Role of Time Buffer in Project Monitoring and Forecasting of Steel Structures – A New Approach to Structural Planning

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Role of Time Buffer on Project Monitoring and Forecasting of Steel Structures – A New Approach to Structural Planning

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Abstract: Project monitoring and forecasting are the key to structural planning. The methods of project monitoring and forecasting practiced in the construction of steel structures include cash inflow-outflow, earned value etc. These methods measure the work completed in terms of tonnage, square meter etc. and hence they do not differentiate between work done on the critical path and work done on non-critical paths. Critical path defines the lead time of a project and the activities on the critical path can be called as bottlenecks. Project managers should focus on these bottlenecks to avoid delays and subsequent losses. The purpose of this study is to develop a project monitoring and forecasting method that enables project managers to focus on the bottlenecks and take decisions accordingly. During planning of durations, construction personnel add time buffer to compensate for the uncertainties and to protect against schedule deviations. In this paper the duration thus added as buffer is quantified by considering the factors that construction personnel consider while allocating time buffer. This becomes the Initial Project Buffer (IPB). If an activity is delayed, buffer is reduced and if it is ahead of schedule, buffer is added. Remaining Project Buffer (RPBN) is the time buffer available after duration N from the commencement of the project. The authors have developed a Project Buffer Index (PBI) incorporating IPB and RPBN. The two important parameters in forecasting namely Duration Required for Completion (DRC) and Cost at Completion (CAC) are also arrived at. The proposed method is then applied to the construction of a pipe-rack structure and validated.

Keywords: *Construction, Time Buffer, Structural Planning, Project Monitoring, Project Forecasting*

1. Introduction

Construction of steel structures consists of structural fabrication and structural erection. Structural fabrication includes fabrication of beams, columns, purlines, chequered plates etc. The fabricated members are erected using crane or other lifting equipments based on the total weight of the members. Structural erection includes lifting of members, their alignment, welding and scrap cutting (Fig. 1).

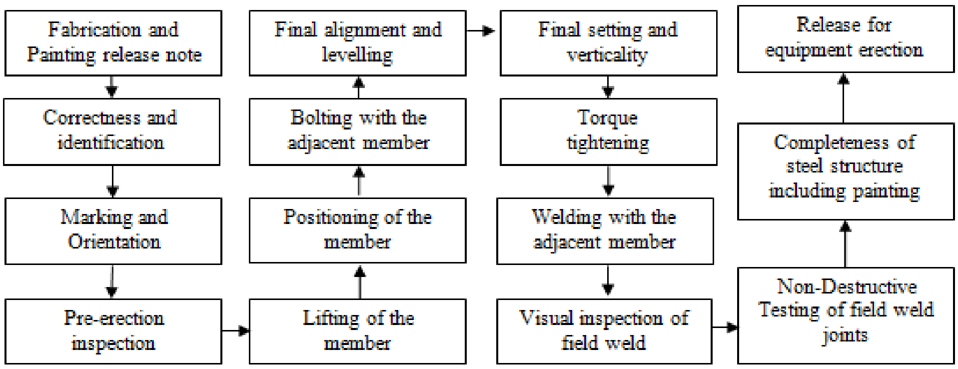

Fig 1: *Flow chart illustrating the erection process*

Structural fabrication is followed by structural erection. Components such as motors, gear boxes, wagon tipplers, hydraulic pumps etc. are installed thereafter. These are important components of a Material Handling System (MHS). Construction of MHS includes construction of conveyors, transfer towers, silos etc.

The sequence of structural fabrication is based on the priority given by the erection personnel. Also, erection does not wait for the entire fabrication to get over. After the structure attains enough strength, the components are installed. Due to this inherent complexity in the sequencing of the process, the construction personnel often lose focus and eventually end up in delays or quality issues. The focus should be on the bottleneck. It is often seen that the construction personnel is unaware of the bottleneck. Bottlenecks are activities on the critical path. Critical path is the sequence of activities that dictate the lead time of the project. Measurements should direct managers to the point that needs their attention, the bottlenecks [1]. The existing methods of project monitoring and forecasting like Earned Value Method, Earned Duration Method, Earned Schedule Method, Cash inflow-outflow etc. do not allow the construction personnel to keep their focus on the bottlenecks. They use tonnage as the scale of measurement. Earned Value is the monetary value of the work done. The Earned Value parameters like Schedule Performance Index, Cost Performance Index, Schedule Variance and Cost Variance are in time units and often become a source of misinterpretation. In the Earned Schedule method, Earned Schedule is obtained by identifying the time increment of Planned Value in which the Earned Value occurs thus giving the output in time units [2].

Earned Duration in Earned Duration Management is the work performed expressed as the proportion of the approved duration assigned to that work of an activity [3]. But these methods of Earned Value Management ignore the difference between critical and non-critical activities in the whole project [4].

In this paper a new method of project monitoring and forecasting incorporating the concept of time buffer is introduced which enables project managers to keep focus on bottle necks and take decisions accordingly.

The objectives of the study are

1) To identify the factors of time buffer of a material handling project that involves construction of steel structures.
2) To propose a project monitoring and forecasting method using time buffer.

2. Time Buffer

For the purpose of this study, time buffer is defined as the extra time added knowingly or unknowingly by construction personnel to the minimum possible duration of any activity in order to protect against schedule deviation. There are always three durations for any activity, these are pessimistic time, most likely time and optimistic time (Fig.2). Median is the duration in which there is 50% chance that the task will get over within or before that duration [1]. The difference between the median of the probability distribution and the estimated time is the safety given or in other words time buffer. Thus the estimated duration of the activity will be:

$$Estimated\ Duration = Duration\ of\ Median + Time\ Buffer \quad (1)$$

Uncertainty existing in every project is the underlying cause for most of the problems and in order to compensate for this uncertainty construction personnel add time buffer in their activity durations. This is not to be confused with floats in a project network. Float is added or being created during networking or interconnecting the activities, while time buffer is the extra time added by the construction personnel to individual task durations, during the duration allocation of the activities to compensate for uncertainties. Even though both float and time buffer serves the purpose of protecting the schedule from deviation, the first one is added in the networking stage while the latter is added during the estimation of the individual task duration.

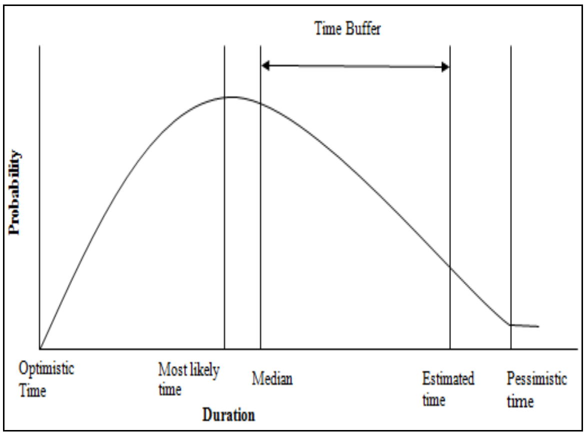

Fig 2: *Schematic diagram showing the three durations and time buffer*

3. Factors of Time Buffer

Construction personnel add time buffer to each and every activity by considering certain factors. For the purpose of this study, these factors of time buffer are classified into ten categories. Categories like project characteristics, pre-requisite work, labour force, job/worksite conditions, information flow and weather are considered from various literature [5][6][7] while factors corresponding to the categories like quality and safety characteristics, plant and machinery, raw materials and consumables and design characteristics are considered based on the nature of the construction work. Project characteristics include factors like contract delivery method, contract period, size of the project, interdependency of activities, degree of difficulty in the work and size of the company. The category pre-requisite work include factors like delays in obtaining permit, completion of the pre-requisite work, rework being required due to the quality of the pre-requisite work and delays in inspection for the previously completed work. Design constructability and design errors/ issues are included in the category design characteristics. Quality and safety characteristics have factors like strict specification requirements, strict safety consideration, degree of inspection and availability of the safety equipments. Reliability, availability and productivity of the trade's equipment are considered in the category plant and machinery (P&M). In the category labour force, the factors considered are reliability of the labour force, availability of the labour force and experience and skill of the crew. The category raw materials and consumables include factors like receiving incorrect quantity of raw materials and consumables, not getting raw materials and consumables in time and quality issues in the raw materials and consumables. The factors related to the category job/work site conditions include overcrowded job site conditions, accessibility of the work area and distance of material transfer required from the receiving area to the task location. Confidence in the Request for Information (RFI) process, liability pressure, negotiations, required co-ordination with other trades and change in the scope of the work are factors considered in the category information flow. Weather conditions like temperature, rain and wind associated with the location belong to the tenth category.

Engineering Procurement and Construction (EPC) with a lump sum payment mode, EPC with item rate, Concession Agreement (toll), Public Private Partnership etc. are some of the contract delivery methods. Contractual milestones are always considered in estimating the duration of the activities, thus contract period becomes an important factor of time buffer.

Size of the project becomes a factor of time buffer due to the quantum of resources involved. A project of value INR 300 crore involves fabrication and erection of approximately 15000 MT of steel structures. If this project has to be completed in say 450 days, then it will take 370 labourers to work day and night as per the productivity norms. Initially the project may not require that much manpower but during the peak period this value doubles and becomes 740. Dealing with such large numbers adds to the uncertainty and thus size of the project needs to be considered during estimation of durations.

Projects as a whole are highly interdependent. Erection depends on fabrication. Similarly, installation of components depends on structural erection. For the main contractor, the activities are highly dependent and are to be considered while allotting time buffers. But for a sub-contractor, who handles the activities not as a whole but instead as a part, like fabrication or erection interdependency is lesser.

In fabrication there exists a higher degree of repeatability. Moreover work is done on ground level, leveled surface or a bed. So safety related issues are less. Besides this, there are a lot of automated and semi-automated equipments like Submerged Arc Welding (SAW) machine, puck cutting machine etc, being used. The effect of climate will be less in case of fabrication. But erection involves working at heights. Hence the chance of accidents due to fall of men and material is high. Climatic conditions are to be considered during erection and related activities. Welding on a wet surface leads to electrocution. Besides that, erection does not enjoy the privilege of selection of work as per the availability of materials or equipments since in erection, activities are done stage-wise. All these make erection more difficult than fabrication and thus degree of difficulty of work becomes an important factor of time buffer. Size of the company is an important factor due to the fact that for a small subcontractor unforeseen events and variations due to these definitely have more effect when compared to a big contractor. So they consider all the uncertainties while allotting buffer to activities, leading to a lengthier schedule.

If the design is not constructible, then lifting becomes difficult and hence this factor has an impact on erection than on fabrication. Design errors and design issues always exist in a construction project. Drawings are often revised. If the design issues are minor, then the same can be solved within the site level. If the issues are major then it takes time to make corrections, due to interface and RFI delays.

Quality is all about meeting the specification requirements. Specifications are mentioned in the drawing in accordance to the Project Quality Plan (PQP) where allowed tolerances are specified. If the specification requirements are strict, then it comparatively takes more time for execution.

Availability of labour force means the availability of labour that has the skill required for the job. These labourers should be regular to site so that work goes on uninterrupted. This depends on the reliability of the labour force. The labour should have the skill and experience that the job requires. For example, the welding of a column or beam does not require a 6G welder. Suppose the team gets a job for pipeline welding and they lack the expertise to do the same since pipeline welding requires a 6G welder. It takes time to arrange such expertise. Instead, if the gang has a 6G welder already, they are able to do both normal structural and pipeline jobs. Similarly, the availability of equipments is also important. Availability, reliability and productivity are the three important factors that are always considered when it comes to issues regarding equipments. Erection involves more equipment compared to fabrication. Crane is the most important equipment used at site. A crane is selected on the basis of load that is to be lifted. It takes time for shifting of cranes, assembly and load testing.

Availability of raw materials in the right quantity and quality is important in case of construction work just as it is for manufacturing jobs. This depends on the type of raw materials and the local market. Some materials can’t be stored at site for a long time, for example paint. Those materials that are available in local market can be purchased as and when required. But identification of the suppliers who are capable of supplying the items in the required quantity is very important. In MHS jobs, the main raw material is steel. Steel is of different grades. The commonly used grade of steel is IS 2062 E250BR. This is purchased in bulk. So availability of the same may not be subject to uncertainty. Consumables commonly used are welding electrodes, LPG, Oxygen and Argon. E7018 is the most commonly used welding electrode. This is readily available in the local market. But when it comes to special purpose welding like in chutes and tanks, some special electrodes are required.

Overcrowded or cluttered work area is very critical for safety. In order to avoid safety issues due to overcrowding, logistics needs to be planned beforehand. This is a factor which usually planners do not consider while making their schedule, but may create an impact in the progress of the activity. Accessibility of cranes and trailers is an important factor. In fabrication, material shifting becomes very difficult if proper accessibility is not there. Distance of the material transfer required from the receiving area to the task location has a direct impact on task durations.

If in a construction project an external agency has been engaged for implementing a particular technology that the main contractor is not skilled at and if that leads to certain legal issues or issues related to health and safety or the environment, the liability to rectify the same shall lie with the main contractor (if not otherwise specified in the contract) and shall lead to delays. Thus, liability has a direct impact on task durations. A project involves negotiations at various stages, for example procuring materials, proposing value engineering practices, contractor's claims, change of scope etc. Thus considering time for negotiation leads to addition of buffers. Issues related to co-ordination are comparatively less when the same contractor deals with most of the activities. But when these are handled by different contractors, delays may develop due to lack of co-ordination and improper communication. So when construction personnel encounter activities that are outsourced they tend to add more buffer. Changes in scope of work as the project advances are seen more in projects that deal with entirely new technologies.

4. Project Monitoring using Time Buffer

In this section a project monitoring model using time buffer is developed (Fig. 3). The Initial Project Buffer (IPB) is obtained by considering the severity of the top ten factors of time buffer. A delay in critical activities reduces the project buffer while an early completion increases the project buffer. This can be monitored by asking the construction personnel the time they required to complete the activity. From this we get the project buffer available after duration N, which is the Remaining Project Buffer (RPB_N). The duration required for the project to complete is the Planned Duration (PD). The Project Buffer Index (PBI) (Eqn. 2) is developed from the IPB and RPB_N. Based on the value of PBI the area of focus can be arrived at. Project monitoring is not just schedule monitoring, it also includes cost monitoring as defined by the Cost Performance Index (CPI) [8] (Eqn.3).

$$PBI = 1 - \left[\frac{(IPB - RPB_N) \times (PD - RPB_N)}{(N \times IPB)} \right] \quad (2)$$

$$CPI = \frac{Earned\ Value(EV)}{Actual\ Cost(AC)} \quad (3)$$

Figure (Fig. 3) below illustrates the static (IPB) and dynamic parameters (RPB_N, AC and EV) of the project monitoring model. Various reports generated at site are used to arrive at the values of the dynamic parameters. RPB_N is obtained from the Daily Progress Report (DPR) whereas the cost performance parameters i.e. Actual Cost (AC) and Earned Value (EV) are obtained from the Job Cost Report (JCR) and Progress Invoice (PI) respectively. It is to be noted that the model does not require any additional information gathering. It makes use of the already available information in the site reports.

			Area to be focussed			
IPB	PBI	≥1	Focus on resource utilization	<1	CPI	EV
		0-1	Focus on the critical activities and check the actual cost			
		<0	Focus on the critical activities to avoid further damage			
RPB_N		≥1	Project is going good	>1		AC
		0-1	Focus on the critical activities			
		<0	Focus on the critical activities. Will lose the current financial gains due to delay and associated expenses			

***Fig.3**: The project monitoring model*

4.1. Project forecasting using Time Buffer

The two important parameters of forecasting are Duration Required for Completion (DRC) and the Cost at Completion (CAC). Here for the sake of forecasting Needed Project Buffer (NPB) is considered which is the project buffer required to complete the project in terms of Budget at Completion (BAC), Earned Value (EV) and Earned Value Project Buffer (EVPB). Duration Required for Completion of the project (DRC) can be calculated as:

$$DRC = (PD + (NPB - RPB_N)) - N \quad (4)$$

Where Needed Project Buffer NPB can be defined as:

$$NPB = (BAC - EV) \times EVPB \quad (5)$$

And Earned Value Project Buffer (EVPB) is defined as:

$$EVPB = \frac{IPB - RPB_N}{EV} \quad (6)$$

The Cost at Completion (CAC) can be defined as:

$$CAC = AC + \left[\frac{AC}{IPB - RPB_N} \times NPB \right] \qquad (7)$$

Where AC is the Actual Cost incurred till the date of monitoring. It is to be noted that when RPB_N is positive it is to be added to the NPB during calculation of CAC.

5. Case study

In this section, the proposed monitoring and forecasting method is applied to an already constructed pipe-rack structure and verified. The pipe-rack structure was constructed for a steel plant. The purpose of this structure is to carry pipes that transport hot gas and steam from the electric arc furnace to the coal gasification plant. A micro-level schedule is made in MS Project and the duration is skimmed (Fig. 4) based on the severity of the top ten most frequent factors and the proposed formulae are applied. The severity of the top ten frequent factors is obtained by conducting a survey among construction personnel working in construction of MHS projects. 60 construction personnel were interviewed.

Piperack - 1 Skimmed Schedule cpy - Copy

	Task Name	Duration	Start	Finish	Total Slack
1	ERECTION OF PIPERACK - 1 (JSPL - ANGUL)	64.34 days	Mon 03-12-12	Wed 13-02-13	0 days
2	SHIFTING	34.32 days	Mon 03-12-12	Thu 10-01-13	0 days
257	ASSEMBLY	11.44 days	Wed 05-12-12	Tue 18-12-12	0 days
260	LIFTING	63.15 days	Mon 03-12-12	Wed 13-02-13	0 days
261	Column	26.33 days	Mon 03-12-12	Wed 02-01-13	0 days
293	Beams	27.82 days	Thu 06-12-12	Mon 07-01-13	7.19 days
500	Cross Bracing	20.02 days	Mon 21-01-13	Wed 13-02-13	0 days
508	Floor Bracing	14.78 days	Mon 07-01-13	Wed 23-01-13	0 days
515	WELDING	60.7 days	Thu 06-12-12	Wed 13-02-13	0 days
738	FINISHING	7.63 days	Thu 24-01-13	Sat 02-02-13	0 days
741	INITIAL PROJECT BUFFER	9.57 days	Sat 02-02-13	Wed 13-02-13	0 days

Fig.4: *Screenshot of the skimmed schedule in MS Project*

5.1. Results and Discussions

A severity chart is made by considering the time construction personnel allot as time buffer to a twelve day activity (Table 1). From the severity chart it can be seen that construction personnel on an average add 1.8 days to a twelve day activity. Thus the time buffer accounts for 15.08% of the total project duration. The activity duration is skimmed by this 15.08% and the duration saved is added as the Initial Project Buffer (IPB), which is the project buffer available for the whole project. The Planned Duration is 64 days (order value is INR 28.10 lakhs), thus IPB becomes 10 days. RPB_N is obtained from the daily progress report which is maintained in the company database. The value of PBI, DRC and CAC for the monitoring periods and their corresponding area of focus are shown (Fig. 5, 6, 7).

Table 1*: Severity chart*

Sl. No.	Factors of Time Buffer	Severity (Days)
1	Climate – weather conditions such as temperature, rain, and wind associated with the location of the project	3
2	Degree of difficulty in the work	2.2
3	Productivity of the trade's equipment	1.3
4	Interdependency of activities	3.2
5	Design errors or design issues	1.0
6	Contract period	1.2
7	Distance of material transfer required from receiving area to task location	1.3
8	Liability pressure	1.6
9	Reliability of the trade's equipment and/or tools	1.5
10	Completion of prerequisite work (work before you are not done yet).	1.8

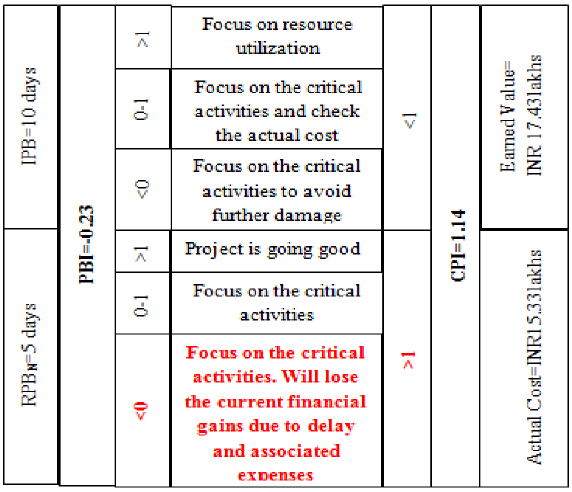

Fig.5*: Project monitoring as on N=24days*

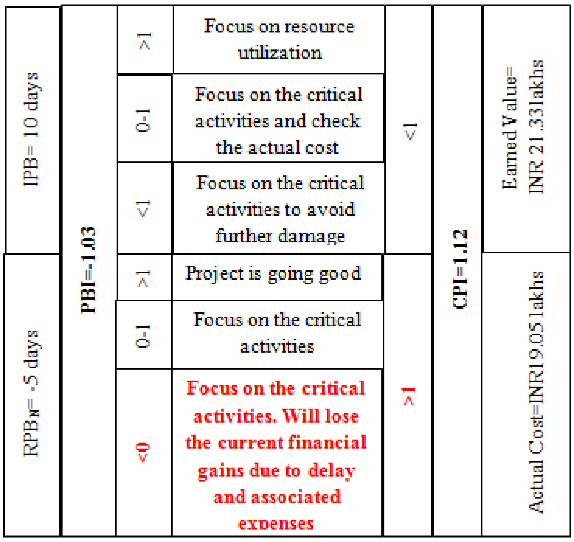

***Fig.6**: Project monitoring as on N=51days*

<table>
<tr><td colspan="2">DRC= 20 days</td><td>CAC= INR 26.20 lakhs</td></tr>
<tr><td colspan="3">NPB=2 days</td></tr>
<tr><td rowspan="2">EV= INR 21.33 lakhs</td><td colspan="2">EVPB=0.70 days per lakh</td></tr>
<tr><td>IPB= 10 days</td><td>RPB_N= -5 days</td></tr>
</table>

***Fig.7**: Project forecasting as on N=51days*

6. Conclusions

From the case study it is seen that PBI value can be negative even when RPB_N is not negative. This is because the rate of buffer consumption is very high and if such a trend is continuous entire buffer is usually consumed by the end of the project. This enables the project manager to think ahead and be prepared even though the current scenario is favourable. This would not be possible if monitoring and forecasting is based on actual cost and earned value only. A high rate of buffer consumption severely impacts the duration required to complete the project and its cost at completion considerably goes up. Thus, the parameters illustrated in the study i.e. PBI, DRC and CAC are very useful for a project manager while taking decisions. It helps in keeping focus on the bottlenecks.

7. Acknowledgements

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