Alexandria Engineering Journal (2011) 50, 179–185

Alexandria University
Alexandria Engineering Journal
www.elsevier.com/locate/aej
www.sciencedirect.com

FACULTY OF ENGINEERING
ALEXANDRIA UNIVERSITY

ORIGINAL ARTICLE

Linear projects scheduling using spreadsheets features

Fatma Abd El-Mohye Agrama

Civil Engineering Department, Menofia University, Egypt

Received 13 October 2010; accepted 26 January 2011
Available online 22 July 2011

KEYWORDS
Construction management;
Scheduling;
Linear projects;
Line of balance

Abstract Linear projects represent a large portion of the construction industry. Highway, pipeline, and tunnels are good examples that exhibit repetitive characteristics where the same unit is repeated several times. Scheduling of linear projects always represent a major challenge to project managers. These projects require schedules that maintain resource continuity for an activity from one unit to the next one and achieve logic constraints at the same time. The line of balance (LOB) method is well suited for scheduling such projects. Spreadsheets are efficient computational tool used in many field with wide range of calculations. The requirements associated; within logical lag between continuous non-typical repeated activities are developed in a spreadsheet algorithm. In this study, the schedule times for each activity sequentially from unit to the next can be tabulated and graphically displayed in LOB plot. Details of the model development and computerized implementation are described. An example application is presented to illustrate the proposed approach. The advantages and future extensions of the proposed approach are then discussed.

1. Introduction

Construction projects that contain many identical units, wherein activities repeat from one unit to another, are characterized as repetitive projects. These projects are classified according to repetition nature [1] into: (1) horizontal repetition that is repeated due to their geometrical layout such as highway, pipelines, and multi-bay single-storey projects and this kind is usually called as linear projects; (2) vertical repetition, projects that are repeated due to vertical repetition of a floor with skeleton considerations such as high-rise buildings; (3) both horizontal and vertical repetition, projects that integrate between the above two kinds such as multi-bay multi-storey buildings. However, [2] stated that linearity of projects may be due to the uniform repetition of a set of activities through the project (e.g., multiple similar houses and high-rise buildings comprising typical floors); or due to geometrical layout of the project (e.g., highway and pipelines).

Network based methods such as critical path method (CPM) are proven to be powerful scheduling and progress control tools, but are not suitable for projects of a repetitive nature [3–5]. Previous studies outlined disadvantages of using

E-mail address: fatmagrama@hotmail.com

1110-0168

Peer review under responsibility of Faculty of Engineering, Alexandria University.
doi:10.1016/j.aej.2011.01.018

Production and hosting by Elsevier
ELSEVIER

CPM technique for scheduling linear projects. It becomes extremely detailed thus making the network difficult for the user to visualize and manage even for a small linear project. It does not address maintaining work continuity nor achieve a constant rate of repetitive work to meet a programmed rate of completed units [6–9].

Alternate graphical methods have been provided a simplistic formulation to maintain crew work continuity for repeated activities through sequential units of such projects. The exact origins of the graphical techniques in construction management are not clear and there may actually have been multiple origins such: [10–13]. Even the name attached to the method has varied when it has appeared in the literature. The name "linear scheduling method" (LSM) is adopted if it is used to schedule horizontal repetitive projects (i.e. linear in geometry). The name "vertical production method" (VPM) is adopted if it is used to schedule vertical repetitive projects. The name "line of balance method" (LOB) or "time space scheduling method" is used for any type of repetitive projects, as classified by [14]. The controlling activity path is identified [15] through a LSM based on the time and distance relationships of activities. The controlling activity path is similar to the critical path of CPM. A similar approach is introduced [16]; the repetitive scheduling method that ensures continuous resource utilization. However, these methods are mainly graphical based techniques which limit their practical use. Although graphical methods are not adequate in scheduling linear construction projects, they are the familiar one which represents a start point for various inspired mathematical research-based techniques since the 1960s.

There have been several attempts to develop mathematical models to solve the various problems associated with scheduling repetitive projects. A mathematical algorithm for scheduling linear projects is presented [2]. The controlling path (logically and resource critical units) is identified based on utilizing CPM network of a single unit within constant activity production rate and defining start-to-start or finish-to-finish relationships. However, this model does not consider variable activity production rates; does not determine the activity start and finish times for each unit nor draw a bar chart for each activity at all units. There have, however, been sequential mathematical efforts to identify and treat problems associated with scheduling and optimizing linear projects such: [1,2,6,17,18].

This study introduces a spreadsheet algorithm, in essence LOB based technique, which determines the relationship controlling start time of the activity at first unit. It maintains crew work continuity for activities from one unit to the next one, without permitting any interruption, and achieves logical constraints; simultaneously. The non-typical activities are assumed, i.e. consequently activity durations can be varied along the repeated units.

2. Scheduling representation

In graphical representation of linear projects, repetitive activities are plotted as boxes (or lines) with constant or varying durations, with the axes being units versus time. Fig. 1 shows forms of LOB scheduling technique plot, where activities are represented as boxes, whose width is the activity duration at this unit. In this case, the left side of the boxes represent the start times of the activities at sequential units, where the right sides represent the finish times.

3. Developed model

To simplify the modeling task and present a model in a format that is customary to practitioners, a spreadsheet tool Excel 2003 is used for implementation. The spreadsheets have been proven suitable as a tool for developing computerized models, such one at hand. The model is presented in three steps: first is the spreadsheet data; second is for the model calculations; whereas third is LOB diagram. The details are provided in the following subsections on the example application to demonstrate its simplicity and usefulness. This example consists of twelve activities; each activity repeated through five units. The typical unit network is non-serial as presented in Fig. 2.

3.1. Network data entry

Most activities use several types of resources to be performed. The present technique assumes that only the most significant resource will be considered (single resource). Multiple resources will be treated in a subsequent research work. Initially, the following data required are: (a) number of repetitive units N; (b) finish-to-start logical activities' relationships and

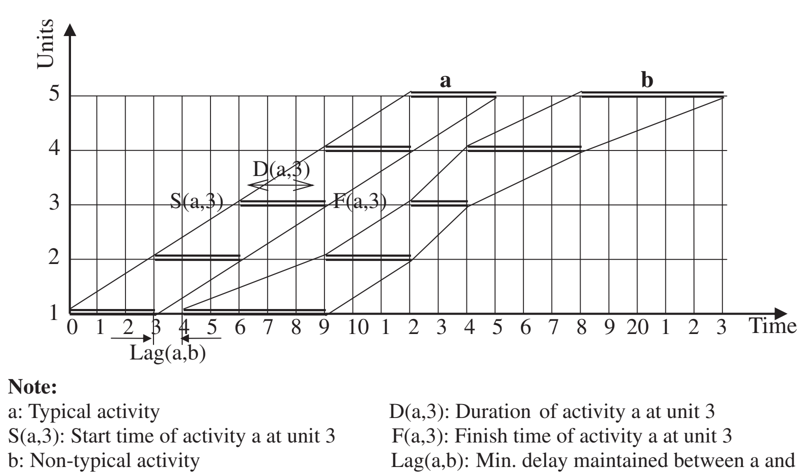


Figure 1 LOB representation forms.

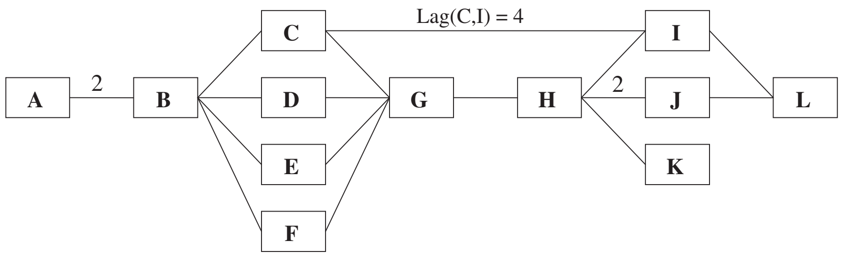


Figure 2 Typical unit network for example application.

associated lags if any; (c) Durations $D(i,n)$ for each activity i at sequential units n.

Fig. 3 represents the interface of the spreadsheet data, whereas the activities data can be entered from rows 11 and down. Activities number and description will be represented in columns A and B. Columns C–L represent the predecessors and associated lags. Activities' durations at each unit will be entered from column M and right; adjacent to associated activity. Number of units will enter in cell C4 at the above block.

3.2. Schedule calculations

Having the initial data specified, schedule calculations are done in another spreadsheet. To do this; LOB consideration that maintains work continuity through sequential units and logical relationship consideration that guarantees the completely finishing of all predecessors before the activity start must be conducted by the following way. Once the no predecessors' activity(ies) in the first unit starts at time zero Eq. (1), the start times of this activity at sequential units can be calculated considering work continuity constraint as Eq. (2). However, The finish time $F(i,n)$ can be calculated using Eq. (3).

$$S(i,1) = 0 \quad i = 1,2,\ldots,I; P(i) = 0 \tag{1}$$

where; I is the total number of activities and $P(i)$ is the total number of predecessors of activity i.

$$S(i,n) = S(i,n-1) + D(i,n-1) \quad n = 2,3,\ldots,N; \; i = 1,2,\ldots,I \tag{2}$$

$$F(i,n) = S(i,n) + D(i,n) \quad n = 1,2,\ldots,N; \; i = 1,2,\ldots,I \tag{3}$$

Otherwise, start time at first unit of activity i, which has predecessors, must be adjusted first on all possible paths, using controlling values, in order to prevent a conflict in the logical relationship and guarantee work continuity. Controlling start times $CS(i,n)$ of activity i, according to the predecessors figures at unit n, is calculated at first unit maintaining work continuity of the activity i, Eq. (4), see Fig. 4. In this figure, activity b is a predecessor of current activity c. A dashed line parallel to the right side of the predecessor b represents the "red" limit, respecting logical relationship constraint considering lag. This limit must not be violated by starting of any successor, first term of Eq. (4). However, to start activity c at first unit maintaining work continuity; slope of the left side of activity c must be respected by parallel lines down from each unit to the first one; considering logical limit, second term of Eq. (4), forming controlling start times of activity c.

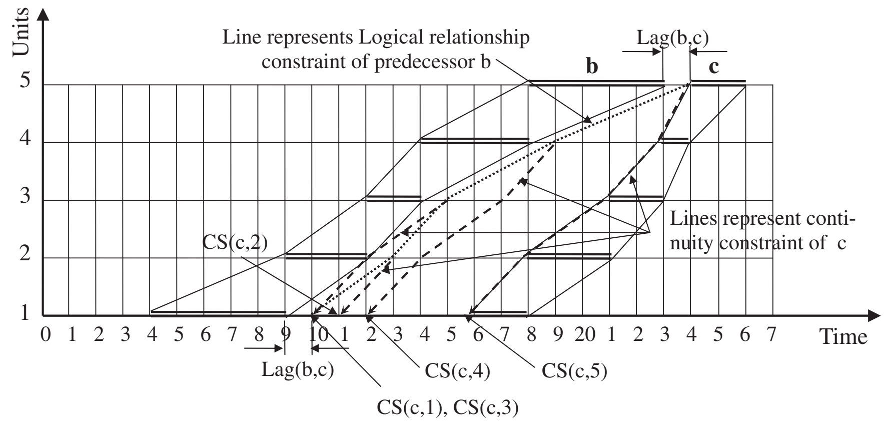
No. of Activity = 12

No. of Units = 5

Activity Description		Predecessors										1	2	3	4	5
No.	Activity	P(1)	Lag(1)	P(2)	Lag(2)	P(3)	Lag(3)	P(4)	Lag(4)	P(5)	Lag(5)	D(1)	D(2)	D(3)	D(4)	D(5)
1	A											12	0	0	0	0
2	B	1	2									10	10	10	10	15
3	C	2	0									4	4	4	4	4
4	D	2	0									6	6	6	8	8
5	E	2	0									6	6	6	6	6
6	F	2	0									11	11	11	11	11
7	G	3	0	4	0	5	0	6	0			0	5	5	5	5
8	H	7	0									5	5	0	5	5
9	I	3	4	8	0							4	4	4	4	4
10	J	8	2									8	8	8	8	8
11	K	8	0									5	5	5	5	5
12	L	9	0	10	0							0	0	0	0	10

Data / Model / LOB Chart

Figure 3 Spreadsheet data for example application.



Note: CS(c,1) to CS(c,5) are controlling relationships to maintain the two constraints for S(c,1)

Figure 4 Controlling relationship.

$$CS(i,n) = \text{Max}[F(p,n) + \text{Lag}(i,p)] - \sum_{1}^{n-1} D(i,n)$$

$$p = 1,2,\ldots,P(i);\ P(i)\neq 0;$$
$$n = 1,2,\ldots,N;\quad i = 1,2,\ldots,I \tag{4}$$

where $[F(p,n) + \text{Lag}(i,p)]$ term guarantees the completely finishing of predecessor p; and $\sum_{1}^{n-1} D(i,n)$ term maintains work continuity through sequential units up to unit under consideration.

However, the start time $S(i,1)$ of this activity at first unit must be equal to the maximum controlling start times $CS(i,n)$, Eq. (5). Where Eqs. (2) and (3) are reapplied to calculate the start and finish times of activity i at sequential units n. The total project duration (PD) can be determined using Eq. (6). The algorithm for the suggested methodology is illustrated in the flowchart given in Fig. 5.

$$S(i,1) = \text{Max}[CS(i,n)]\quad n = 1,2,\ldots,N;$$
$$i = 1,2,\ldots,I;\ P(i)\neq 0 \tag{5}$$

$$PD = \text{Max}[F(i,N)]\quad i = 1,2,\ldots,I \tag{6}$$

3.3. Detailed schedule calculations

Implementation for activities' calculation is provided in the second spreadsheet, as shown in Fig. 6. In this sheet, entered data from column A–L are recopied to simplify calculations. However, schedule of all repetitive activities at each unit are set up in columns at the right of column L. Project duration is calculated according to Eq. (6), in cell C5 at the above block. The spreadsheet formulae for the first repetitive activity are set up in row 11. To obtain a complete spread sheet, the formulae for the first activity are copied down according to the number of activities, and the formulae for typical repetitive unit are copied across to the right according to the number of units. Start times of the activities at first unit (Eqs. (1) and (5)) which specified at column O, consider the maximum values of activity controlling starts calculated in other columns according Eq. (4). However, the second term of the same equation is calculated at individual columns labeled by Delta (n); to simplify the calculations. For the other units, columns are set up to calculate start and finish times of all activities using Eqs. (2) and (3), see Fig. 6.

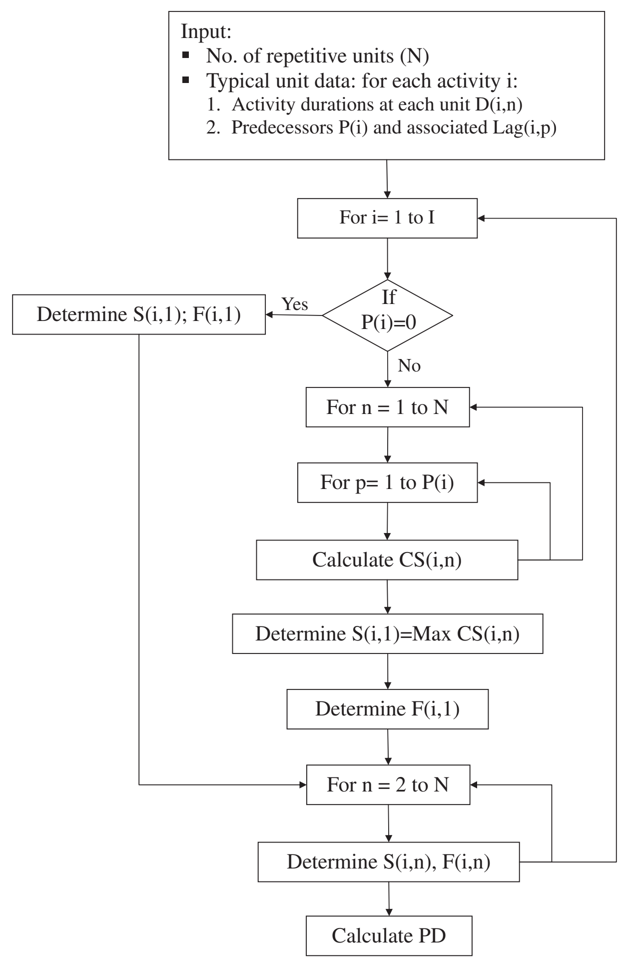


Figure 5 Model procedure flowchart.

3.4. LOB diagram

The degree of the detail of the LOB diagram must be carefully evaluated. If too many activities are plotted, the diagram becomes a jungle of oblique lines that also sometimes cross each other. An alternative is proposed which displays the LOB dia-

No. of activities=	12
No. of Units=	5
Project Duration=	127

Activity Description		Predecessors										Unit 1				Unit 2		
No.	Activity	P(1)	Lag(1)	P(2)	Lag(2)	P(3)	Lag(3)	P(4)	Lag(4)	P(5)	Lag(5)	D(1)	CS(i,1)	Start(1)	Finish(1)	D(2)	Delta(2)	CS(i,2)
1	A											12	0	0	12	0	12	0
2	B	1	2									10	14	14	24	10	10	14
3	C	2	0									4	24	53	57	4	4	30
4	D	2	0									6	24	43	49	6	6	28
5	E	2	0									6	24	45	51	6	6	28
6	F	2	0									11	24	25	36	11	11	24
7	G	3	0	4	0	5	0	6	0			0	57	65	65	5	0	61
8	H	7	0									5	65	70	75	5	5	65
9	I	3	4	8	0							4	75	76	80	4	4	76
10	J	8	2									8	77	77	85	8	8	77
11	K	8	0									5	75	75	80	5	5	75
12	L	9	0	10	0							0	85	117	117	0	0	93

2			Unit 3					Unit 4					Unit 5				
CS(i,2)	Start(2)	Finish(2)	D(3)	Delta(3)	CS(i,3)	Start(3)	Finish(3)	D(4)	Delta(4)	CS(i,4)	Start(4)	Finish(4)	D(5)	Delta(5)	CS(i,5)	Start(5)	Finish(5)
0	12	12	0	12	0	12	12	0	12	0	12	12	0	12	0	12	12
14	24	34	10	20	14	34	44	10	30	14	44	54	15	40	14	54	69
30	57	61	4	8	36	61	65	4	12	42	65	69	4	16	53	69	73
28	49	55	6	12	32	55	61	8	18	36	61	69	8	26	43	69	77
28	51	57	6	12	32	57	63	6	18	36	63	69	6	24	45	69	75
24	36	47	11	22	24	47	58	11	33	24	58	69	11	44	25	69	80
61	65	70	5	5	61	70	75	5	10	61	75	80	5	15	65	80	85
65	75	80	0	10	65	80	80	5	10	70	80	85	5	15	70	85	90
76	80	84	4	8	76	84	88	4	12	76	88	92	4	16	76	92	96
77	85	93	8	16	77	93	101	8	24	77	101	109	8	32	77	109	117
75	80	85	5	10	75	85	90	5	15	75	90	95	5	20	75	95	100
93	117	117	0	0	101	117	117	0	0	109	117	117	10	0	117	117	127

Data | Model | LOB Chart

Figure 6 Schedule calculations spreadsheet.

gram of each individual path, one path at a time. The use of shaded or color-filled boxes showing the movement of the crews can help. The choice of the appropriate scale is also critical for better understanding and for communicating the information contained in the LOB schedule. An experienced scheduler can select a suitable level of detail and scale. It is expected that foremen and subcontractors will be more receptive to LOB diagrams than to precedence networks. Fig. 7 shows LOB diagrams for scheduling the twelve activities organized in four paths using Excel standard chart type, stacked bar, within some implementations. It is preferable to attach the typical CPM network above or near the LOB diagram to be relationships more readable. Identifying the controlling path will be favorite; as well. In this example application, path "ABFGHJL" represents the controlling path; see the third LOB diagram in Fig. 7.

4. Comments and conclusion

In this paper a suggestion of novel model has been demonstrated for example application. To validate the used technique, another experiment conducted on [2] was checked and performed well. The main features of the proposed technique performance, that gives an efficient tool to schedule and represent linear project, can be defined as follows:

- It maintains both the resource continuity and logical relationships.
- It determines the start and finish times for each activity at repeated units in an easy analytical way.
- It generates LOB diagrams for each individual path that can help alleviate visual problems of presentation.
- The non-typical activity feature allows for changing the number of repeated units from one activity to another without disrupting the underlying philosophy, just defining zero for undesired activity's unit duration. Hence, this model is suitable for scheduling projects with identical and semi-identical repeated units.
- It has been implemented on a spreadsheet tool that is customary to many practitioners.
- The technique may be widely accepted by schedulers and managers.

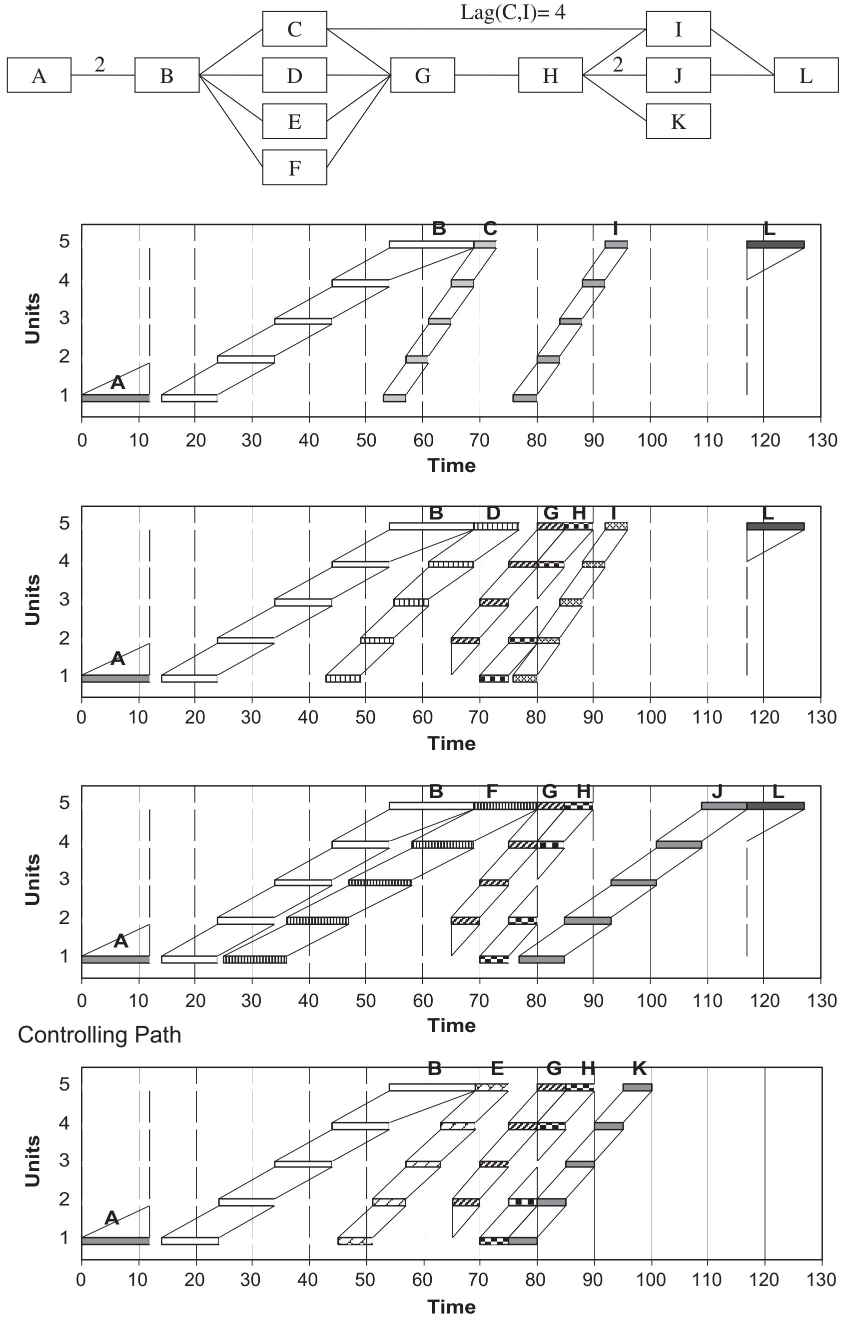


Figure 7 LOB diagram for the example application.

5. Future extensions

This paper presented a versatile technique for scheduling linear projects. The major benefit of the proposed approach is the ability to guarantee logic constraint while satisfying resource continuity. An Excel spreadsheets algorithm was implemented to automate the model. An example application was solved to demonstrate its familiar interface, programmability features, and visual presentation capabilities.

Despite its important benefits, the writer will currently pursue a possible extension to optimize schedule of the linear projects within multiple activity resources and/or within effective interruptions for activities.

References

[1] F.A. Agrama, The Line of Balance Technique by Genetic Optimization. Doctor of Philosophy thesis, Tanta Univ., Egypt (2006).

[2] M.A. Ammar, E. Elbeltagi, Algorithm for Determining Contrlling Path Considering Resource Continuiuty, Journal of Computing in Civil Engineering, ASCE 15 (4) (2001) 292–298.

[3] D. Arditi, M.Z. Albulak, Line-of-Balance Scheduling in Pavement Construction, Journal of Construction Engineering and Management, ASCE 112 (3) (1986) 411–424.

[4] D. Arditi, O.B. Tokdemir, K. Suh, Challenges in Line-of-Balance Scheduling, Journal of Construction Engineering and Management, ASCE 128 (6) (2002) 545–556.

[5] S. Selinger, Construction Planning for Linear Projects, Journal of the Construction Division, ASCE 106 (2) (1980) 195–205.

[6] T. Hegazy, O. Moselhi, P. Fazio, BAL: An Algorithm for Scheduling and Control of Linear Projects, Transportation ASCE International (1993) C81–C814.

[7] R.M. Reda, RPM: Repetitive Project Modeling, Journal of Construction Engineering and Management, ASCE 116 (2) (1990) 316–330.

[8] S.A. Suhail, R.H. Neale, CPM/LOB: New Methodology to integrate CPM and Line of Balance, Journal of Construction Engineering and Management, ASCE 120 (3) (1994) 667–684.

[9] S.M. Hafez, Practical Limitations of Line of Balance in Scheduling Repetitive Construction Units, Alexandria Engineering Journal 43 (5) (2004) 653–661.

[10] R.I. Carr, W.L. Meyer, Planning Construction of Repetitive Building Units, Journal of the Construction Division, ASCE 100 (3) (1974) 403–412.

[11] C.J. Khisty, The Application of the Line of Balance' Technique to the Construction Industry, Indian Concrete Journal (1970) 297–320.

[12] J.J. O'Brien, V.P.M. Scheduling, For High-Rise Buildings, Journal of the Construction Division, ASCE 101 (4) (1975) 895–905.

[13] E. Turban, The Line of Balance- A management by Exception Tool, Journal of Industrial Engineering XIX (9) (1968) 39–47.

[14] R.A. Yamin, D.J. Harmelink, Comparison of Linear Scheduling Model (LSM) and Critical Path Method (CPM), Journal of Construction Engineering and Management, ASCE 127 (5) (2001) 374–381.

[15] D.J. Harmelink, J.E. Rowings, Linear Scheduling Model: Development of Controlling Activity Path, Journal of Construction Engineering and Management, ASCE 124 (4) (1998) 263–267.

[16] R.B. Harris, P.G. Ioannou, Scheduling Projects with Repeating Activities, Journal of Construction Engineering and Management, ASCE 124 (4) (1998) 269–278.

[17] K. Hyari, K. El-Rayes, Optimal Planning and Scheduling for Repetitive Construction Projects, Journal of Management in Engineering 22 (1) (2006) 11–19.

[18] A. Senouci, H.R. Al-Derham, Genetic Algorithm-Based Multi-Objective Model for Scheduling of Linear Construction Projects, Journal of Advances in Engineering Software 39 (2008) 1023–1028.