1=3
JJ	4	KK	4	SS	5+1=6
KK	4	LL	4	SS	2+1=3
LL	4	MM	1.6	SS	3+1=4
		NN	3.86	SS	3+1=4
MM	1.6	OO	3.83	FF	6+1=7
NN	3.86	OO	3.83	SS	15+1=16
OO	3.86	PP	3.83	SS	6+1=7
		QQ	1.5	SS	6+1=7
PP	3.83	RR	4	FF	2+1=3
QQ	1.5	RR	4	FF	2+1=3
RR	4	SS	3.5	SS	2+1=3
		TT	4	SS	2+1=3
SS	3.5	UU	4	FF	1+1=2
TT	4	UU	4	SS	4+1=5
UU	4	VV	3.83	SS	1+1=2
		WW	0.875	SS	1+1=2
VV	3.83	XX	4	FF	5+1=6
WW	0.875	XX	4	FF	5+1=6

Table 4.5 CPM and LOB Integrated Time Analysis with Forward Pass and Backward Pass

Activity	Successor	Relationship	Lag(days)	D(days)	Forward pass		Backward pass	
					ES _i	EF _N	LS _i	LF _N
A ^C	B	SS	7	12	0	12	0	12
B ^C	C	SS	4	9	7	16	7	16
C ^C	D	SS	2	7	11	18	11	18
	E	SS	2					
D ^C	F	SS	3	8	13	21	13	21
E	F	SS	2	7	13	20	14	21
F ^C	G	SS	4	9	16	25	16	25
G ^C	H	FF	5	12	20	32	20	32
H ^C	I	SS	5	10	27	37	27	37
	J	SS	5					
I ^C	K	SS	5	10	32	42	32	42
J	K	FF	2	9	32	41	33	42
K ^C	L	SS	2	7	37	44	37	44
L ^C	M	SS	3	8	39	47	39	47
	N	SS	3					
M	O	SS	3	8	42	50	43	51
N ^C	O	SS	5	10	42	52	42	52
O ^C	P	SS	2	7	47	54	47	54
	Q	SS	2					
P	R	FF	2	10	49	59	51	61
Q ^C	R	FF	2	12	49	61	49	61

R ^C	S	SS	2	7	56	63	56	63
S ^C	T	SS	2	7	58	65	58	65
	U	SS	2					
T	V	FF	2	10	60	70	61	71
U ^C	V	SS	6	11	60	71	60	71
V ^C	W	SS	2	7	66	73	66	73
	X	SS	2					
W	Y	FF	2	12	68	80	70	82
X ^C	Y	FF	2	14	68	82	68	82
Y ^C	Z	SS	2	7	77	84	77	84
Z ^C	AA	SS	2	7	79	86	79	86
AA ^C	BB	SS	3	8	81	89	81	89
	CC	SS	3					
BB	DD	FF	3	12	84	96	85	97
CC ^C	DD	FF	3	13	84	97	84	97
DD ^C	EE	SS	3	8	92	100	92	100
	FF	SS	3					
EE	GG	FF	2	13	95	108	96	109
FF ^C	GG	FF	2	14	95	109	95	109
GG ^C	HH	SS	2	7	104	111	104	111
HH ^C	II	SS	4	9	106	115	106	115
	JJ	SS	4					
II	KK	FF	3	10	110	120	111	121
JJ ^C	KK	SS	6	11	110	121	110	121
KK ^C	LL	SS	3	8	116	124	116	124
LL ^C	MM	SS	4	9	119	128	119	128
	NN	SS	4					
MM	OO	FF	7	20	123	143	124	144
NN ^C	OO	SS	16	21	123	144	123	144
OO ^C	PP	SS	7	12	139	151	139	151
	QQ	SS	7					
PP ^C	RR	FF	3	24	146	170	146	170
QQ	RR	FF	3	22	146	168	148	170
RR ^C	SS	SS	3	8	165	173	165	173
	TT	SS	3					
SS	UU	FF	2	9	168	177	169	178
TT ^C	UU	SS	5	10	168	178	168	178
UU ^C	VV	SS	2	7	173	180	173	180
	WW	SS	2					
VV ^C	XX	FF	6	36	175	211	175	211
WW	XX	FF	6	35	175	210	176	211
XX ^C				11	206	217	206	217

- Perform forward and backward pass calculations, similar to overlapping activities of CPM networks, to determine different activities' timings, as given in Table 4.5. Critical activities (by the CPM definition) are shown bold in Fig. 4.8. The resulting project duration (T_p) is 217 days, which is equal to the desired total project duration (217 days). The complete CPM time analysis of the 24 Green valley villas is given in Fig. 4.8, which shows start timings (early and late) of the first unit and finish timings (early and late) of the last unit.

3.4 Results

- The scheduled project duration for one Green valley villa is 175 days.
- After calculating the total project duration of 24 Green valley villas using LOB is 397 days.
- By integrating both LOB and CPM the total project duration of 24 Green valley villas is reduced from 397 days to 217 days.
- Integrated CPM and LOB repetitive scheduling model has been developed that that combine the benefits of both CPM and LOB in easy analytical non graphical manner, where the actual progress rate(R_a)per/day and the actual number of crews(C_a) per/activity are calculated.

3.5 Comparison of Results

The Comparison of LOB Calculated Project Duration and Integrated (LOB & CPM) Project Duration is shown in Table 4.6. Where the total project duration by LOB calculation is 397 days and after integrating both LOB and CPM the duration is reduced to 217days. Integrated LOB and CPM method reduces the project duration and optimize the resources for the work continuity. RSM schedule is presented graphically as an X-Y plot of unit production lines that continue across designated units of the project. X-axis plot represents time and the Y-axis plot represents units. Comparison between both Graphical and Non-graphical (mathematical calculation) is when there are huge number of activities in the Scheduled project its not possible to represent each and every activity in Graphical manner as shown in Fig 4.9 & Fig 4.10.

Table 4.6 Comparison of LOB Calculated Duration and Integrated (LOB and CPM) Duration

Activity	D(days)	LOB Calculated Duration				LOB and CPM integrated Duration			
		ES ₁	EF _N	LS ₁	LF _N	ES ₁	EF _N	LS ₁	LF _N
A ^C	12	0	12	0	12	0	12	0	12
B ^C	9	12	21	12	21	7	16	7	16
C ^C	7	21	28	21	28	11	18	11	18
D ^C	8	28	36	28	36	13	21	13	21
E	7	28	35	29	36	13	20	14	21
F ^C	9	36	45	36	45	16	25	16	25
G ^C	12	45	57	45	57	20	32	20	32
H ^C	10	57	67	57	67	27	37	27	37
I ^C	10	67	77	67	77	32	42	32	42
J	9	67	76	68	77	32	41	33	42
K ^C	7	77	84	77	84	37	44	37	44
L ^C	8	84	92	84	92	39	47	39	47

M	8	92	100	94	102	42	50	43	51
N ^C	10	92	102	92	102	42	52	42	52
O ^C	7	102	109	102	109	47	54	47	54
P	10	109	119	111	121	49	59	51	61
Q ^C	12	109	121	109	121	49	61	49	61
R ^C	7	121	128	121	128	56	63	56	63
S ^C	7	128	135	128	135	58	65	58	65
T	10	135	145	136	146	60	70	61	71
U ^C	11	135	146	135	146	60	71	60	71
V ^C	7	146	153	146	153	66	73	66	73
W	12	153	165	155	167	68	80	70	82
X ^C	14	153	167	153	167	68	82	68	82
Y ^C	7	167	174	167	174	77	84	77	84
Z ^C	7	174	181	174	181	79	86	79	86
AA ^C	8	181	189	181	189	81	89	81	89
BB	12	189	201	190	202	84	96	85	97
CC ^C	13	189	202	189	202	84	97	84	97
DD ^C	8	202	210	202	210	92	100	92	100
EE	13	210	223	211	224	95	108	96	109
FF ^C	14	210	224	210	224	95	109	95	109
GG ^C	7	224	231	224	231	104	111	104	111
HH ^C	9	231	240	231	240	106	115	106	115
II	10	240	250	241	251	110	120	111	121
JJ ^C	11	240	251	240	251	110	121	110	121
KK ^C	8	251	259	251	259	116	124	116	124
LL ^C	9	259	268	259	268	119	128	119	128
MM	20	268	288	269	289	123	143	124	144
NN ^C	21	268	289	268	289	123	144	123	144
OO ^C	12	289	301	289	301	139	151	139	151

PP ^C	24	301	325	301	325	146	170	146	170
QQ	22	301	323	303	325	146	168	148	170
RR ^C	8	325	333	325	333	165	173	165	173
SS	9	333	342	334	343	168	177	169	178
TT ^C	10	333	343	333	343	168	178	168	178
UU ^C	7	343	350	343	350	173	180	173	180
VV ^C	36	350	386	350	386	175	211	175	211
WW	35	350	385	351	386	175	210	176	211
XX ^C	11	386	397	386	397	206	217	206	217

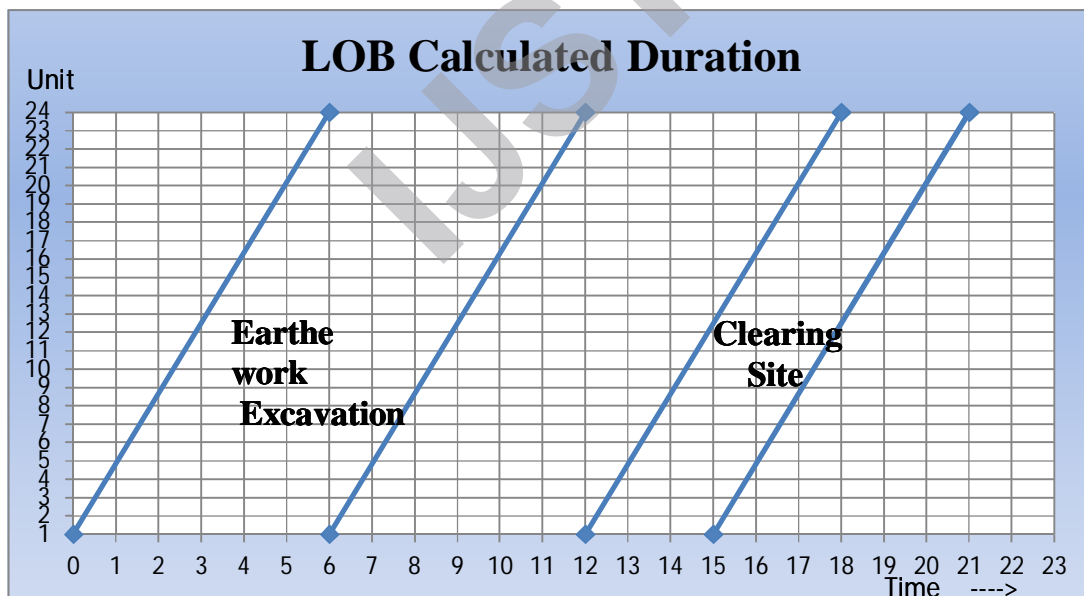


Fig. 4.9 Graphical Representation of LOB Calculated Duration

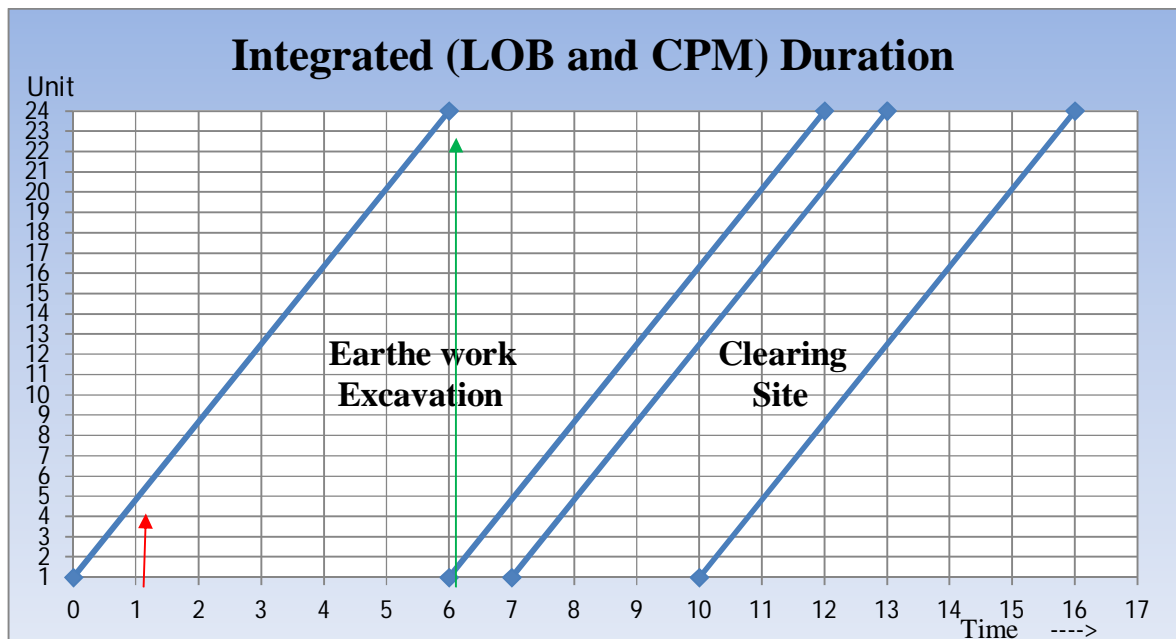


Fig. 4.10 Graphical Representation of Integrated (LOB and CPM) Duration

Line represented in red colour is an actual production rate/day (R_a) and the green colour line represents the actual number of Crews/ activity (C_a). So representing the actual production rate and actual number of crews required is not possible in the Graphical manner for all the activities of project. Integrated CPM and LOB repetitive scheduling model has been developed by combining the benefits of both CPM and LOB in an easy analytic non-graphical manner. In Fig 4.9 second activity is started after the completion of 24 units of first activity whereas in Fig 4.10 second activity starts after the completion of first unit of first activity. Logical relationships using overlapping activities make the work to be done parallelly one after the other for the continuity of work. Calculation of actual production rate and actual number of crews are shown in the above Table 4.2.

4.summary and conclusions

4.1 summary

Scheduling of repetitive projects represents a challenge for construction planner and managers. In repetitive construction projects the resource requirements are not constant throughout the project, they vary day to day. Practically in this integrated CPM and LOB repetitive scheduling method the actual progress rate and number of crew requirement are calculated according to the schedule. According to the desire rate of delivery resources can be hired. Considering the actual progress rate and actual number of crews the project can be completed on time according to the given construction schedule.

The project selected for this study is “Green valley Exclusive Gated Community”, phase-I 24west face villas with ground floor, first floor and Second floor with open terrace has been constructed. Each flat having 2635 Sq. ft. built up area. Complete villas construction schedule is done by the MS Project Professional software. The duration calculated by CPM for one villa is 175 days. However the integrated CPM and LOB repetitive scheduling model has been developed and combines the benefits of both CPM and LOB in an easy analytical non-graphical manner. The results of integrated CPM and LOB repetitive project scheduling method which is non-graphical 24villas are scheduled in 217days by allocating the number of actual progress rate per day and allocating actual number of crews per activity.

4.2 conclusions

Based on the results, the following conclusions have been drawn:

- Integrated CPM and LOB repetitive scheduling model combines the benefits of both CPM and LOB in an easy analytical non-graphical manner.
- Overlapping activities of a typical unit is used to specify activities relationships and Constant activity duration is assumed along all repetitive units.

- Time of the project can be saved and the proper utilization of the resource can be done by using the integrated CPM and LOB method.
- The major benefits from the proposed model are the ability to perform network schedule considering logical dependency constraints while satisfying work continuity and availability constraints.
- The integrated CPM and LOB repetitive project scheduling method reduces the project duration by 45.3% when compared to CPM standard method.
- The main advantage of the integrated CPM and LOB is that it helps the project manager in overall planning and controlling of the project from beginning to completion of project.

4.3 scope of future-study

The proposed model can be further improved by considering more units of repetitive projects. Integrated CPM and LOB repetitive project scheduling can be applied for scheduling precast bridges, repetitive electrical substations projects and painting work in the multi-story buildings. Requirement extended to consider the learning curve effect, variable activity durations, imposed work interruptions and there is a scope for further enhancement of CPM and LOB integrated model for better analysis. The soft computing technique such as Fuzzy, ANN and GA can be used for optimization of project duration as well as project cost.

IJST

References

- Ammar, M. (2003). "Float analysis of non-serial repetitive activities". *J. Constr. Manage. Econ.*, ASCE, 21(5), 535–542.
- Ammar, M. A. and Elbeltagi, E. (2001). "Algorithm for determining controlling path considering resource continuity". *J Comput Civil Eng* ASCE, 15(4), 292-98.
- Ammar, M., and Mohieldin, Y. (2002). "CPM/RSM: CPM-Based repetitive scheduling method". III Middle East Regional Civil Engineering Conf., Egypt Section, ASCE, Reston, VA.
- Arditi, D, and Albulak, M. Z. (1986). "Line-of-balance scheduling in pavement construction". *J.Constr. Eng. Manage.* ASCE, 112(3), 411-24.
- Carr, R. I, and Meyer, W. L. (1974). "Planning construction of repetitive building units". *J. Constr. Div.* ASCE, 100(3), 403-12.
- El-Rayes, K., and Moselhi, O. (1998). "Resource-driven scheduling of repetitive projects". *J. Constr. Manage. Econ.*, ASCE, 16(4), 433–446.
- Fan, S., and Tserng, H. (2006). "Object-oriented scheduling for repetitive projects with soft logics". *J. Constr. Eng. Manage.*, ASCE, 132(1), 35–48.
- Harmelink, D. J., and Rowings, J. E. (1998). "Linear scheduling model: Development of controlling activity path". *J. Constr. Eng. Manage.*, 124(4), 263–268.
- Harris, R. B, and Ioannou, P. G.(1998). "Scheduling projects with repeating activities". *J. Constr. Eng. Manage.* ASCE, 124(4), 269-73.
- Hegazy, T., and Kamarah, E. (2008). "Efficient repetitive scheduling for high-rise construction". *J. Constr. Eng. Manage.*, 134(4), 253–264.
- Hegazy, T., and Wassef, N. (2001). "Cost optimization in projects with repetitive nonserial activities". *J. Constr. Eng. Manage.*, 127(3), 183–191.
- Johnston, D. W. (1981). "Linear scheduling method for highway construction". *J. Constr. Div.*, 107(C02), 247–261.
- Lucko, G. (2008). "Productivity scheduling method compared to linear and repetitive project scheduling methods". *J. Constr. Eng. Manage.*, ASCE, 134(9), 711–720.

Lucko, G., and Orozco, A. (2009). "Float types in linear schedule analysis with singularity functions". *J. Constr. Eng. Manage.*, ASCE, 135(5), 368–377.

Maravas, A., and Pantouvakis, J. (2011). "A fuzzy repetitive scheduling method for projects with repeating activities". *J. Constr. Eng. Manage.*, ASCE, 137(7), 561–564.

Reda, R. M. (1990). "RPM: repetitive project modeling". *J. Constr. Eng. Manage.* ASCE, 116(2), 316-30.

Russell, A. D, and Wong, W. C. M. (1993). "New generation of planning structures". *J. Constr. Eng. Manage.* ASCE, 119(2), 196-214.

Selinger, S. (1980). "Construction planning for linear projects". *J. Constr. Div.* ASCE, 106(CO2), 195-205.

Suhail, S., and Neale, R. (1994). "CPM/LOB: New methodology to integrate CPM and line of balance". *J. Constr. Eng. Manage.*, ASCE, 120(3), 667–684.

IJST