Line Balancing for Work Scheduling on a Construction Project

Naoto Mine  
Department of Construction Management, Universiti Tunku Abdul Rahman, Kampar, Malaysia, naoto@utar.edu.my

Shinji Matsumoto  
(Retired) Shimizu Corporation Co., Ltd., Tokyo, Japan, shinji.matu@abeam.ocn.ne.jp

Yoshitsugu Uchiyama  
Technology Planning Office, Shimizu Corporation, Co., Ltd., Tokyo, Japan, yoshi@shimz.co.jp

Abstract
The Japanese construction industry has witnessed rapid development of many construction methods and equipment in building construction in recent years. However, the efficient application of such methods has been found wanting. From the standpoint that building construction embodies numerous types of activity that require deliberate management, therefore, a comprehensive organizational and management technique is crucial and instrumental to site productivity. The aim of the present study is to establish a work scheduling and management tool for optimum construction and practical use. The authors were involved in a number of actual construction projects for the purpose of this study and demonstrated the application of MAC (Multi-Activity Chart) as a tool for work scheduling and management. The fundamental concept of this management tool is to organize several work teams with fixed members and to repeat the same work cycle constantly and to eliminate or reduce idle time. The necessity and significance of MAC as an on-site management tool is demonstrated in relation to the learning curve effect on a building construction project. A discussion of the outcome of the application of MAC on the project was undertaken.

Keywords
Line balancing, Building construction project, Multi-Activity Chart, Learning curve effect

1. Introduction
Building construction involves various types of activity carried out by workers and machinery. A recurring problem in construction planning is combining activity assignments and labour so that the activities can be undertaken in an optimum manner. To date, a best method that can be deployed to manage such recurring problem is still elusive and yet to be firmly established. In building construction, numerous construction methods are available together with various activity and labour combinations. After the construction method is selected, it is essential to organize work teams and construction machinery to carry out the site activities. Authors call this stage as work scheduling. The study proposes a work scheduling method for optimum construction and it shall be demonstrated and applied on an actual building construction project. Systemizing the production of construction work is central in this method which means organizing several work teams with fixed members and repeating the same work cycle with
minimum or without idle time at all. In manufacturing systems this type of production is called “line balancing”. As a result of repetition, learning curve effect and management of work efficiency can be expected. Specifically in the study, Multi-activity Chart (MAC) is proposed and shall be demonstrated to be particularly effective in systematizing the production of construction work on a project.

2. Construction system planning

Construction system planning is a basic and challenging aspect of construction project management. It is essential to the execution of all construction work activities on a project site. It concerns choice of construction methods which will involve deployment of plant and equipment, site work activities and their durations, human resources required and interrelationships amongst activities. A construction plan provides the basis for work scheduling. Traditionally work scheduling focuses on time control and management. A basic objective of planning is to optimize the execution of construction work activities on a project site. The given conditions or constraints on a project site are seldom consistent and may vary with time. Hence a construction plan may need a review in the light of varying conditions or constraints.

Figure 1 depicts the procedure for construction system planning. Selection of a construction method is rather qualitative whilst work scheduling is quantitative. Work scheduling cannot commence before construction method is selected and the construction method cannot be evaluated without work scheduling.

![Figure 1: Procedure of construction system planning](image_url)

3. Work scheduling with MAC

Work scheduling begins when an outline of construction method is set up through construction method selection. The output of construction method selection generally shows some alternatives. At this stage, the alternative construction methods are subject to quantitative evaluation prior to narrowing down to the most suitable. Specifically work scheduling attempts to apply the selected construction method through the following: (i) dividing the construction area into separate blocks, (ii) determination of cycle time, (iii) organizing work teams, (iv) planning work procedure and work program of each team, and (v) planning construction equipment diversion. The procedure of work scheduling with MAC is shown in Figure 2.

MAC applies work scheduling in which several work teams repeat their work cycles in separate blocks simultaneously. It is a timetable which indicates each work team’s schedule, and who, when, where, and what to do. It is drawn through the detailed analysis of work consisting of one repetitive cycle. It also effectively simulates work conditions on the desk. There are two presuppositions for MAC; (i) work teams with fixed members and construction machinery work constantly every day, (ii) the characteristics of adopted construction method, work procedure and work efficiency data are clarified (the prefabricated methods fit MAC easily).
An example of MAC is shown in Figure 3. This six day-cycle MAC with six work teams was applied to superstructure work. The vertical axis shows time (day) and horizontal axis shows each work team. The numbers on the horizontal axis indicate the specific block where each team works. As this MAC is a model in use, each work team and crane has little idle time. In the planning process, idle time or work overlaps occur in many places on a MAC. A review is necessary by changing the work procedures and work programs, and combining some teams temporarily.

The MAC shown in the figure was related to a hotel construction project on Saipan Island. The construction method was systematized as much as possible under given conditions. An outline of construction method is shown in Table 1 and pictorially depicted in Figure 4. A guest room floor (1st floor to 6th floor) was divided into four blocks and constructed on a six day-cycle.

4. Consideration of learning curve effect on work scheduling method

Work scheduling with MAC is achieved on the assumption that constant crew size (number of workers) and temporary equipment are used every day. Generally under such conditions, work efficiency increases and furthermore there is better quality and safety control. However, in the construction industry, work scheduling is rarely carried out in this way. One reason why the idea to fix members and standardizing

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**Figure 2: Procedure of work scheduling**

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**Figure 3: An example of MAC (a hotel construction project in Saipan Island)**
crew has not been introduced is because there is no quantitative information on the advantages of this procedure. The intention hereafter is to discuss the effect of work efficiency produced by work repetition on work scheduling.

![Figure 4: The outline of the construction method](image)

### 4.1 Learning curve effect

When the same work is repeated, work efficiency increases through familiarization. This phenomenon is called the “learning curve effect” or “learning effect”. From former studies on the learning curve effect, it is obvious that most of the work can approximate the log linear model. Thus, the relation between numbers of repetition and cumulative average time is represented as equation (1).

$$A_c = t_1 \cdot x^n$$

where,

- $A_c$: cumulative average time,
- $t_1$: time of first repetition,
- $x$: numbers of repetition,
- $n$: coefficient of learning

From equation (1), total time ($T_c$) for certain numbers repetition ($x$) is calculated as follows:

$$T_c = x \cdot A_c = t_1 \cdot x^n$$

(2)

The ratio of cumulative average time of the second repetition to the first repetition is called a “decreasing constant”, which is calculated by equation (3).

$$P = (1/2)^n \times 100$$

where,

- $P$: decreasing constant (%)

From the results of field studies, decreasing constants of construction work are 75-95 %. In this paper, an 85% decreasing constant (coefficient of learning: $n = 0.234$) is supposed.
4.2 Learning curve effect in crew work

In a construction project, it is very rare to arrange fixed workers for long period of time. In most cases, although part of the crew members may be fixed, the other part exchanges with assignments. In this case, the learning curve effect of the crew decreases, because exchanged workers are not familiar with the work. This decreases productivity of whole project. The relation between the exchange crew size ratio against the original crew size and increasing ratio of total time (ratio between total time when workers are exchanged or not exchanged) is shown in Figure 5. It is apparent that total time increases as the exchanged ratio increases. And as numbers or repetition increases, total time lengthens.

4.3 Standardize crew size

Generally, on a construction project, it is rare to standardize crew size as the work process is congested and various workers alternate. The advantage of the work scheduling method is described using a work model. Two kinds of models are shown in Figure 6. The quantity of work is equal in both models and three kinds of workers, A, B, C, perform their own work. Model-2 shows an example of standardizing crew size, and the other model shows non-standardization. Work repetition in Model-2 is three times that of Model-1. From equation (2), total time of Model-1 \( T_{c1} \) and Model-2 \( T_{c2} \) are represented as:

\[
T_{c1} = t_1 \cdot x_1^{-n}
\]

\[
T_{c2} = \left( t_1 / 3 \right) \cdot 3x_1^{-n}
\]

Thus,

\[
T_{c2} = T_{c1} \cdot 3^{-n}
\]

Generally, when the number of repetition is \( k \) times, total time is represented as follows:

\[
T_{c2} = T_{c1} \cdot k^{-n}
\]

As the above equation is in the same form as equation (1), the reduction ratio can be obtained from Figure 6. When decreasing constant is 85%, total time ratio of Model-1 against Model-2 becomes 0.77 (reduction rate is 23%). In work scheduling, it is more advantageous to increase the number of repetitions by a small
5. Application to a building construction project: an example

5.1 Outline and policy for construction of the project

The outline of the project is shown in Table 2.

The special features of the construction of the project are: (1) to obtain high quality and efficiency by introducing various industrial methods, (2) to increase productivity and rapid progress with work repetition. From the analysis of the features, it is concluded that in order to achieve maximum productivity, the following fundamental policies are to be considered: (a) to adopt simple work methods to suit unskilled foreign workers, (b) to organize the workers into teams for repetitive work to achieve maximum efficiency and work familiarization, and (c) to further improve productivity through efficient use of all resources with due regard to quality.

Table 2: Outline of the project

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of building</td>
<td>Shopping/office complex</td>
</tr>
<tr>
<td>Location</td>
<td>Singapore</td>
</tr>
<tr>
<td>Structure</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td>Number of floors</td>
<td>15 stories</td>
</tr>
<tr>
<td>Total floor area</td>
<td>52,440 m²</td>
</tr>
<tr>
<td>Client</td>
<td>Urban Redevelopment Authority, Singapore</td>
</tr>
<tr>
<td>Design &amp; Construction</td>
<td>Shimizu Corporation</td>
</tr>
</tbody>
</table>

5.2 Construction planning

To reduce construction time and increase work productivity, simplified and prefabricated construction methods are adopted as described as follows: (i) MICCO Slab system (Progressive Strength Method), (ii) Monolithic slab finish, (iii) Precast concrete wall panels, (iv) Pre-assembled reinforcement method, (v) Flying shore method (Unit form of slab), and (vi) Large panel form system. Figure 7 pictorially depicts the outline of the construction method. Figure 8 shows the MAC for the project.

![Figure 7: Outline of the construction method](image-url)
As depicted in Figure 10, all structural works such as reinforcement, concrete and formwork indicated a decrease on ratio of man-hours constantly. Among the three decreases, the tendency is particularly

Figure 8: MAC for the project

Figure 9(1) – (2) show the photos of the project which depict that different construction works progress simultaneously in each area systematically. Figure 10 shows the change of the cumulative average man-hour from 6th floor to 12th floor. The reason of eliminating from 1st floor to 5th floor is that these floors are not typical floors.

Addition to these systematized construction method, during construction dairy work productivity was analysed after collecting and processing actual work results. The analysed productivity data was used to improve work and control cost. The video recording system which is widely applied in assembly-line production was employed on this project to facilitate the control of daily work and to achieve further improvement.

Figure 9 (1): Construction view (2-3 floor)  Figure 9 (2): Construction view (8-9 floor)

5.3 Results of the construction

As depicted in Figure 10, all structural works such as reinforcement, concrete and formwork indicated a decrease on ratio of man-hours constantly. Among the three decreases, the tendency is particularly
evident on formwork and concrete work. The decreasing constants are 90% for formwork, 94% for concrete work, and 96% for reinforcement work respectively. The project was successfully completed using combination of industrialized construction methods and systematized work scheduling method with line balancing.

![Cumulative mean of man-hours ratio](image)

**Figure 10:** Change of cumulative average man-hours for structural works

6. Concluding Remarks

An outline of MAC as a work scheduling method and its application has been discoursed. In a construction system planning, there are two stages which consist of (1) construction method selection and (2) work scheduling. In the former stage, suitable alternative construction methods are selected for application on a project and subject to evaluation from the viewpoint of work efficiency. In the latter stage, work scheduling with MAC is applied which enables optimising work procedures and work crew size. In this stage, the following activities are carried out: (i) dividing the construction area on a project, (ii) determining the cycle time, (iii) organizing work crew, (iv) planning work procedure, and (v) planning of construction equipment. Through the work scheduling construction efficiency is evaluated quantitatively. An example of work scheduling was explained. From the analysis of the man-hours data, it is confirmed that the decreasing cumulative man-hours for each floor was the outcome of the influence of the learning curve effect.

7. References


