

Assessing Accuracy of Estimated Activity Durations in Construction CPM Schedules

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ABSTRACT

This paper's fundamental question is whether construction baseline Critical Path Method (CPM) schedules would benefit from requirements, or generally accepted industry practices, that cap maximum construction activity durations. The research conducted determined if lower estimated duration values for construction activities are more accurate on both an activity-by-activity and global basis. This question was answered by evaluating the accuracy of duration estimates by identifying and evaluating trends in 90 schedules from 45 construction projects. The data sample represented a diverse grouping of projects by markets, delivery methods, and ownership types. In all, more than 30,000 activities were evaluated to form this paper's observations and findings.

The paper has two principle findings. First, schedules that have a higher proportion of construction activities with original durations of one to five working days are more likely to have actual durations that match the baseline estimate. Schedules where at least 90% of construction activities had estimated durations of five or less days were nearly three times more likely to complete individual tasks within the planned duration than schedules where 25% or less of construction activities had durations of one to five days. Second, activities with estimated original durations of five or less days tend to have smaller duration variances than activities with longer original durations. Construction activities with durations between six to ten days had average variances that were 3.6 times larger than activities with durations of less than five days. Accordingly, this research supports the recommendation that industry scheduling and planning efforts would benefit from standards that prescribe maximum estimated durations for construction activities. This benefit would be realized in more accurate activity duration estimates both in terms of lower variances from actual durations and higher likelihood of completed within the planned duration.

INTRODUCTION

University of Kansas professor of architectural engineering and construction management, Dr. Thomas Glavinich, wrote in his book *Construction Planning and Scheduling* "The need for accurate estimates of activity duration cannot be over emphasized. The construction is only as good as the activity durations that make it up. Therefore, the quality and accuracy of estimated activity durations is very important (Glavinich 2004)." Dr. Glavinich's opinion is widely shared in the industry and organizations such as the Project Management Institute (PMI), AACE International

(AACE), and the Associated General Contractors of America (AGC). Furthermore, these organizations have taken the call to arms to publish best practices for estimating construction activity durations. The organizations' more prevalent and cited publications regarding this subject are consistent amongst each other and are well accepted throughout the construction industry. However, the published practices often lack consensus in recommending maximum durations for construction activities and in some cases, do not disclose a definitive or discrete value. Those publications that do provide a definitive value are supported by generic reasoning and do not provide quantitative evidence as justification for its position. This paper explores the subject on whether there is a need for establishing clear, definitive maximum durations for construction activities in order to produce accurate activity and overall project durations.

The CPM is a scheduling technique that is used to determine the overall project duration and to identify the most critical elements of work. This technique employs activities that model discrete scopes of work, estimates durations for each activity, and assigns relationships between activities, often referred to as logic ties. It is these logic ties that determine when an activity can and/or cannot start and/or finish, based upon its relationship with other activities. A series of calculations, commonly referred to as a forward pass and backward pass, is performed to identify the criticality of each activity within the schedule. These passes result in each activity having early and late start and finish dates. These dates are used to determine total and free float values, which is how criticality is often expressed in schedules developed using the CPM.

Estimating activity durations, in particular those that model construction scopes, are an essential function to the CPM. Several prevalent organizations have provided published standards on how to conduct this step. AACE, PMI and the AGC have published books, recommended practices and other writings within the last decade that provide detailed instructions for scheduling professionals and others to follow when calculating the time it takes to complete a single construction activity. While there are some variations and nuances between these publications, there are five (5) common duration estimating methodologies: analogous estimating, parametric estimating, bottom-up estimating, three-point estimating, and Monte Carlo simulations. Each of these estimating methodologies has its positive and negative attributes as well relevancy, based on a project's constraints and defining characteristics. It is not within this scope of this paper to determine which technique is preferable.

In review of the relevant literature and publications from the organizations referenced above, there was a lack of a consistent recommendation as to what level of decomposition and details construction activities are to undergo. There is general consensus amongst qualitative criteria; however, there is little to no consensus for quantitative criteria. For example, AACE's *Recommended Practice 32R-04: Determining Activity Durations* does not provide a clear recommendation for what should be the longest construction activity duration. A review of AACE's other most prevalent recommended practices was completed, and no such qualitative recommendation was found. PMI's *CPM Scheduling for Construction* recommends that the maximum duration for an activity should be half of the full reporting duration, which is commonly 10 to 20 working days (Carson 2014). This recommendation is backed by sound and rational reasoning but lacks empirical or other quantitative

evidence to support its conclusion. Other PMI publications, such as *Construction Extension to the PMBOK Guide* and *Practice Standard for Scheduling* or *Practice Standard for Scheduling*, do not provide any such recommendation. AGC's *Construction Planning and Scheduling* is also silent in providing a quantitative recommendation for what should be the maximum for a construction activity's duration (Glavenich 2004).

RESEARCH METHODOLOGY

Methodology

Three separate studies were conducted to answer the paper's fundamental question. These studies identified and measured trends between activities' estimated durations and as-built at completion durations. Estimated durations represent the expected time it takes to complete the activity and is often referred to as original durations. As-built at completion durations represent the actual time it took to complete the activity and is also commonly referred to as the actual duration.

The first study compares the variance between construction activities' estimated durations for construction activities against their as-built at completion durations. The unit of measurement for variances is days. This first study identifies if any trends exist between original durations and the size of the variance of individual activities. In other words, this study answers the question, "do activities with a shorter estimated duration have smaller variances when compared to the variances of activities with large estimated durations?"

$$\text{Variance} = \text{Original Duration} - \text{Actual Duration} \quad (1)$$

The second study evaluated the percentage of times an activity's actual duration equaled its original duration and identified any relationship between these percentages and estimated durations. This percentage is referred to as the "Success Percentage." For example, if a group of activities with the same original duration have a Success Percentage of 32%, it means that 32% of all the activities within the group had actual and original durations that matched the as-built duration.

$$\text{Success Percentage} = (\Sigma_S \div \Sigma_T) * 100 \quad (2)$$

Σ_S is the total number of activities in the sample in which the actual duration equaled the original duration. Σ_T is the total number of activities in the sample. This evaluates the hypothesis that activities with lower estimated durations have a higher likelihood of being completed within the planned duration that activities with higher original durations.

The third study goes beyond an activity-by-activity analysis and evaluates the global effects on the schedule. This study attempts to identify trends between the percentage of activities in a schedule of a given estimated duration and the overall Success Percentage for all activities in the schedule. This study answers the question, "do schedules that have a higher proportion of activities with lower original durations have a higher overall, average Success Percentage?"

Data Sample

The findings in this paper were based upon the evaluation of schedules from 45 different and diverse projects. The evaluation of each project included, at minimum, the analysis of its baseline CPM schedule and its as-built CPM schedule. For all three studies, the original durations were taken from baseline CPM schedules that general contractors submitted on or around the notice to proceed (“NTP”). Actual durations were taken from as-built CPM schedules that general contractors submitted on or after the project’s final completion. All CPM schedules used for this study are consistent with Level 4 “Project Level Schedules” as defined by AACE’s *Recommend Practice 37R-06: Schedule Levels of Detail as Applied in Engineering, Procurement, and Construction*. The 45 projects spanned several markets, delivery methods, and ownership types (i.e.: public or private). The schedules were created and maintained in Primavera P6.

The research was based on task-dependent construction schedule activities. Construction activities were defined by the researchers as CPM tasks in which construction equipment and/or craft labor was expended to create the work. Milestones, procurement activities, labor associated with indirect and general conditional scope, and other general site services were not included in the analysis. In all, 30,556 baseline CPM schedule activities were included in the 90 schedules and 14,148 qualifying construction activities were evaluated to form this paper’s observations and findings. Activities over 20 working days were not considered because the sample size was too low to qualify as a valid data set.

Furthermore, the researchers organized groups of activities by original, estimated duration as shown in the baseline CPM schedules as shown in Table 1. This was done for several reasons. First, it assisted in normalizing outliers and trends for activities with similar estimate durations. It was observed that activities with estimated durations of 5, 10, 15 and 20 days produced variances and Success Percentages that were atypical for activities of similar duration values. These groups were selected to provide clarification of detailed information that is better suited for readers and scheduling professionals who may apply the recommendations in real world applications. The definition of these groups made the graphical display of the information easier to consume by the reader and did not materially detract from the accurately displaying and representations of the studies’ results.

Table 1. Group Definitions

Group	Description
Group 1	Original durations of 1 to 5 days
Group 2	Original durations of 6 to 10 days
Group 3	Original durations of 11 to 15 days
Group 4	Original durations of 16 to 20 days
Group 5	Original durations of 5, 10, 15 or 20 days

RESULTS

First Study: Relationship between Original Durations and Duration Variances

Group 1 activities (one to five days) tend to exhibit less variance when compared to other groups. Group 1 activities had an average activity variance of -0.99 days. The average variance for all groups combined was -3.34 days. Note that negative variance values in Table 2 indicate that actual duration was greater than the original duration; in other words, Group 1 activities' actual durations were on average 0.99 working days longer than their original durations.

Table 2. Average Variance for Each Group

Group 1	Group 2	Group 3	Group 4	Group 5	Weighted Average
-0.99	-3.61	-4.64	-0.81	-3.43	-3.34

As the estimated, original duration value increases, so does the average variance. Group 4 (16 to 20 days) appears to be an exception to this observation. The spread between the lowest and largest variance for Group 4 activities is 21.72 working days. The spread for the average variance for all 14,148 qualifying construction activities was just 13.98 working days, a narrower difference of 7.74 working days. In addition to the variance spread, consideration also must be given to the small sample size for Group 4 activities. Only eight out of the 45 projects had 2% or more of its total number of construction activities with durations of 16 to 20 working days.

Second Study: Average Success Percentage for Each Group

The average Success Percentage for Group 1 activities was 36.1% and this was the highest rate of all five groups. On average for all activities, they have a one out of four probability of meeting their estimated, original duration. As planned durations increase, the Success Percentage decreases. Table 3 shows the Success Percentage for all the groups.

Table 3. Average Success Percentage for Each Group

Group 1	Group 2	Group 3	Group 4	Group 5	Weighted Average
36.1%	22.4%	20.6%	27.0%	20.0%	26.1%

The observations and trends within this study are similar to those found within the immediately prior study; the lower the duration, the higher likelihood for baseline activities to be completed as expected. The lone exception is, again, Group 4 activities. Further data review showed an outlier in which one schedule had a Success Percentage of 100% for all Group 4 activities. No other schedule had a Success Percentage greater than 33.3% for Group 4 activities. When this outlier is removed, the Success Percentage for Group 4 decreases to 12.4%.

Third Study: Relationship between Original Durations and Schedules' Overall Success Percentages

Schedules that have a higher proportion of Group 1 activities have a positive correlation with schedules that have higher Success Percentages. As the proportion of Group 2, 3, 4 and 5 activities within a schedule increase, the schedule's overall Success Percentage decreases. Figure 1 and Figure 2 show plots of the percentage of all schedule activities within groups against the average Success Percentage for all sample projects. It demonstrates the positive correlation between Group 1 activities and average Success Percentages for all activities in a schedule. It also illustrates the negative correlation between Success Percentages and schedules with large proportions of Group 2, 3, 4, and 5 activities.

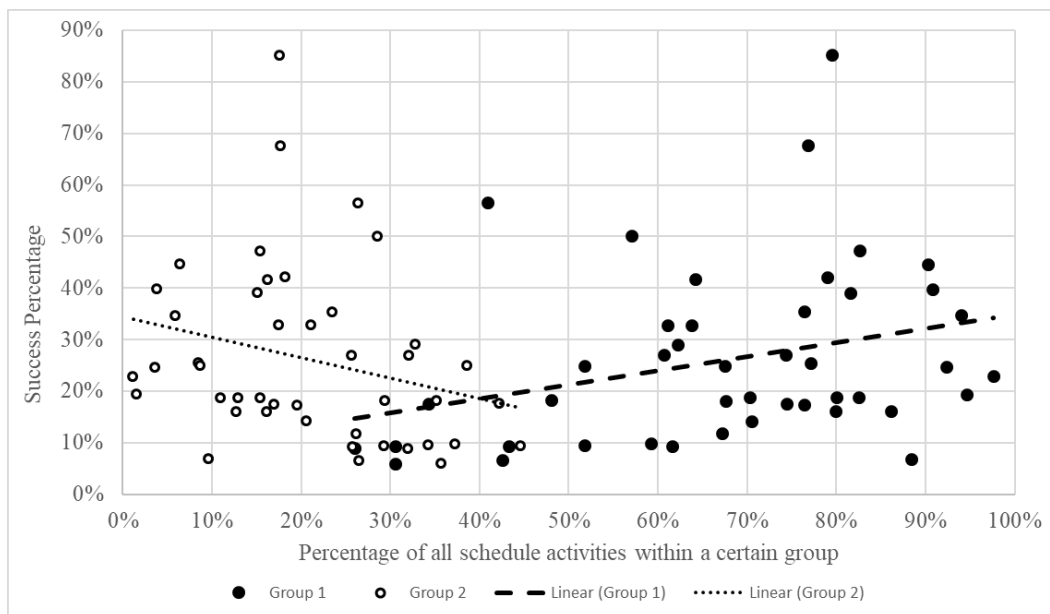


Figure 1. Scatter Plot of Average Success Percentages and Proportions of Groups 1 and 2 Activities

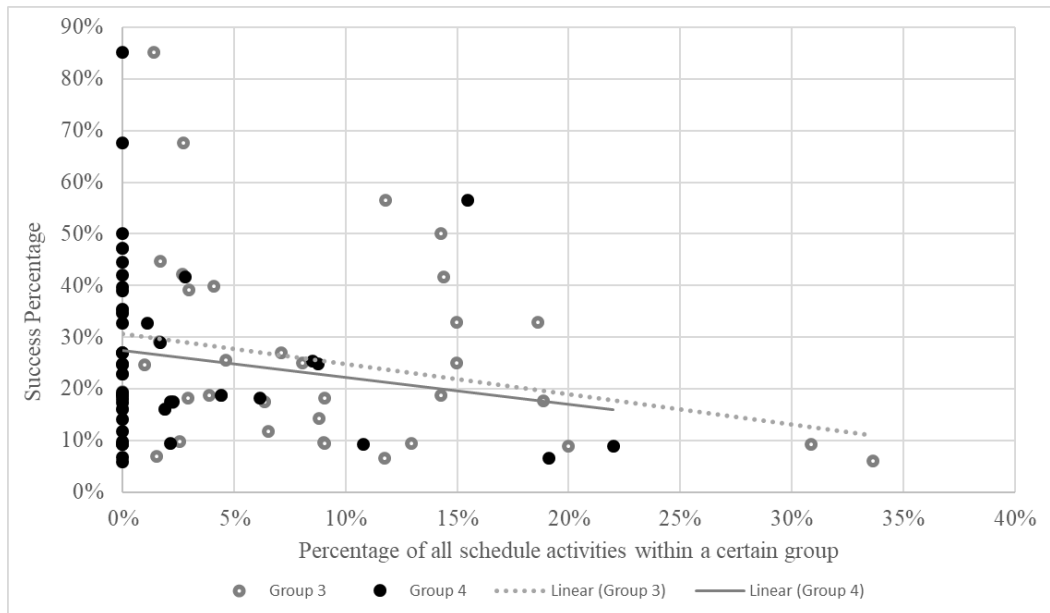


Figure 2. Scatter Plot of Average Success Percentages and Proportions of Groups 3 and 4 Activities

Shown in Figure 3, is a similar scatter plot of Group 5 (5, 10, 15 or 20 days) activities. It also shows a negative correlation between the percentage of activities in a schedule that are in Group 5 and the Success Percentage of all activities within the schedule.

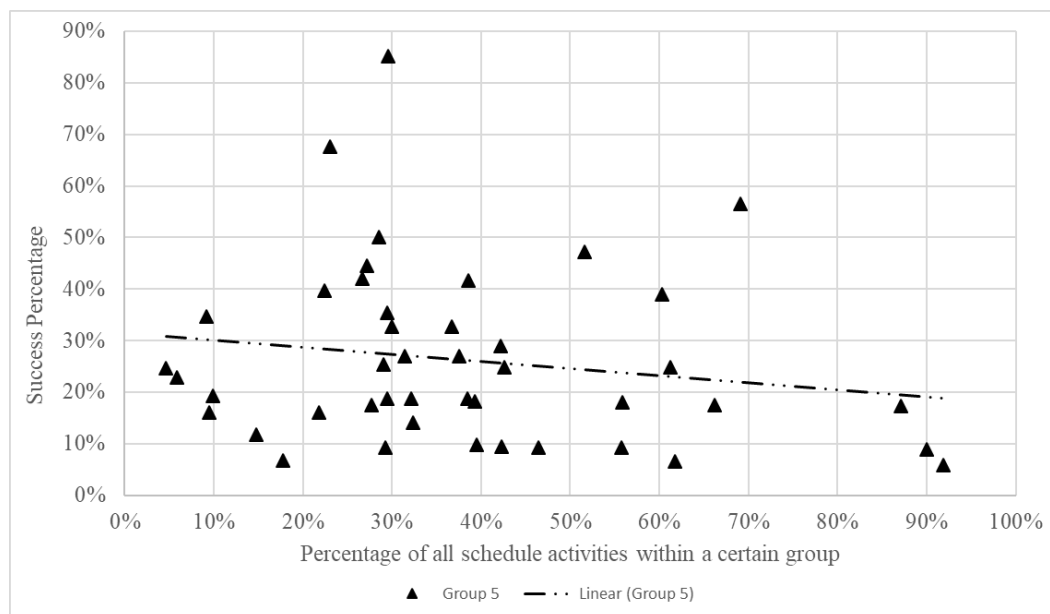


Figure 3. Scatter Plot of Average Success Percentages and Proportions of Group 5 Activities

Groups 2, 3, 4 and 5 show a similar trend of negative correlation percentage of a group's activities in a schedule and the schedule's overall Success Percentage. However, the trendline slopes for Groups 2, 3 and 4 are similar and steeper than Group 5. This can be attributed that proportion of Group 5 activities also fall into Group 1. Table 4 shows the trend line slopes for activities in Groups 2, 3, 4 and 5.

Table 4. Trendline Slopes for Groups 2, 3, 4 and 5

Group 2	Group 3	Group 4	Group 5
-.398	-.586	-.518	-.138

DISCUSSION AND ANALYSIS

The results show a positive correlation between lower estimated activity durations and improved accuracy, both in terms of individual activity estimated durations and the overall accuracy of all activities in a schedule. The results captured within this paper resulted in two major findings. First, schedules that have a higher proportion of construction activities with original durations of one to five working days are more likely to have actual durations that match the baseline estimates. Schedules where at least 90% of construction activities had estimated durations of five or less days were nearly three times more likely to complete individual tasks within the planned duration than schedules where 25% or less of construction activities had durations of one to five days. Second, activities with estimated original durations of five or less days tend to have smaller duration variances than activities with longer original durations. Construction activities with durations between six to ten days had average variances that were 3.6 times larger than activities with durations of less than five days.

Possible Explanations

There are several plausible explanations for these results. First, activities with smaller estimated durations have narrower constraints when it comes to variances. Activities in Group 1 are closer to zero than those activities in other groups.

Second, additional care and effort is needed to decompose activities into durations of a working week or less. This additional effort often requires a deep fundamental understanding of the project scope and the anticipated means and methods in which the project will be completed. This effort requires several vital project management techniques such as pre-planning, evaluating project constraints and risks, calculating resource productivities and efficiencies, and coordination with stakeholders (Project Management Institute 2011).

Third, further decomposition can often lead to better definition of the scope being modeled by the activity and may reduce confusion as to when the activity actually started and finished. The elimination of esoteric activity definitions may also improve infield monitoring which increases a project's likelihood in mitigating risks and capitalizes on opportunities contemporaneously.

Fourth, decomposing activities can also allow project teams to identify potential gains in efficiency and improved preferential sequencing that otherwise would be

possible with schedules that build upon activities with larger estimated durations. This would allow for improved sequencing that promotes trade continuity and lessens volatility in anticipated resource demands. Further decomposition of activities can also improve upon defining the interface amongst trades that will reduce inefficiencies that are caused by crew staking in physical areas.

Recommendations

This paper offers several practice recommendations that can be immediately implemented by schedulers and other professionals in the construction industry. The first recommendation is that schedulers and planners should strive to decompose scopes of work in the schedule so that no activity has a duration greater than 10 working days.

The second recommendation is that schedulers and planners should detail and sequence their work so that no activity on the longest path to completion or near the critical path has a duration greater than five (5) working days. This will ensure that the most critical elements of the project are well defined and provide a greater understanding of how each activity interfaces with other critical elements. This recommendation provides a reasonable option in the event project constraints do not allow for all construction activities to be decomposed and detailed to levels as described in the above recommendation.

The researchers of this paper also recognize that there may be other instances in which it may not be prudent to provide such detail in baseline CPM schedules. An alternative would be to implement the “rolling wave” methodology of schedule maintenance. This is an approach in which baseline activities are decomposed into small duration tasks as the project progresses (Hobb 2007). This decomposition is completed for activities that are anticipated to start in the next 30 to 90 calendar days. Project managers and schedulers can apply the rolling wave methodology in such a fashion that the maximum construction activity duration is just 5 working days. The product of applying these findings in conjunction with the rolling wave methodology may also result in more accurate short interval schedules (i.e. 3 week look ahead, Short Interval Schedules). These types of schedules are a crucial tool in daily and weekly coordination for subcontractors and foreman (Douglas 2010).

The final recommendation is for construction owners, such as city governments, developers, and transportation departments, to codify these recommendations into their contract documents. Requiring general and prime contractors to abide by these requirements may ensure schedules are an effective risk management, project management and communication tool.

It should be noted that these recommendations do not materially conflict with other recommendations cited in this paper. This paper's recommendations in no way invalidates or makes obsolete the techniques and practices prescribed in cited publications. It is the intent of this paper's recommendations to compliment and progress these existing works.

CONCLUSION

This research studied the correlation between estimated activity durations and accuracy of those durations as compared against their as-built condition. This research was done to determine if scheduling and planning best practices should establish a recommended maximum activity duration.

The results show a positive correlation between lower estimated activity durations and improved accuracy, both in terms of individual activity estimated durations and the overall accuracy of all activities in a schedule. The results captured within this paper resulted in two major findings. First, schedules that have a higher proportion of construction activities with original durations of one to five working days are more likely to have actual durations that match the baseline estimate. Schedules where at least 90% of construction activities had estimated durations of five or less days were nearly three times more likely to complete individual tasks within the planned duration than schedules where 25% or less of construction activities had durations of one to five days. Second, activities with estimated original durations of five or less days tend to have smaller duration variances than activities with longer original durations. Construction activities with durations between six to ten days had average variances that were 3.6 times larger than activities with durations of less than five days.

This research supports the conclusion and recommendation that it would be reasonable and prudent for published scheduling and planning best practices to recommend a maximum estimated duration for construction activities. This paper also includes several other practical recommendations that scheduling and planning professionals can implement immediately on their projects.

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