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Learning Curve Effect in Scheduling Repetitive Projects

Mohamed Eslam [1], Ahmed Elyamany [2], Ahmed ElHakeem [3]

[1] Graduate student, Construction and Building Engineering Department, Arab academy for science, technology and Maritime Transport, Cairo, Egypt.
[2] Assistant Professor, Construction Engineer and Validity Department, Zagazig University, Egypt.
[3] Associate Professor, Construction and Building Engineering Department, Arab academy for science, technology and Maritime Transport, Cairo, Egypt.

ملخص البحث:

تعد الكثير من المشروعات الانشائية بمثابة مشروعات تكرارية. لذا فقد قام الباحثون بتطوير العديد من الطرق لعمل برامج زمنية لهذه الفئة من المشروعات، أشهرها هي طريقة خط الإتزان. وعلي الرغم من إنجاز هذه الطريقة لبرامج زمنية تتوافق مع زمن المشروع و محددات الموارد، الا انها اهملت تاثير منحني التعلم الخاص بأطقم التنفيذ. ورغم ثبوت تاثير منحني التعلم علي طريقة خط التزان الا ان التطويرالذي تم في هذه الطريقة لم يشمل تأثير منحني التعلم علي البرنامج الزمني المنفذ بهذه الطريقة. لذا، يهدف هذا البحث لتطوير نموذج يمكنه الاستفادة من تأثير منحني التعلم في تحسين البرامج الزمنية المنفذة بطريقة خط الاتزان. و قد تم التحقق من نتائج التطوير المقترح علي البرنامج من خلال تطبيق النموذج المقترح علي مشروع فعلي، حيث اثبت تحليل النتائج نحسنا في البرامج الزمنية باستخدام تاثير منحني التعلم.

Abstract:

Many construction projects could be considered as repetitive projects. Researchers developed many scheduling models for repetitive projects. Although these models showed enhancement in meeting deadline and resources limitations, they ignored the effect of learning curve on the production rate of construction crews. The effect of learning in repetitive work are being studied since the 1930. Despite the fact that there is an effect on Line of Balance (LOB), no further development has been made to their applications. This paper develops a scheduling model which incorporate the effect of learning with LOB. The model is validated using a case study to show the learning effect on activities duration.

Keywords: Scheduling, Repetitive Project, Line of Balance, Learning curve, crew productivity

Introduction:

Project management software is designed to make the job of a project manager easier and more efficient, providing applications to aid in planning, to manage project costs, and to track activities and monitor schedules. As more and more public works departments face the realities of increasing workloads and shrinking resources, finding technology applications that allow productivity gains becomes more important. The use of project management software as a tool for managing and organizing work has grown and continues to grow at a rapid pace in all industries.

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 many times 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. *(Arditi et al 2002)*

LOB scheduling technique assumed the production rate is linear (constant rate of production over time). In reality, the more times an operation is performed, the shorter the time needed to perform it. This phenomenon is called the learning curve effect. To incorporate effects of learning into the LOB method, the learning rate of each activity should be established and then converted into man-hour estimates. The resulting LOB diagram are neither linear nor parallel anymore. *(Arditi et al. 1999, Zahran el al. 2014)*

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 relationship logic and float 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 used in a model to determine the number of crews needed to meet a project duration deadline. Activities' total float are utilized to relax non-critical activities without influencing the total project duration.

Hegazi 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. *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. Although, this model showed enhancement in calculating optimum number of crews and resources limitations, it neglected the effect of learning curve.

Objective

This paper aims to develop a model for scheduling repetitive projects. The proposed model incorporates the learning effect with LOB scheduling technique.

Model Development:

Building the proposed model is achieved through the following steps; shown in Fig.1.

1) Input data and scheduling first unit.
2) Transforming first unit to a repetitive units (LOB schedule).
3) Calculating activities' duration using learning curve effect.
4) Obtain output data.

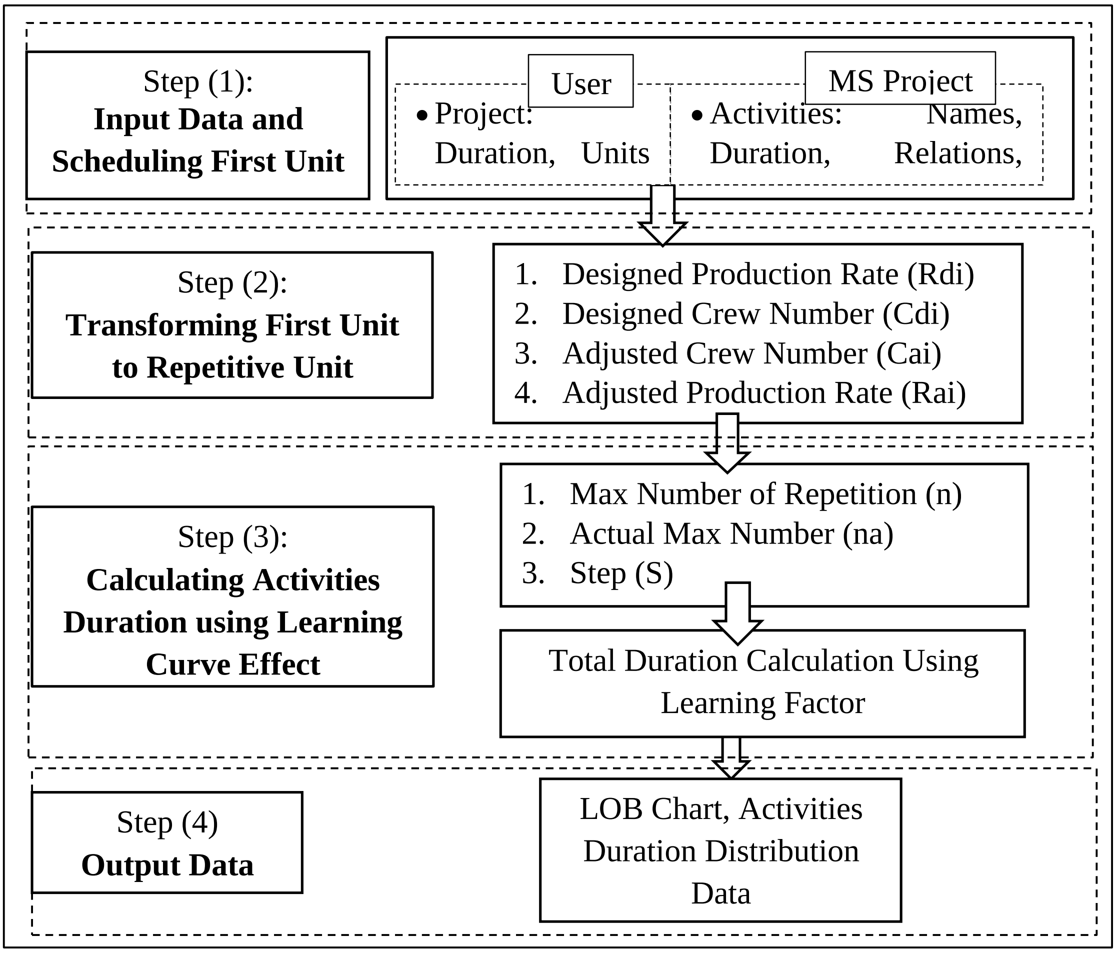

Fig. 1. Model Flow Chart

Step (1): Input Data and Scheduling First Unit:

First, the user enters model input data such as; activities names, duration, and relations. Then, the user enters the following data to the model; target project duration, number of project units, and learning factor for each activity.

Step (2): Transforming First Unit to Repetitive Units:

In this step the model transfer scheduling of the first unit, into scheduling of repetitive unit. This step aims to calculate the number of crew for each activity and production rate to perform LOB schedule. The input data are used to calculate the designed production rate (R_d) required to achieve project total duration. R_d is calculated using equation (1).

$R_d = (N-1) / (D_p-D_1+TF)$
(1)

Where, R_d = Designed production rate, N = Number of units, D_p = Total project duration, D_1 = Duration of first unit, TF = Total float.
Calculating R_d for each activity is used in calculating number of crews needed to be hired to achieve this rate. The designed crew number (C_d) can be calculated for each activity using equation (2).

$$C_d = D_1 * R_d \quad (2)$$

Where, C_d = Designed crew number, R_d = Designed production rate, and D_1 = Duration of first unit.

C_d should be round up to the nearest integer to produce an adjusted number of crews (C_a). The design production rate is adjusted accordingly to obtain adjusted production rate (R_a).

Calculating adjusted crew number and production rate for each activity are used in calculating total activities' durations discussed in the next step.

Step (3): Calculating Activities Duration using Learning Curve Effect:

This step aims to calculate total activities' duration taking into consideration the learning effect. The duration of any activity can be defined as the duration between the start time (ST) of the first unit (N_1) and the finished time (FT) of the last unit (N_L).

Activity duration depends on the number of crews needed to perform the work and the number of repetition cycles of these crews.

Activities Durations Calculation:

The duration of any activity can be defined as the duration between the start time (ST) of the first unit (N_1) and the finished time (FT) of the last unit (N). As shown in Fig. 2, activities are not necessarily performed by the same crew, in which case, the duration is calculated using equation (3).

$$D_{ti} = D_{tCj} + S_t \quad (3)$$

Where, D_{ti} = Total Duration of activity i, D_{tCj} = duration of crew j to complete the activity, S_t = Summation of lags between start time of (C_1) and start time of C_j (C_j = $\underline{S_1 + \ldots + S_{j-1}}$). Where, S_1 = lag between unit of C_1 and C_2 , and S_{j-1} = lag between unit of C_j and its predecessor crew C_{j-1}. The C_j is assumed to continue working in (n) units until it finishes the activity. Next, D_{tCj} should be calculated with considering the learning effect.

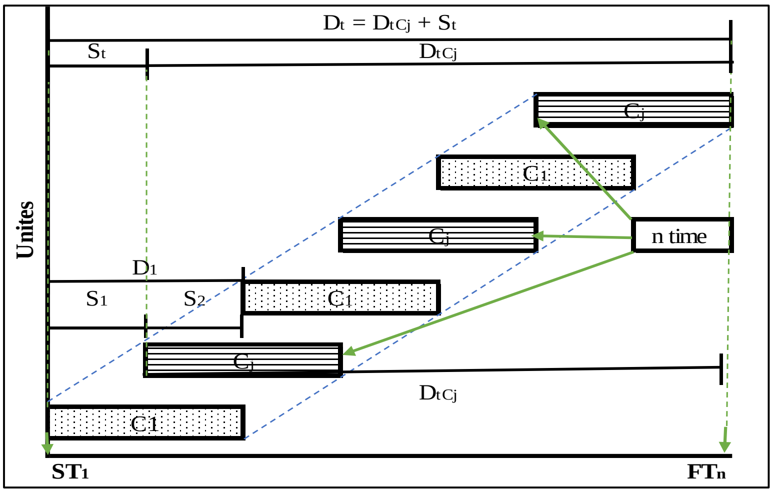

Fig. 2. Repetitive Activity Duration

Learning Effect Calculation:

Several studies have been done to predict the effect of learning on repetitive activities. The easiest and most commonly used model for construction activities is the straight-line power model. This model was first introduced in the 1930's for the production of aero planes. It is also called the log linear model as it is represented on a log-log scale. The model assumes that each time the number of cycles doubles, the duration needed to finish a cycle is decreased by a constant percentage called the learning rate (K), provided that there is no interruption of work *(Zahran et al, 2016).* This relation is presented in equation (4):

$$D_{nj} = D_1 \times n_j \wedge^{(\log k / \log 2)} \qquad (4)$$

Where, D_{nj} = Duration of unit number (n) in crew j (C_j), n_j = Number of units in C_j, k = the learning rate factor.

As shown in Fig. 3, the duration of activity is decreased as a result of learning from repetition. Increasing number of units finished by C_j result in decreasing in duration needed to finish this unit. By calculating the duration of each unit in a certain activity with C_j, the learning reduction in duration can be calculated using equation (5)

$$D_{tCj} = D_{1j} + \text{round up } (D_{2j}) + \ldots\ldots + \text{round up } (D_{nj}) \qquad (5)$$

Where, D_{tCj} = duration of crew j to complete the activity, D_{1j} = Duration of the first unit, D_{2j} = Duration of the second unit in the same crew (C_j), D_{nj} = Duration of the last unit in (C_j).

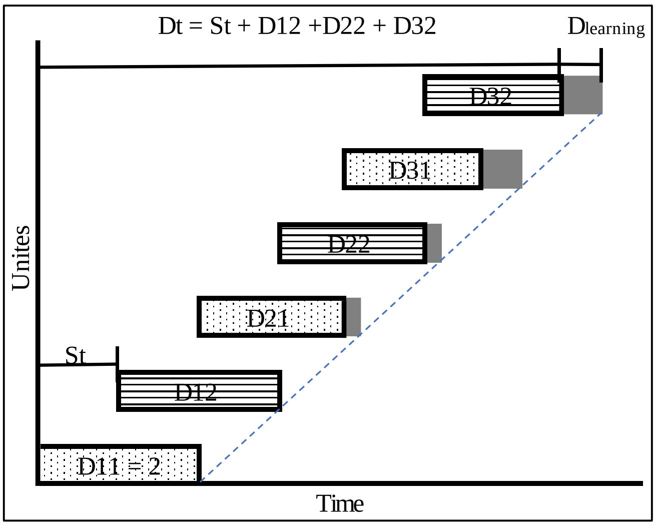

Fig. 3. Learning Effect Calculations

Step (4): Output Data:

The proposed model achieves its objectives by producing two main outputs: 1) LOB chart. 2) Crew duration distribution. The LOB chart indicates the variation in activities duration through project units as a result of learning curve effect. The crew duration distribution is shown in the form of a table. This table indicates the change in crew durations for each project unit.

The output data provide the scheduler with the following:

1. Number of crews and durations for each activity.
2. LOB chart to show the production rates of each activity and project total duration.
3. Activities duration table to show the reduction in duration as a result of learning effect.

Model Validation:

Model validation aims to check the model ability to calculate activities' duration. The proposed model is validated using the same case study discussed in *Ammar (2013)*. The case study consists of a project with 10 identical repetitive units. The target project duration is 70 days and a minimum buffer time of one day is to be maintained between activities. Work breakdown for the first unit and the activities' estimated duration are shown in Table 1. The total project duration was 74 days if the learning effect is ignored. Data are entered to the model with an assumption that K for all activities are equal 90%. As calculated by the proposed model, activities' duration are shown in Fig. 4.

Table 1. Case Study

Activity	Duration	Predecessors	Relation
A	4	---	---
B	6	---	---
C	2	---	---
D	8	A	FS
E	10	B	FS
F	16	B	FS
G	6	C	FS
H	4	D	FS
I	8	E	FS
J	10	F,G	FS
K	6	H,I	FS

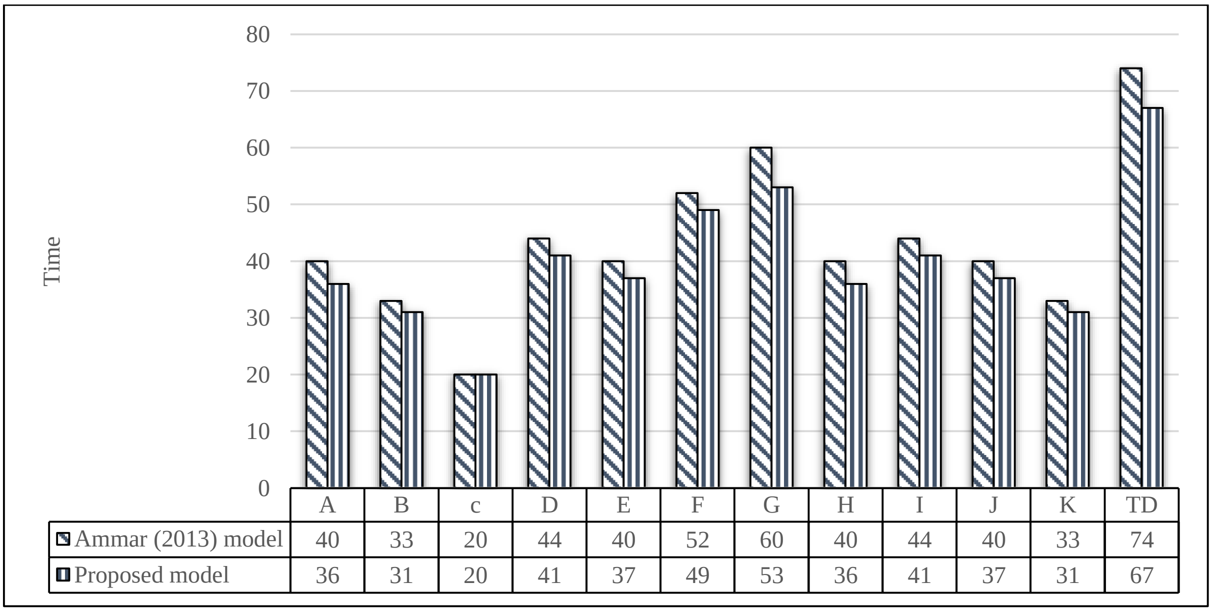

Fig. 4. Result Comparison to Ammar (2013) Case Study

Using the proposed model, total project duration is reduced to 67 days compared to 74 days for Ammar (2013) model. The proposed model saves 7 days. Additional benefits is introduced by the proposed model which is a reduction in the duration of non-critical activities. For the presented case study this reduction equals 34 days. The reduction in the duration of non-critical activities increases the total float of these activities which can be used in case of resources limitation.

Changes in activity duration is shown in Table 2. For example, activity A, 60% of units can be completed in 4 days while this duration is decreased to 3 days in the last 40% of units. The change in duration is a result of learning curve effect.

Table 2. Activities Duration Distribution Through Units

Activity	**Unit #1**	**Unit #2**	**Unit #3**	**Unit #4**	**Unit #5**	**Unit #6**	**Unit #7**	**Unit #8**	**Unit #9**	**Unit #10**
A	4	4	4	4	4	4	3	3	3	3
B	6	6	6	6	6	6	5	5	5	5
C	2	2	2	2	2	2	2	2	2	2
D	8	8	8	8	7	7	7	7	7	7
E	10	10	10	9	9	9	9	9	9	9
F	16	16	16	16	15	15	15	15	14	14
G	6	6	6	5	5	5	5	5	5	5
H	4	4	4	4	4	4	3	3	3	3
I	8	8	8	8	7	7	7	7	7	7
J	10	10	10	9	9	9	9	9	9	9
K	6	6	6	6	6	6	5	5	5	5

Conclusion:

Repetitive construction projects are those include identical units such as highways, tunnels, and bridges. Resource-based planning techniques, such as Line of Balance (LOB), have been used to schedule repetitive projects to ensure work continuity. Many studies attempted to combine benefits of both the Critical Path Method (CPM) and the LOB method.

Reviewing the literature of LOB scheduling models, it has been found that none of the mentioned research work has taken into consideration the effect of learning. This study presented a model for scheduling repetitive projects. The proposed model incorporates the learning effect with LOB scheduling technique. The proposed model was validated using a case study previously discussed in Ammar (2013). The developed model gives the planner the availability of using learning effect in repetitive projects.

The learning curve effect has a great impact on activities' durations. The total activities' durations are reduced under the effect of learning. This reduction can reduce the project total duration. The studying of this reduction gives the scheduler the advantage of real estimate for project duration. The non-critical activities' reduction increases total float of these activities. This total float can be used in case of resource limitations.

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