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Modeling LOBusing CPM Software for Scheduling Repetitive Projects

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Abstract:*One drawback of the Line of Balance (LOB) method is the unavailability of commercial software featuring its fundamentals. Studies pointed out this drawback as a factor that prevents a more frequent use. Recognizing the potential of the LOB method for managing construction projects, the objective of this paper is to propose a methodology for modeling Line of Balance schedules using CPM software like MS Project®. Previous researches developed an integrated Critical Path Method (CPM) and LOB model in an analytical nongraphical manner. This paper advances LOB modeling one step further to deal with other possible logical dependencies between activities. The presented framework can be used to develop a scheduling model that can link input and output data to commercial scheduling software; MS project®. The results of model application on a case study show the model ability in dealing with all possible relations with lags between activities and data transfer to MS project®.*

Keywords: *Construction Management, Scheduling, Repetitive Project, Line of Balance, MS project***.**

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I. Introduction

Repetitive construction projects are those include identical units such as highways, tunnels, bridges, railways, pipeline networks, sewer mains, high-rise buildings, and housing development projects. In such projects, crews repeat the same work with the same volume and specification in various locations. Scheduling repetitive projects focus on keeping the crew always busy by enabling each crew to finish work in one location of the project and move promptly to the next location in order to minimize work interruptions.*(El-Rayes 2001, Arditi and Albulak, 1986)*

Resource-based planning techniques, such as Line of Balance (LOB), have been used to schedule repetitive projects to ensure work continuity. LOB is well suited to projects that are composed of activities of a linear and repetitive nature. LOB is oriented toward the required delivery of completed units and is based on knowledge of how many units must be completed on any day so that the programmed delivery of units can be achieved. Once a target rate of delivery has been established for the project, the rate of production of each activity is expected not to be less than this target rate of delivery. *(Lumsden 1968, Arditi et al 2002)*

Zack and Collins (2013) reveal a survey from the UK construction industry that only 1% of the respondent companies use the Line of Balance, while 54% use bar charts. The increasing usage of LOB comes in recent years when increasing demand for cost control and resource optimization has forced schedulers to focus on more than just the critical path. The limited usage of the technique is attributed to the lack of powerful and user-friendly computer applications. The most commonly accepted commercial scheduling software packages are based on the CPM using the precedence diagramming method as the network analysis algorithm. *(Shaikh, 2010)*

CPM and Scheduling Repetitive Project:

The critical path method (CPM) was developed in the late 1950s by researchers at the E. I. Du Pont de Nemours Company with a limitation of activities cannot be overlapped. With the introduction of the Precedence Diagram Method (PDM), schedulers are determining the sequence of the activities in such a way that the execution goes on in the most efficient way possible. This sequencing is modeled using relationships between activities, called dependencies, which may be “finish-to-start” (FS), “start-to-start” (SS), “finish-to-finish” (FF) and “start-to-finish” (SF). This link establishes a relationship between activities, where one of them is the predecessor (the activity that comes before logically), and the other is the successor (the activity that comes after logically). *(Vegas and Moreira, 2015)*

The use of the CPM and its PDM variation in all industries - including construction - in both computer hardware and scheduling software, has dramatically increased in the last three decades (Galloway 2006; Liberatore et al. 2001). Despite the wide application of CPM in construction management *(Jaafari, 1984)*, it fails on a practical basis to schedule repetitive projects *(Fan and Tserng 2006)*. CPM has been criticized for their inability to model repetitive projects *(Selinger 1980; Reda 1990; Russel and Wong 1993)*. CPM formulation accounts for neither resource availability nor works continuity *(Hegazy and Kamarah 2008, Mattila and Abraham 1998)*.

So, this paper objective is to develop a model for scheduling repetitive projects which has the following characteristics: 1) considers activities relations like FS, SS, FF, and SF. 2) Links input and output data with commercial scheduling software such as MS Project®.

Improvements to LOB Techniques:

Many studies attempted to combine benefits of both the Critical Path Method (CPM) and the LOB method. *Suhail and Neal（1994)*, developed a methodology to combine the activity's relationship logic of the CPM method and the scheduling logic of crew work continuity in LOB method. Using this methodology, shortcomings of both CPM and LOB in planning and scheduling repetitive projects are avoided. This methodology was used in developing a model, which can determine the number of crews needed to meet a project duration deadline.

Hegazy and Wassef (2001) developed a model to minimize total construction cost (direct cost, indirect cost, interruption cost, incentives, and liquidated damages) by integrating LOB and CPM method. The model uses genetic algorithms to obtain the optimum construction methods, number of crews, and interruptions for each repetitive activity. Then, in *2004 Hegazy et al*, presented the formulation of a distributed scheduling model for scheduling, resource planning, and cost optimization in large construction programs that involve multiple distributed sites. *Hegazy and Kamarah (2008)* developed a practical model for scheduling and cost optimization of high-rise construction. The model's objective is to minimize total construction cost while respecting the time and resource constraints of a project.

Ammar and Mohieldin (2002) developed a CPM-based repetitive scheduling model that utilizes the benefits of CPM to schedule repetitive activities in an easy non-graphical approach. This model accounts for only the most significant resource for each activity. *Ammar (2003)* developed a model for determining different types of floats for non-serial repetitive activities, in which the time float and rate float are extended to repetitive activities. The analysis was based on a repetitive scheduling method, which utilizes a CPM network of a typical unit, and overlapping between activities are used to model repetitive activities.

Ammar (2013) proposed an integrated CPM and LOB model to schedule repetitive projects in an easy non-graphical way, considering both logic dependency and resource continuity constraints. Overlapping activities of a single typical unit are used to model duration and logical relationships of repetitive activities. The proposed model essentially consists of four steps. In the first step, basic LOB calculations are performed to ensure resource continuity. Activity duration along all repetitive units is calculated in the second step. In the third step, overlapping activities are used to model logical relationships between consecutive activities. Next, CPM time analysis is performed to specify activities' timings and floats and project completion time.

Development to Ammar (2013) Model:

Ammar (2013) discussed that logical dependency relationship among different activities can be specified according to the selected rate of progress of each activity. The actual progress rate of each activity is compared with that of its successors. As shown in Fig. 1, if R_{aA}, $R_{aB,}$ and R_{aC} represent actual progress rates of activities A, B and C, three scenarios can be encountered. Those scenarios are: 1) $R_{aA} < R_{ab}$, 2) $R_{ab} > R_{aC}$, and 3) $R_{aA} = R_{aB} = R_{aC}$.

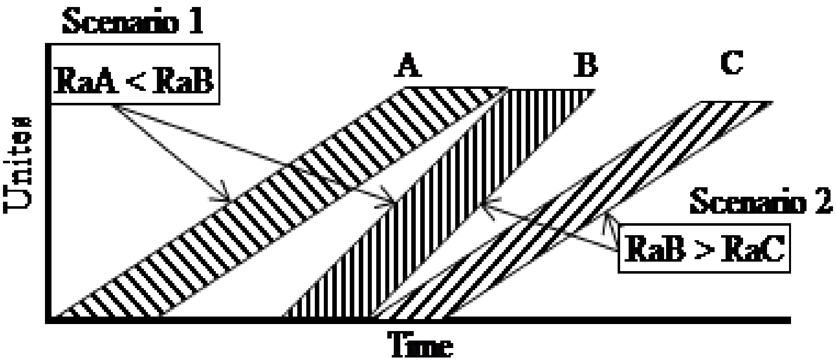


Fig. 1. Relations Scenarios

Start to Start relation:

$R_{aA} < R_{aB}$ represents the scenario when activity B is faster than activity A (leading to convergence). Then, the finish time (FT) of the last unit of the activity A controls the start time (ST) of the last unit of activity B. Therefore, a finish-to-finish (FF) relationship exists in the last unit (N). The FF relation is a relation between FT of activity A (FT_A) and FT of activity B (FT_B) in the last unit N. The FF calculations depend on the activities relations in the first unit which can be FS, SS, SF, or FF relation.

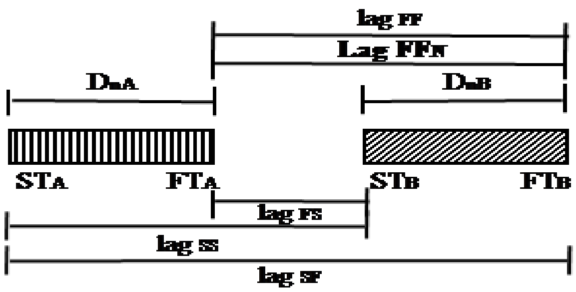


Fig. 2. Lag FF relation in the first unit

As shown in Fig. (2), the possible relation cases between activities in the first unit are; 1) FS with lag $_{FS}$, 2) SS with lag $_{SS}$, 3) FF with lag $_{FF}$, or 4) SF with lag $_{SF}$. In each relation case, a Lag FF on the last unit should be calculated using the duration of the last unit (D_n).

Ammar (2013) pointed that in case the relation between activity A and B in the first unit is FS with lag $_{FS}$, the relation is between activity ST_A and FT_B. To get the relation between FT_A and FT_B in the last unit (N), anFF relation in unit N (Lag FF_N) between activity A and B can be calculated using equation (1):

$$\text{Lag } FF_N = \text{lag }_{FS} + D_{nB} \qquad (1)$$

Where, Lag FF_N = A finish to finish relation between activity A and B in the last unit (N), D_{nB} = Duration of activity B in the last unit N, lag $_{FS}$ = Lag between FT of activity A and ST of activity B.

In case the relation between activity A and B in the first unit is SS with lag $_{SS}$, the relation is between activity ST_A and ST_B. To get the relation between FT_A and FT_B in unit N, anFF relation in unit N (Lag FF_N) between activity A and B can be calculated using equation (2):

$$\text{Lag } FF_N = \text{lag }_{SS} + D_{nB} - D_{nA} \qquad (2)$$

Where, lag $_{SS}$ = Lag between ST of activity A and ST of activity B, D_{nA} = Duration of activity A in the last unit.

And, In case the relation between activity A and B in the first unit is FF with lag $_{FF}$, the relation is between activity FT_A and FT_B. To get the relation between FT_A and FT_B in unit N, anFF relation in unit N (Lag FF_N) between activity A and B can be calculated using equation (3):

$$\text{Lag } FF_N = \text{lag }_{FF} \qquad (3)$$

Where, lag $_{FF}$ = Lag between FT of activity A and FT of activity B.

And, In case the relation between activity A and B in the first unit is SF with lag $_{SF}$, the relation is between activity ST_A and FT_B. To get the relation between FT_A and FT_B in unit N, anFF relation in unit N (Lag FF_N) between activity A and B can be calculated using equation (4):

$$\text{Lag } FF_N = \text{lag }_{SF} - D_{nA} \qquad (4)$$

Where, lag $_{SF}$ = Lag between ST of activity A and FT of activity B.

Finish to Finish relation:

$R_{aB} > R_{aC}$ represents the scenario when activity B is faster than its succeeding activity C. In this scenario, the FT of the first unit (N_1) of activity B controls the ST of N_1 of activity C. Therefore, an SS relationship (Lag SS) can be specified in the N_1. The SS relation is a relation between ST of activity B (FT_B) and ST of activity C (FT_C) in the last unit N_1. The SS calculations depend on the activities relations in the first unit which can be FS, SS, SF, or FF relation.

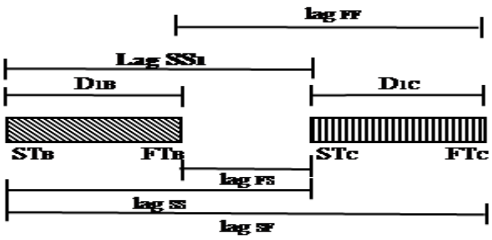


Fig. 3. Lag SS relation in N_1

As shown in Fig. (3), the possible relation cases between activities in the first unit are; 1) FS with lag $_{FS}$, 2) SS with lag $_{SS}$, 3) FF with lag $_{FF}$, or 4) SF with lag $_{SF}$. As in previous scenario, a Lag SS should be calculated using the duration of the first unit (D_1). To get the relation between ST_B and ST_C in N_1, an SS relation in the first unit (Lag SS_1) between activity B and C can be calculated using equation (5):

$$\text{Lag } SS_1 = D_{1B} + \text{lag}_{FS} \quad (5)$$

Where, Lag SS_1 = Start to start relation between activity B and C in the first unit, D_{1B} = duration of activity B in the first unit, lag $_{FS}$ = Lag between FT of activity B and ST of activity C.

Then, In case the relation between activity B and C in the first unit is SS with lag $_{SS}$, the relation is between activity ST_B and ST_C. To get the relation between ST_B and ST_C in N_1, anSS relation in the first unit (Lag SS_1) between activity B and C can be calculated using equation (6):

$$\text{Lag } SS_1 = \text{lag}_{SS} \quad (6)$$

Where, lag $_{SS}$ = Lag between ST of activity B and ST of activity C.

And In case the relation between activity B and C in the first unit is SF with lag $_{SF}$, the relation is between activity ST_B and FT_C. To get the relation between ST_B and ST_C in N_1, anSS relation in the first unit (Lag SS_1) between activity B and C can be calculated using equation (7):

$$\text{Lag } SS_1 = \text{lag}_{SF} - D_{1C} \quad (7)$$

Where, D_{1C} = Duration of activity C in the first unit, lag $_{SF}$ = Lag between ST of activity B and FT of activity C.

And In case the relation between activity B and C in the first unit is FF with lag $_{FF}$, the relation is between activity FT_B and FT_C. To get the relation between ST_B and ST_C in N_1, anSS relation in the first unit (Lag SS_1) between activity B and C can be calculated using equation (8):

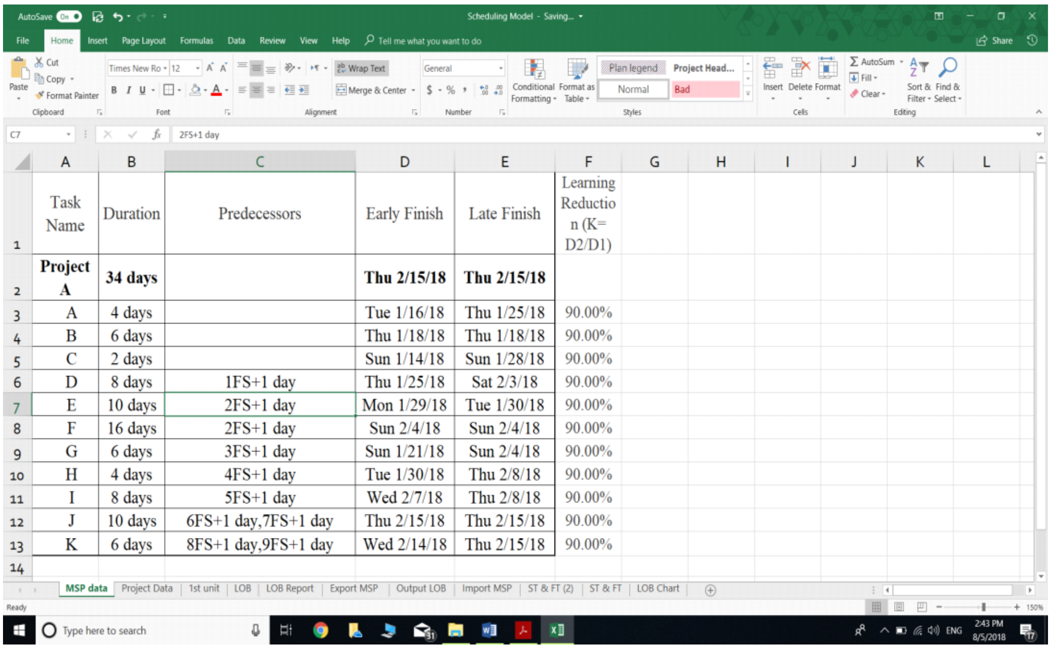
$$\text{Lag } SS_1 = \text{lag}_{FF} + D_{1B} - D_{1C} \quad (8)$$

Where, lag $_{FF}$ = Lag between FT of activity B and FT of activity C.

When both activities have the same production rate, either n SS or FF relationship can be specified, with corresponding lag values as discussed in scenarios 1 and 2.

Link MS Project® to the Proposed Model:

The user can schedule the first unit of the project in MS Project® and export the resulted data to the model. Exported data include; first unit total duration and activities data (name, duration, predecessors and finish time). As shown in Fig. 4, The imported data from MS Project® to the model are coded. MS Project® describes durations with numbers and text. The predecessor data are described by; 1) predecessor ID number, 2) relation type, and 3) The lag between activities. The relation code entered by the user is; FS, SS, FF, or SF. Table 1 shows MS Project® Coding Data.



Task Name	Duration	Predecessors	Early Finish	Late Finish	Learning Reduction (K= D2/D1)
Project A	**34 days**		**Thu 2/15/18**	**Thu 2/15/18**	
A	4 days		Tue 1/16/18	Thu 1/25/18	90.00%
B	6 days		Thu 1/18/18	Thu 1/18/18	90.00%
C	2 days		Sun 1/14/18	Sun 1/28/18	90.00%
D	8 days	1FS+1 day	Thu 1/25/18	Sat 2/3/18	90.00%
E	10 days	2FS+1 day	Mon 1/29/18	Tue 1/30/18	90.00%
F	16 days	2FS+1 day	Sun 2/4/18	Sun 2/4/18	90.00%
G	6 days	3FS+1 day	Sun 1/21/18	Sun 2/4/18	90.00%
H	4 days	4FS+1 day	Tue 1/30/18	Thu 2/8/18	90.00%
I	8 days	5FS+1 day	Wed 2/7/18	Thu 2/8/18	90.00%
J	10 days	6FS+1 day,7FS+1 day	Thu 2/15/18	Thu 2/15/18	90.00%
K	6 days	8FS+1 day,9FS+1 day	Wed 2/14/18	Thu 2/15/18	90.00%

Fig. 4. Exported Data from MS Project®

Table 1. MS Project® Coding Data

ID	Tasks	Duration	T1	T2	Predecessors
1	A	74			
2	B	60	1FF+3d		1FF+3d
3	C	40	2FF+2d		2FF+2d
4	D	105	3SS+2d		3SS+2d
5	E	100	3SS+2d		3SS+2d
6	F	137	5SS+5d	4SS+10d	5SS+5d,4SS+10d
7	G	126	6FF+12d		6FF+12d
8	H	60	7FF+3d		7FF+3d

Model Development:

Building the proposed model is achieved through scheduling the first unit in MS Project® then the data are linked to the model. The model can be divided into four steps; 1) Data Input, 2) LOB calculations, 3) Activities' relations (CBM schedule), and 4) Output data. The model flow chart can be found in Fig. 5.

Data Input:

The user enters the first unit data to MS project® including; activities names, duration, and relations. The resulted data are exported to the model, which is activities (names, duration, predecessors and finish time) and first unit total duration.

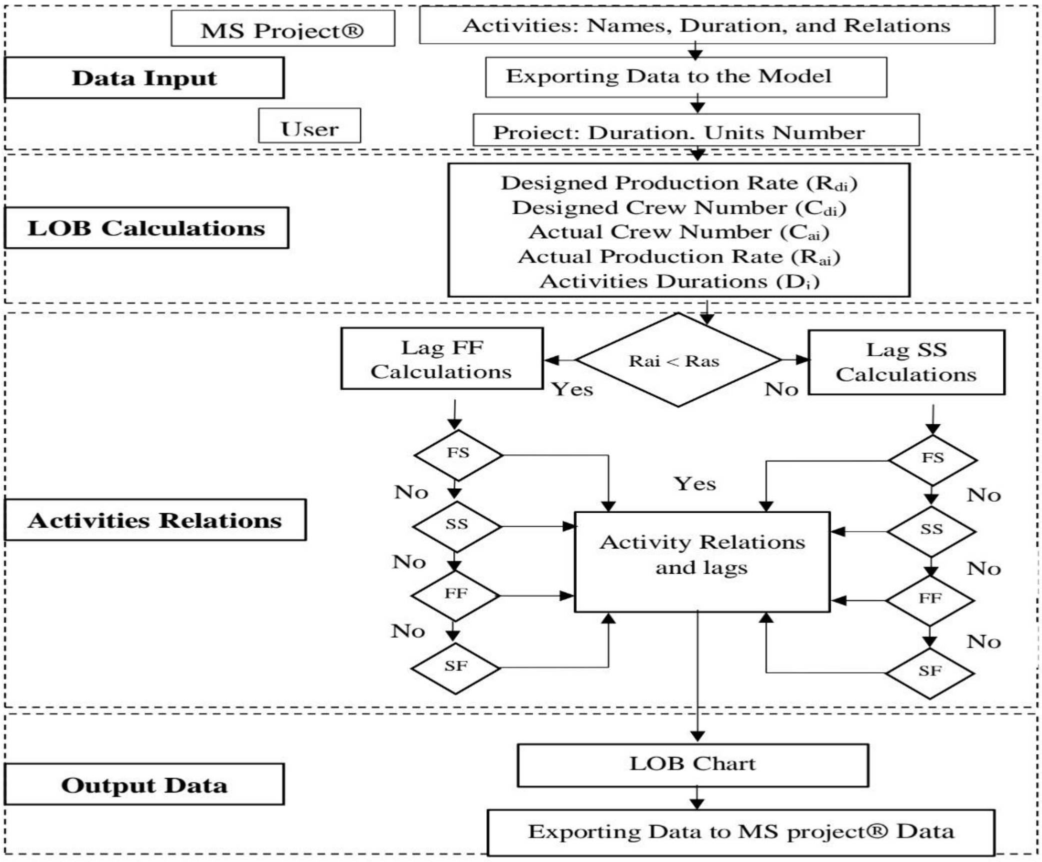


Fig. 5. Model Flow Chart

LOB Calculations:

Here, the model transfers the schedule of the first unit, into the scheduling of the repetitive unit. This step aims to calculate activities number of crews and production rate to perform LOB schedule. As discussed in Ammar (2013), the designed production rate (R_d) needed to be used in activities in order to calculate the project total duration. R_d can be calculated using equation (9).

$R_{di} = (N\text{-}1) / (D_p\text{-}D_1\text{+}TF_i)$ (9)

Where, R_{di} = Designed production rate for activity (i), N = Number of units, D_p = total duration of project, D_1 = Duration of first unit, TF_i = Total float for activity (i).

R_d for each activity is used in calculating a number of crews needed to be hired to achieve this rate. Then, the designed crew number (C_d) can be calculated for each activity using equation (10).

$C_{di} = d_{1i} * R_{di}$ (10)

Where for activity (i), C_{di} = Designed crew number. C_{di} should be round up to calculate an actual number of crews (C_{ai}) where, C_{ai} = Round up of (C_{di}). Then the actual production rate (R_{ai}) can be calculated where, $R_{ai} = d_{1i} / C_{ai}$, C_{ai} = Actual crew number, and R_{ai} = Actual production rate. Calculating actual crew number and production rate for each activity are used in calculating total activities' durations. Then, each activity total duration can be calculated using equation (11).

$D_{Ti} = d_{1i} + (N – 1) / R_{ai}$ (11)

Where, D_{Ti} = Total duration for activity (i).

Activities Relations:

Ammar (2013) assumed activities relation in the first unit is FS, and he calculated activities relation related to this assumption. As discussed before, PDM gives the scheduler the activities execution in the most efficient way possible. So, using equations from (1) to (8) gives the model the advantage of dealing with the relations FS, SS, FF, and SF. Then, a CBM scheduling to the project are generated.

Output Data:

The model achieves its objectives by producing two main outputs: 1) LOB chart. 2) MS Project® exported file. The LOB chart indicates the activities duration and production rates. The Exported file to MS Project® contains activities names, total duration, and relations in a format that MS Project® can read as discussed in the input data.

The output data helps scheduler to get the following advantages:

- Activities number of crews, durations, and relationships.
- LOB chart, which shows the activities production rates and project total duration.
- CBM scheduling in a traditional well-known planning program as MS project®.

Case Study

As a verification of the developed model, the Case study is a project with 15 identical units. The desired contract duration is 90 days. Work breakdown for the first unit and the activities estimated duration are presented in Table 2. The calculations are presented as follows.

- CPM time analysis is performed for the first unit using the unit duration of each activity. The resulting CPM duration of the first unit (D_1) is 34 days and the critical path is A-B-D-E-F.
- LOB calculations are performed based on target project duration (D_d) equal 90 days. The desired project rate of delivery (R_d) = (15 – 1)/(90 – 36) = 0.26. The theoretical and actual number of crews and the actual progress rate of each activity are calculated as shown in Table 3.
- Activities relations are calculated using Equations (1) through (8). For example, consider the relation between activity E and D. Since $Ra_E > Ra_D$, then the relation is FF at the N_n. The relation between E and D in the first unit is FF. Using equation (4) the Lag FF_n = lag $_{FF}$ = 0. Table 4 presents Activities Relation Calculations.
- CPM calculation is performed where the total project duration is 86 days. The output data are; the LOB chart, activities duration distribution and the exported file to MS project® (Table 5). The LOB chart to the critical path A-B-D-E-F as shown in Fig. 6 can be represented by the ST and FT of the first unit and ST and FT of the last unit.

Table 2. Planning Data of a Typical Unit

Activity	Duration	Predecessor	Relation
A	5	-	-
B	5	A	FS
C	2	B	FS
D	10	B	FS
E	5	C	FS
		D	FF
F	13	E	FS
		D	FS
G	12	F	FF
H	3	G	FS

Table 3. LOB Calculations

Activity	D_1	R_d	C_d	C_a	R_a	D_T
A	5	0.26	1.29	2	0.40	40
B	5	0.26	1.29	2	0.40	40
C	2	0.24	0.49	1	0.50	30
D	10	0.26	2.59	3	0.30	50
E	5	0.26	1.29	2	0.40	40
F	13	0.26	3.37	4	0.30	58
G	12	0.26	3.11	4	0.33	54
H	3	0.26	0.78	1	0.33	45

Table 4. Activities Relation Calculations

Activity	P_1	Lag SS	Lag FF	P_2	Lag SS_2	Lag FF_2
A	--	--	--	--	--	--
B	A	5	--	--	--	--
C	B	--	2	--	--	--
D	B	5	--	--	--	--

E	C	2	--	D	--	0
F	E	5	--	D	--	13
G	F		0	--	--	--
H	G	12	--	--	--	--

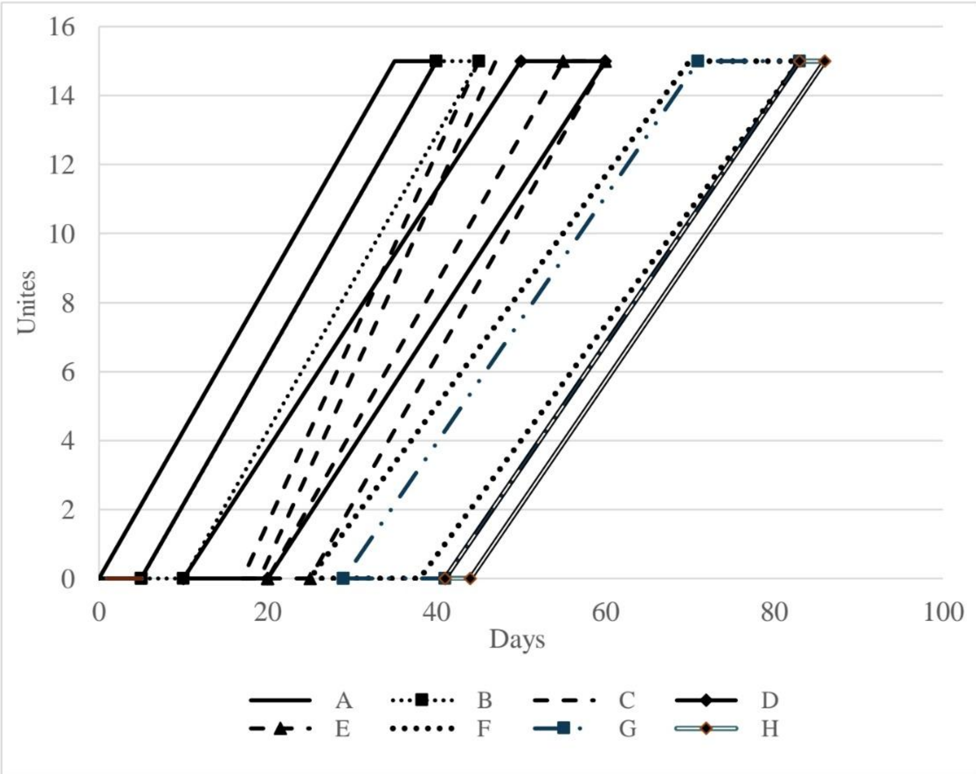


Fig. 6 LOB Chart

Table 5. Exported Data to MS Project®

Activity	Duration	Predecessors
A	40 days	
B	40 days	1SS+5d
C	30 days	2FF+d
D	50 days	2SS+5d
E	40 days	3SS+2d,0
F	58 days	5SS+5d,4FF+13d
G	54 days	6SS+d
H	45 days	7SS+12d

II. Conclusion

A study in 2013 stat that, 1% of the construction companies in UK are using LOB. The limited usage is attributed to the lack well-known computer programs based of this technique. Reviewing the literature of LOB, Ammar (2013) developed a framework for scheduling repetitive project using integration between CPM and LOB in an analytical format. This study presented a development to Ammar (2013) framework to be capable of using all possible relations between activities. This paper introduced steps of developing the model based on the proposed methodology. The model was verified through a case study with different relation. The result data discussed the duration comparisons and model output data.

Linking data to MS project® helps in decreasing the planning process duration. MS project® is a well-known software and many construction companies using it in the planning process. So, the scheduling of the first unit can be easily performed in it. Linking to MS project® and the model helps in decreasing input data by the users. The easy process of exporting the output data to MS project® is useful in organizing the project data on a well-known software. The schedulers now have the ability to get all the output data in a well -known format for them. The developed model helps scheduler in using FS, SS, FF, and SF relation between activities in the first unit not only FS.

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