Integration of offsite and onsite schedules in modular construction

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Abstract

Modular construction enables delivery of a building as an assembly of a set of modules manufactured offsite in a controlled manufacturing facility environment. Unlike stick-built practices, modular construction enables higher schedule control of construction projects due the inherent concurrency of offsite and onsite construction operations. Literature provides simulation-based scheduling methods that integrate offsite and onsite construction activities. These methods, however, depend largely on availability of data such as productivity rates for offsite and onsite activities. This paper presents an alternative BIM-based framework that integrates linear schedules of onsite and offsite construction operations in a manner that synchronizes work progress of these operations. The proposed framework considers limited capacities of storage areas in the manufacturing facility and on site as well as, the availability of trucks for delivering the fabricated modules from manufacturing facility to the jobsite. The use of BIM provides visualization capabilities for the integrated schedule and allows for monitoring simultaneously the work progress of offsite and onsite activities. Conclusions are drawn concerning the suitability of developed framework for integrated scheduling of modular construction projects.

Keywords

BIM, Integration, Scheduling, Modular Construction.

1 Introduction

A recent survey of 800 engineers, architects, and contracting professionals reveals modular construction advantages including shorter project schedules (66% of respondents); lower cost (65% of respondents); and reduced construction waste (77% of respondents) [1]. Independent KPMG research found that financial net savings for offsite construction projects are 7% due to shortened construction period without considering the savings generated from decreasing the interest of borrowing [2]. These savings enable faster rental income and lower escalation in construction costs. The combination of offsite and onsite construction in a "50-storey office building" project in central London generated combined savings of £ 36 million [2].

Offsite construction provides other benefits such as; enhanced predictability of time and cost, reduced noise from construction, and improved health and safety. According to size and complexity of manufactured components, offsite construction types are grouped into five categories; 1) modular, 2) hybrid, 3) panelized, 4) prefabricated components, 5) processed material [3]. Modular construction reduces considerably the schedule of construction projects which may generate significant cost savings.

2 Literature review

Parallel scheduling for offsite and onsite construction schedules saves 30 to 50 percent of project duration as compared to stick-built traditional construction processes as shown in Figure 1 [1].
Simulation-based models are reliable tools for probabilistic problems while considering the effect of uncertainties associated with construction projects [4] and [5]. Although, simulation cannot eliminate or control idle times by itself [5] and [6] therefore, simulation-based models require external algorithms to solve the problem of repetitive scheduling effectively [4] and [5] otherwise; simulation models generate same results of CPM as shown in Figure 2 [7] and [8].
Linear scheduling considers the repetitive nature of activities; however, limited number of linear scheduling

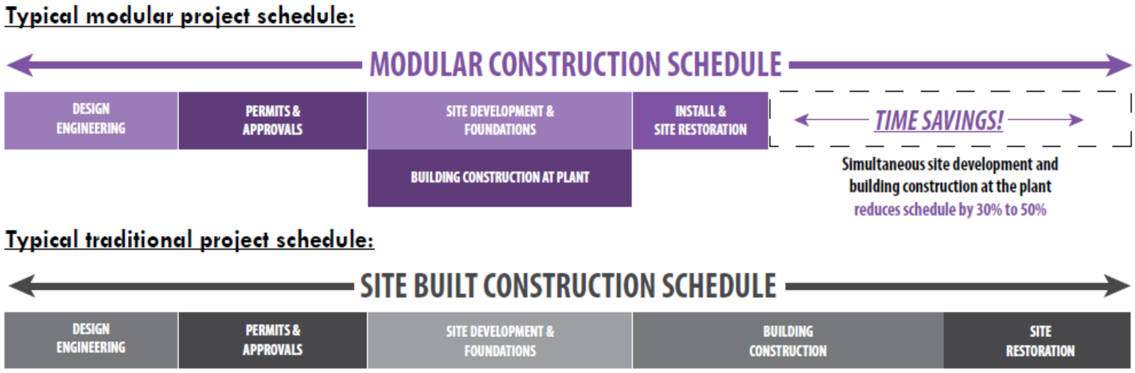

Figure 1. Comparison between modular and traditional construction schedules [1].

based methods account for uncertainty [9]. In the other hand, presentation of LSM was criticized to inability to show task relationships and parallel activities graphically [10] as well as to inability to differentiate between overlapping activities that have equal production rates [11]. Manusr [12] presented an approach that allocates critical activities on the upper side of the line of balance (LOB) chart, and non-critical ones on the lower part for a better presentation. Hegazy et al. [13] extended this approach by introducing BAL system that enhances LSM presentation and eliminates overlapping of activities as shown in Figure 3.

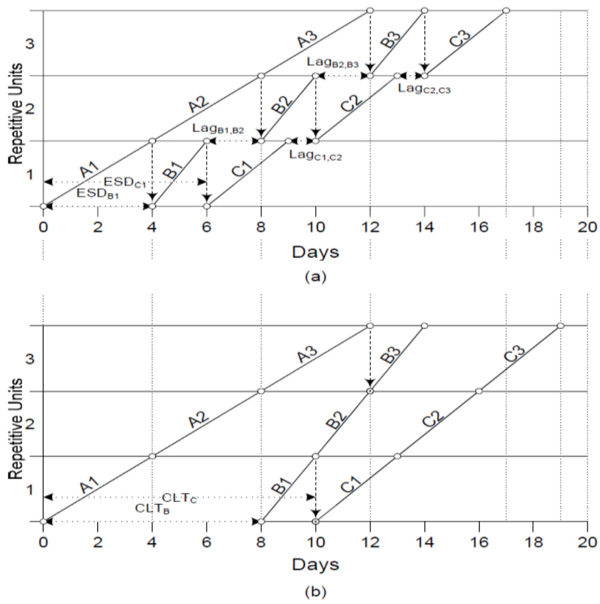

Figure 2. CPM vs. RSM Scheduling (a, b) [7].

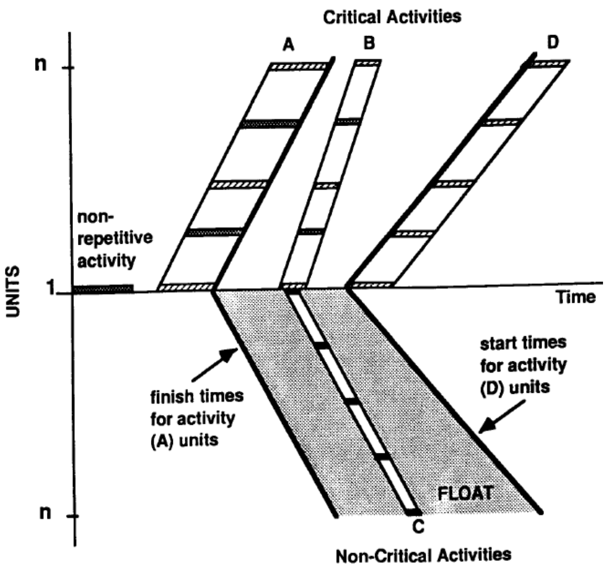

Figure 3. Enhanced Schedule Presentation [13].

Several studies utilized simulation to schedule offsite construction processes [14], [15], [16], [17], and [18]. Other researchers [19], [20], and [21] integrated simulation with building information modeling (BIM) to automate quantity take-off data and to visualize modular and offsite construction activities. Taghaddos et al. [22] presented a simulation-based scheduling model for module assembly yard without linking this model to fabrication shop schedule. Linking simulation model of module yard (onsite) to that of fabrication shop (offsite) is a main challenge for simulation models since it requires manual interventions from project scheduler [22]. Other researchers utilize advanced technologies such as; HLA environment [23] presented a simulation-based model that integrates module assembly yard and fabrication shop schedules in high level architecture (HLA) environment. However, this integration was not supported by a case example to demonstrate its effectiveness. Bu Hamdan et al. [24] presented a system that integrates simulation with BIM to provide an inventory planning and management tool while considering interactions between different construction phases from manufacturing to assembly. However, this system has a non-user-friendly graphic user interface (GUI) which requires manual interventions to define probabilistic distribution functions and requires users who are experts in simulation. Salama et al. [25] suggested an alternative (BIM) based integrated alternative (BIM) based integrated framework for planning and scheduling of hybrid modular construction projects using LSM and CCPM. This framework considers off-site construction only. However, there is a lack of scheduling methodologies that synchronize offsite and onsite operations. Unlike previously mentioned simulation methods that integrate offsite and onsite schedules, the proposed method respects the continuity of resources for activities and visualizes the integrated schedule.

3 Proposed Method

The main benefit of modular construction is shortening the project schedule due to parallel offsite and onsite activities. However, most of scheduling methods introduced in literature to integrate offsite and onsite construction are simulation-based methods. This paper presents a scheduling framework that integrates, visualizes, and synchronizes the linear schedules of offsite and onsite activities in modular construction projects. The proposed method consists of five steps as follows:

3.1 Generating offsite and onsite schedules baseline (aggressive schedule)

In this phase linear schedules that integrate LSM and the CCPM [26] are generated. This includes calculation of aggressive and safe activity durations, sequencing activities, maintaining continuity of schedule, resolving resources conflicts, identification of critical sequence, and adding feeding and project buffers. Also, baseline of offsite and onsite schedules using the flowcharts presented in Figure 4 and 5 respectively.

3.2 Identification of the critical control point (CCP) between offsite and onsite schedules

Identification of the critical control point (CCP) between offsite and onsite schedules is crucial because it connects both schedules and highlights the effects of offsite schedule delays on onsite schedule. CCP is logically constrained by completion of the manufacturing processes and transportation method of modules/panels from offsite manufacturing facility to construction site. Two scenarios affect the position of CCP in respect to transportation as follows:

1- Partial transportation in which manufactured modules/panels are transported by pre-scheduled batches. In this case, CCP is the start date of installation activity for last batch after transportation (i.e. Lifting panels) using Equation (1) as shown in Figure 6.

$$SD_{\mathrm{OLB\,(AG)}} = FD_{\mathrm{OLB\,(AG)}} + D_{\mathrm{LBT}} \qquad (1)$$

Where,

$SD_{OLB\ (AG)}$: Start date of panels' first onsite activity for last batch after transportation at aggressive schedule.
$FD_{OLB\ (AG)}$: Finish date of last offsite manufacturing process for last panel at aggressive schedule.

D_{LBT}: Duration for last batch transportation from offsite manufacturing facility to construction site

2- Full transportation in which the modules/ panels are delivered to construction site after completion of all manufacturing processes. In this case, CCP is the start date of first onsite activity for first panel (SDOFP) (i.e. Lifting panels) using Equation (2) and as shown in Figure 7.

$$SD_{\mathrm{OFP(AG)}} = FD_{\mathrm{OLB\,(AG)}} + D_{\mathrm{LBT}} \qquad (2)$$

Where,
$SD_{OFP\ (AG)}$: Start date of panels' first onsite activity for first panel after transportation at aggressive schedule.
$FD_{OLB\ (AG)}$: Finish date of last offsite manufacturing process for last panel at aggressive schedule.
D_{LBT}: Duration for last batch transportation from offsite manufacturing facility to construction site.

The output of this step is an integrated schedule baseline that is generated using relative scheduling of onsite and offsite activities in respect to the identified CCP in a manner that maintains the continuity of resources in all processes as shown in Figures 6 and 7.

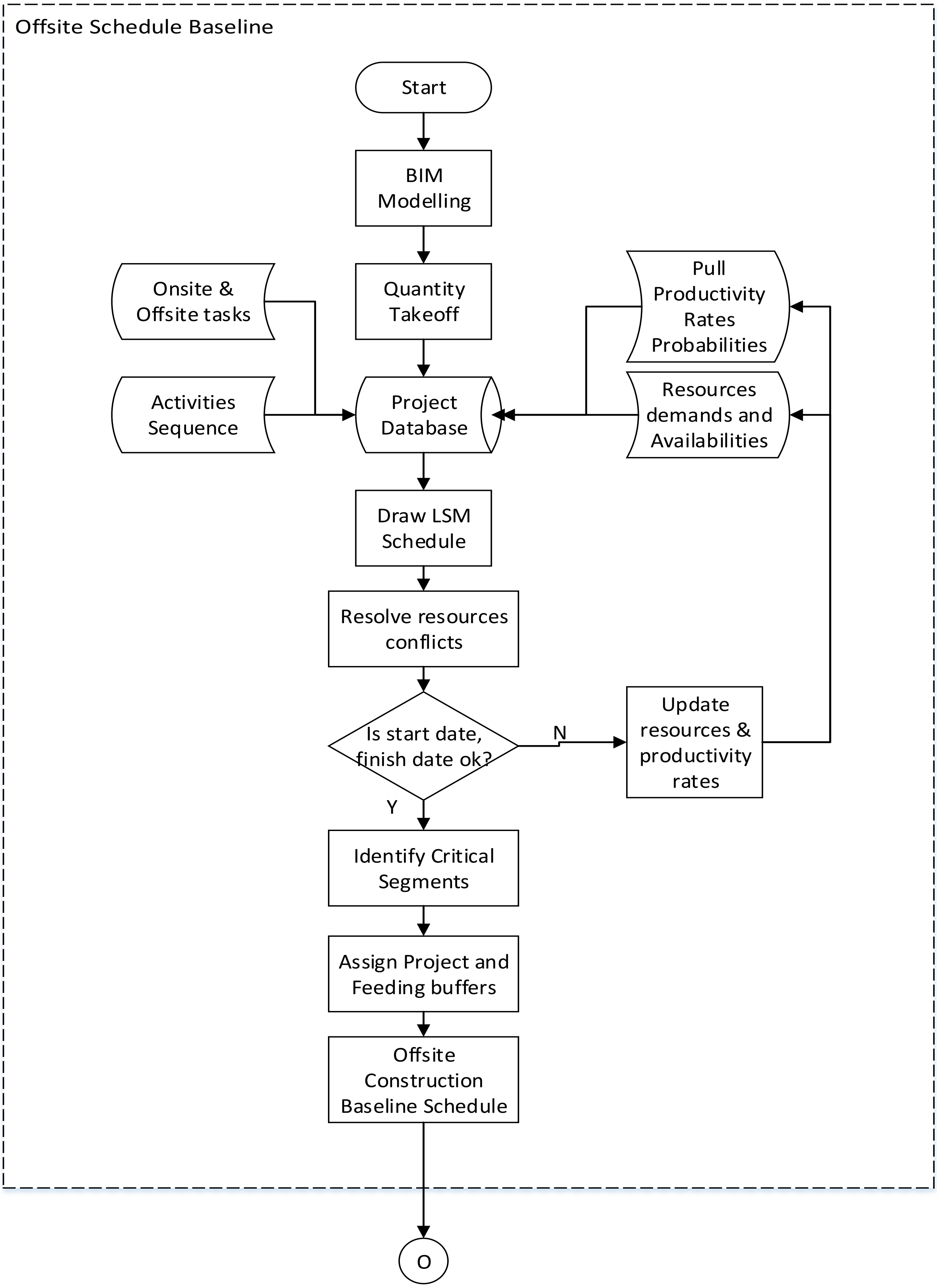

Figure 4. Generating Offsite Schedule Baseline.

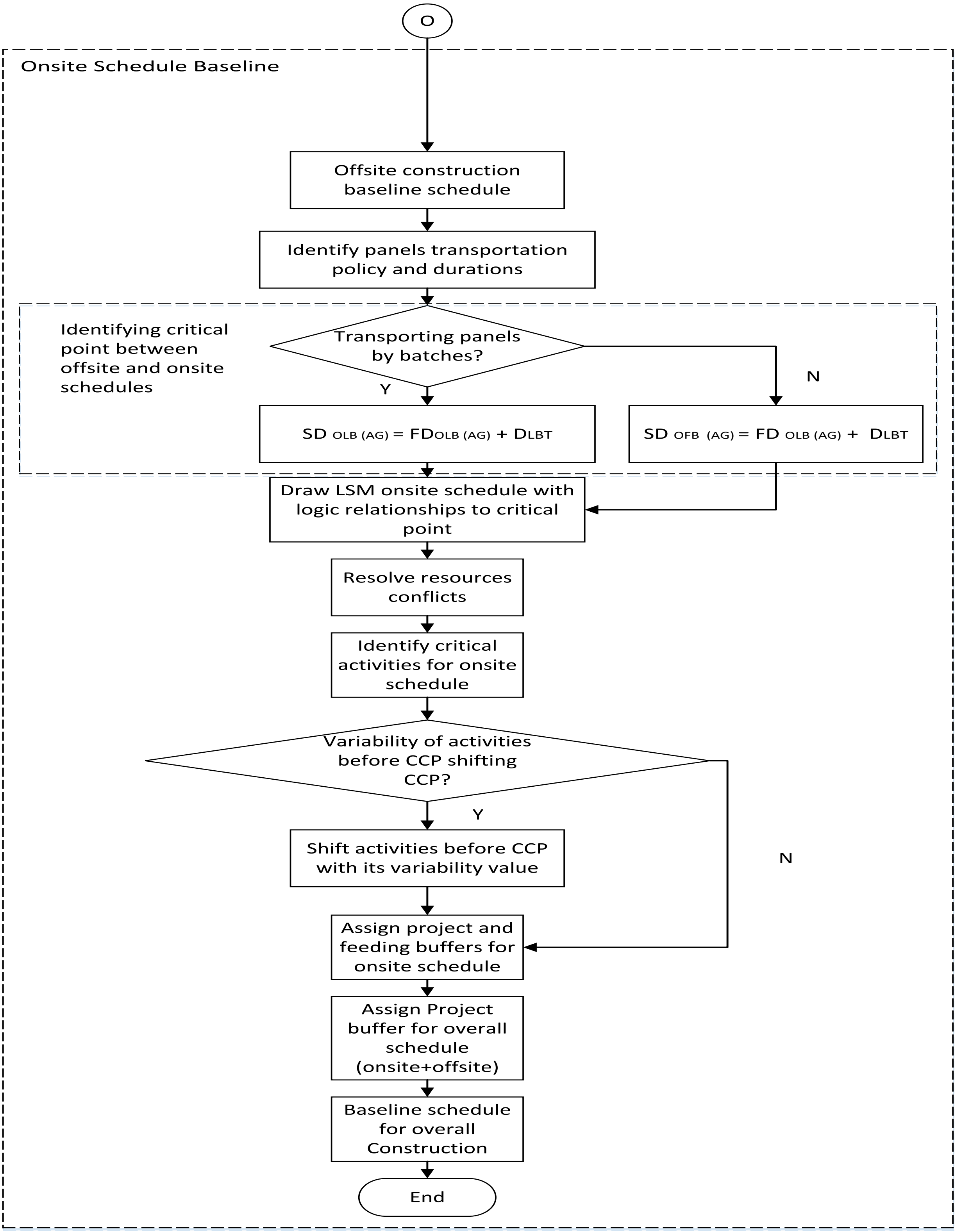

Figure 5. Generating Onsite Schedule Baseline.

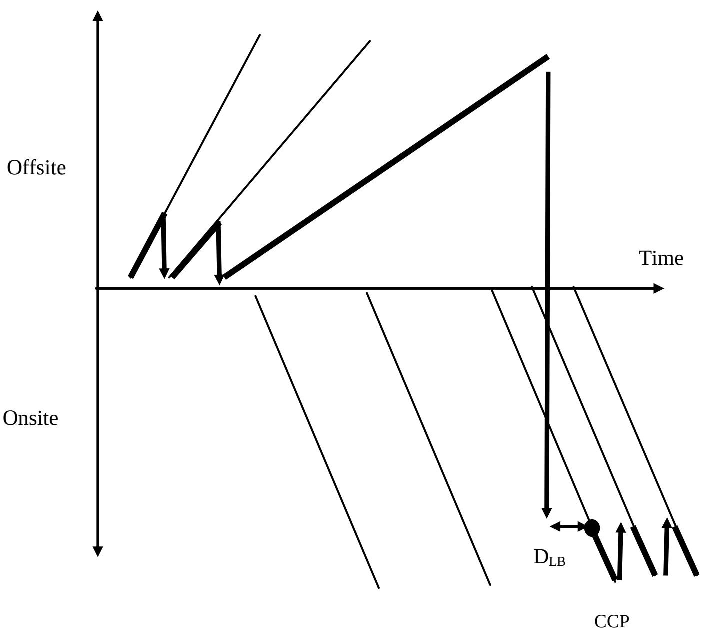

Figure 6. Identifying CCP for the scenario of transporting panels by batches.

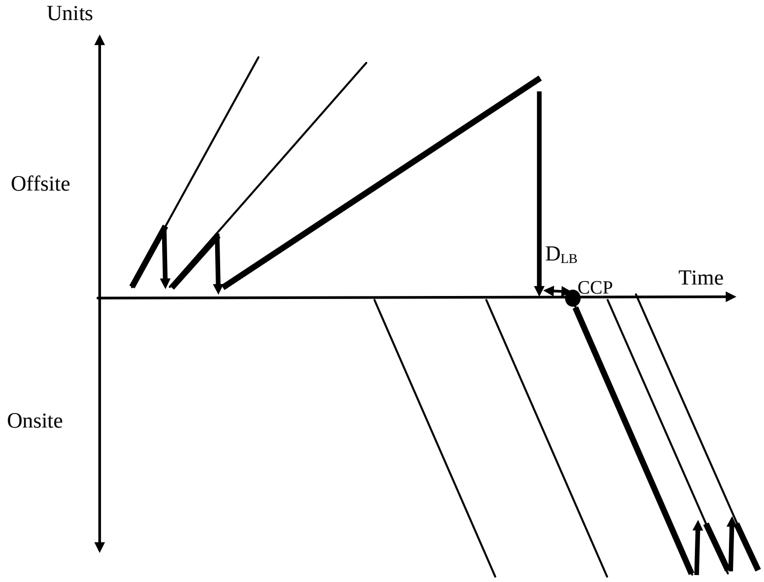

Figure 7. Identifying CCP for the scenario of transporting panels after all batches are manufactured.

3.3 Adding feeding and project buffers

Project and feeding buffers for offsite and onsite schedules are calculated using Equations (3) and (4) respectively. However, the integrated schedule (offsite and onsite) has another overall project buffer based on the variability of onsite and offsite schedules. Both schedules are connected at the CCP to create an overall project critical sequence. Figure 8 shows an example of linear schedule where, feeding buffers are generated from the variability of "resource-critical activities" number D1 to D3 and F1 to F5 [26]. The delay of resource-critical activities delays part of the critical controlling sequence and accordingly the project completion date.

$$\text{Project buffer}=\sqrt{\sum_{P=1}^{P=n}(D_P(CL)-D_P(AG))^2} \tag{3}$$

$$\text{Feeding buffer}=\sqrt{\sum_{F=1}^{F=n}(D_F(CL)-D_F(AG))^2} \tag{4}$$

Where,

DP (CL): safe duration of critical activity with given confidence level "CL".DP (AG): aggressive duration of critical activity with 50% confidence level.

DF (CL): safe duration of resource critical activity with given confidence level "CL".

DF (AG): aggressive duration of resource critical activity with 50% confidence level.

3.4 Shifting processes before CCP

The processes before CCP at onsite schedule are shifted with the amount of its critical sequence variability as shown in Figure 9. The variability of its critical sequence is accumulated in a special buffer named onsite activities buffer (OAB) using Equation 5. This procedure protects the overall project critical sequence from delay by allowing onsite processes before CCP to start early.

$$\text{OAB}=\sqrt{\sum_{O=1}^{O=n}(D_O(CL)-D_O(AG))^2} \tag{5}$$

Where,

DO (CL): safe duration of onsite activity with given confidence level "CL".

DO (AG): aggressive duration of onsite activity with 50% confidence level.

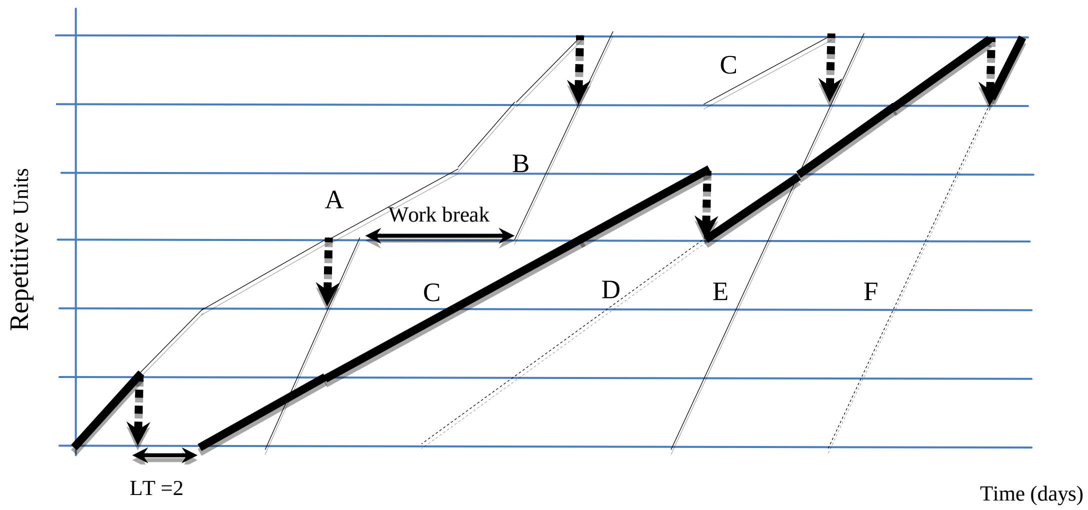

Figure 8: Identification of resource-critical activities [26].

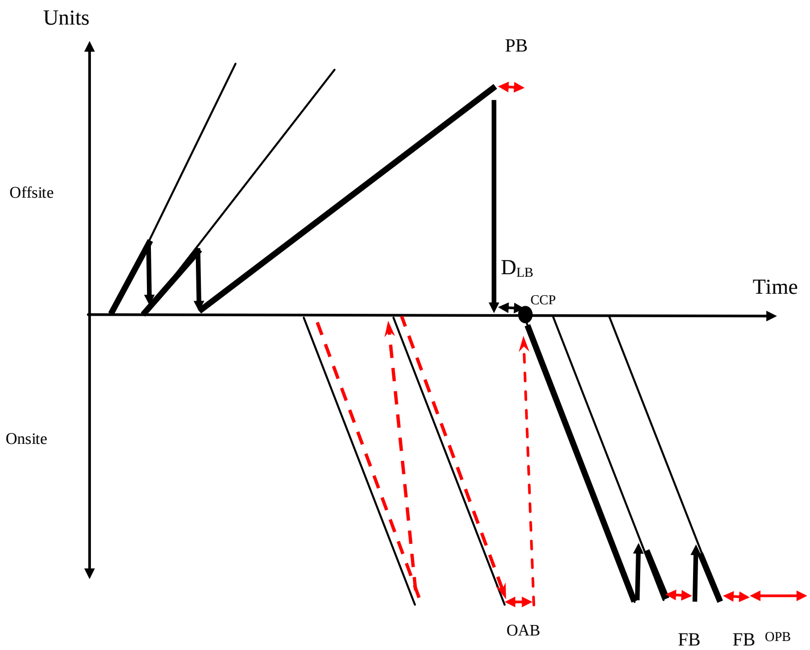

Figure 9. Adding feeding and project buffers.

4. Conclusion

This paper presented a novel method for integrating the linear schedules of offsite and onsite modular construction, supported by a graphical representation that depicts the interactions between offsite and on site schedules. The developed method introduces new systematic procedure for identifying the critical control point (CCP) that inter-connects offsite and onsite linear schedules. The integration framework between LSM of offsite and onsite construction activities mimics the repetitive nature of manufacturing processes and onsite activities while considering uncertainties associated with productivity rates. Automating the presented method provides an easy to use planning and scheduling tool for synchronizing offsite and onsite schedules without using simulation. The overall integrated schedule is expected to assist project manager in planning onsite construction activities while considering the manufacturing plan of offsite activities and vice versa. Example application is described to highlight the essential features of the developed method.

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