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Determining the Measured Mile for Lost Productivity Claims

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Abstract—Proving and quantifying lost productivity is one of the most challenging areas in construction claims. Among the available approaches, the measured mile method is ranked as the most preferred method to quantify lost productivity according to AACE International. The method is preferred, in part, because it eliminates disputes over the validity of the original estimate by comparing actual productivity of similar work, with the primary difference being the impacts in question. Since the distinction between the impacted and non-impacted sections in many projects is not readily observable, researchers and professionals have developed various procedures to help identify the measured mile. In the paper, the authors will review various techniques that have been developed previously and present their Improved Baseline Method.

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Introduction

Productivity can be measured as the ratio between the units of work accomplished (output) and the units of time or efforts expended (input). When the anticipated productivity cannot be met, the contractor would suffer a loss of productivity. Since it can be very costly and difficult to track productivity contemporaneously during construction, proving and quantifying lost productivity may be one of the most contentious and controversial areas in construction claims and disputes. It is a task that usually involves processing data for completed work and corresponding work-hours, calculating productivity, establishing baseline, causation study, and measuring productivity loss. In this paper, productivity is defined as the ratio of input to output, but the inverse is also commonly used.

Although there may exist various methods to quantify productivity loss, the measured mile/baseline method by far is the most preferred for computing lost productivity in the construction industry [1]. The original measured mile method compares the productivity of identical activities which are segregated into unimpacted and impacted periods (or sections) of the project. The resultant difference is asserted to represent the loss of productivity from the impacts. Zink developed a procedure to ascertain the measured mile, by isolating a reasonable linear or near-linear portion in the labor hours – progress curve, which represents the most efficient productivity [2][3]. Thomas and his collaborators introduced the "baseline" concept and proposed a procedure to determine it [4][5][6][7][8][9][10]. When an unimpacted section of the project cannot be found, a baseline, in which light disruption was experienced, may be defined. By doing so, the baseline contains certain productivity loss, and thus it tends to be conservative from the claimant's perspective.

Gulezian and Samelian [11] recommended the use of control charts to ascertain the baseline. However, their procedure may result in no baseline or an erroneous baseline, particularly when the majority of reporting periods are heavily impacted. Gulezian and Samelian's procedure, however, is useful in identifying reporting periods with relatively unusual productivity compared to all the others. This method usually returns a very conservative baseline that may not reflect the attainable sustained productivity.

Ibbs and Liu [12] were critical of Thomas's baseline method, claiming that it was highly subjective due to the arbitrary selection of 10% of total reporting periods as the baseline subset. They also argued that Thomas's method identifies the baseline subset according to the best production in a reporting period rather than the best productivity. They proposed a procedure based on the K-means clustering technique to separate the productivity data into different groups. The average value for the group with the best productivity would serve as the baseline. One issue with K-means clustering technique based method is that it does not guarantee a unique solution for baseline productivity.

In order to address the shortcomings in existing procedures to determine the productivity baseline, Zhao and Dungan [13] in their peer reviewed work published in Journal of Construction Engineering and Management, presented an improved baseline method (IBM). In the IBM, productivity data is segregated into two sets by using the overall average productivity. One set is for the unimpacted/lightly impacted data, and the other is for the heavily impacted data. The data within the unimpacted/lightly impacted set is made more reliable by excluding extreme data points which are not representative of the contractor’s proven productivity levels. This new method provides a useful tool to help determine a baseline that represents the attainable and sustained labor productivity, while reducing the subjectivity in baseline selection.

Data processing, cause and effect analysis, baseline selection, measuring productivity loss and responsibility allocation are all important elements in lost productivity analysis. This paper, however, only focuses on determining the productivity baseline.

Case Study

On a municipal sewer upgrade project, a contractor was to replace and install 15 inch vitrified clay pipe (VCP) sewer pipes. According to the baseline schedule, the installation was planned to be performed in a dry season. Because of delays experienced in preceding work, the contractor actually performed 15” VCP replacement work in a stormy season and installation was hampered by muddy site conditions. Further, unmarked utilities and conflicts were encountered in multiple locations. The contractor had to skip those areas, and mobilize back later after a resolution was provided by the engineer of record. The production data compiled from contemporaneous documentation has been summarized in Table 1, and it can be seen that the impacts were pervasive.

Work Day	Labor Hours	Output (lf)	Calculated Productivity (hr/lf)	Notes in Daily Reports
1	198	54	3.67	
2	201	24	8.38	Utility conflict
3	200	36	5.56	Utility conflict
4	200	54	3.70	Muddy site
5	200	60	3.33	Utility conflict
6	122	36	3.39	Utility conflict
7	245	59	4.15	Muddy site
8	120	19	6.32	Muddy site and utility conflict
9	120	24	5.00	Muddy site
10	120	26	4.62	Muddy site
11	200	28	7.14	Muddy site and utility conflict
12	200	50	4.00	
13	200	40	5.00	Muddy site and utility conflict
14	120	24	5.00	Muddy site
15	120	42	2.86	
16	120	31	3.87	Utility conflict
17	121	16	7.56	Utility conflict
18	120	44	2.73	
19	120	35	3.43	Utility conflict
20	120	37	3.24	
21	200	50	4.00	Come back work
22	220	86	2.56	
23	200	27	7.41	Utility conflict
24	200	58	3.45	
25	200	31	6.45	Come back work
26	200	49	4.08	Muddy site
27	160	45	3.56	
28	199	48	4.15	Come back work
29	200	54	3.70	
30	200	22	9.09	Muddy site and come back work
31	220	73	3.01	
32	200	54	3.70	Come back work
33	200	54	3.70	Come back work
34	120	30	4.00	Come back work
35	120	48	2.50	Come back work

Table 1— Contemporaneous Production Data for 15" VCP Sewer

Applying Zink's Measured Mile Procedure

A systematic procedure for measured mile calculation as a method was introduced in Zink [2][3]. The procedures Zink proposed include:

- Plot the actual labor man-hours expended versus the corresponding percentage of work completion.
- Exclude the first and last 10% from the analysis because the productivity during these periods may be impacted by "build-up" and "tail-out" effects.
- Identify as the measured mile a linear or near-linear portion showing the most efficient rate of progress in the middle 80% of the curve.

The measured mile selected by Zink's procedure is a continuous period of time in which the most efficient productivity is uniform or nearly uniform. Another assumption for the original measured mile method is that the measured mile has to be impact free.

Since the impacts were pervasive, there were no impact free periods that can be identified. For demonstration purposes, Zink's procedure is still applied to the 15" VCP replacement work described in the section of case study. The first 10% and the last 10% of the total labor hours are excluded from analysis. Analysis of the actual labor hours focuses on the intermediate 80% of the labor hours. Four consecutive daily productivities, Day 18 to Day 21, are identified as the measured mile period and the resulting measured mile productivity is calculated to be 3.37 hr/lf, as shown in Figure 1. In practice, a measured mile period or segment with uniform or nearly uniform productivity may not exist due to pervasive disruptions in many projects, including the case study project in this paper. Zink did not define how to identify from the chart the linear portion that would represent the most efficient rate of progress. Consequently, this method of identifying the measured mile is subjective, and thus different analysts may select different portions as their linear or near linear segments. Further, a perfect linear portion is rare because of the normal variability in a contractor's productivity. That is, the same worker or crew may not maintain an identical level of productivity between periods on a project even in the absence of disruptions assignable to other parties.

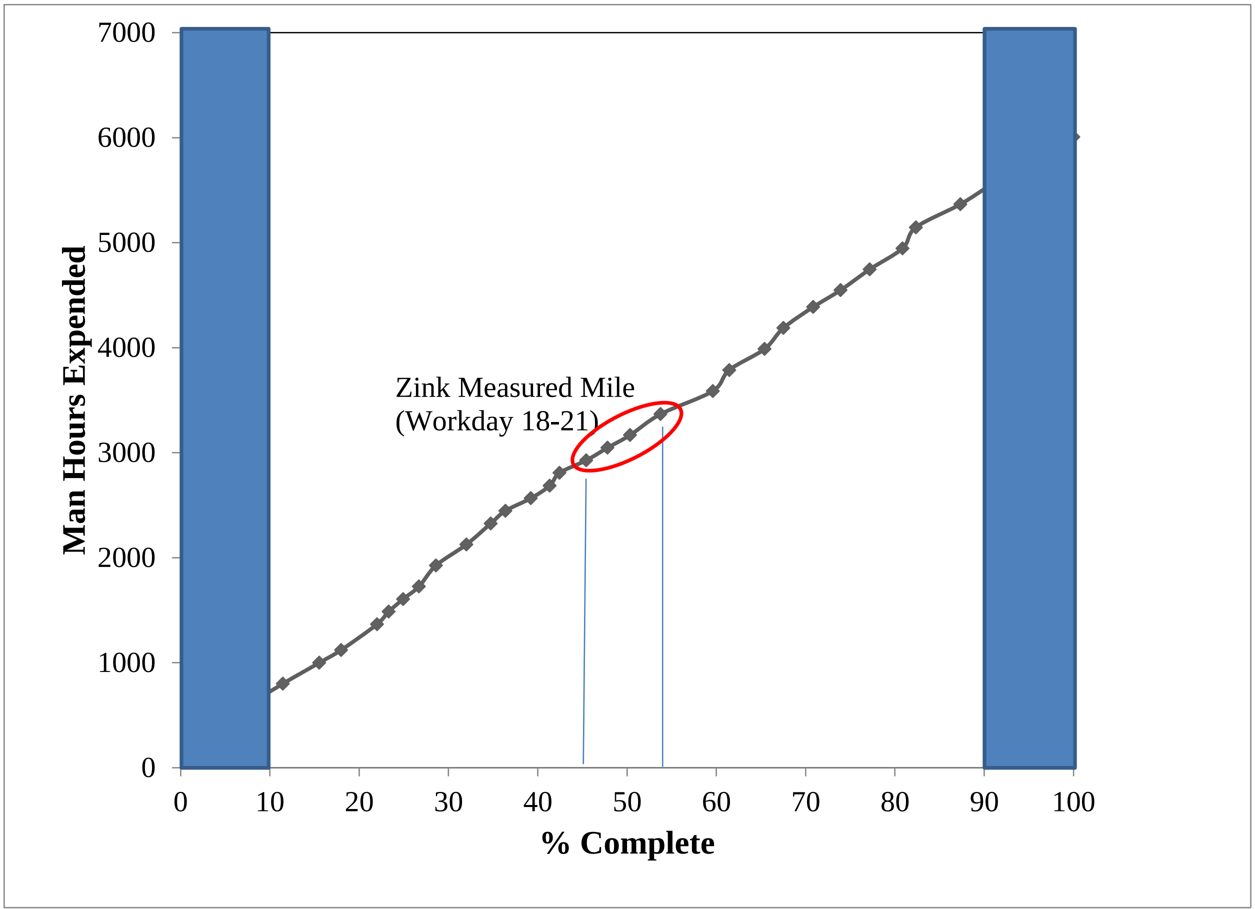

Figure 1— Zink Measured Mile

Applying Thomas's Baseline Method

In order to improve on the weaknesses in the original measured mile method, which requires that the measured mile must be continuous and impact free, Thomas [11] defined that a baseline period is a period of time in which the best productivity is achieved. However, the baseline procedure he proposed captures the reporting periods with highest production as the baseline. The baseline period is not required to be a continuous, non-impacted time frame, while the measured mile period has to be a consecutive set of time periods. The steps to determine a baseline proposed by Thomas and his collaborators can be summarized as follows:

1. Determine the total number of reporting periods;
2. The size of the baseline subset is selected as 10% of the total number of reporting periods and should not be less than 5;
3. The contents of the baseline subset are the reporting periods that have the highest production or output;
4. The baseline is the median or average of productivity value per period or the productivity average in the baseline subset.

Thomas and his collaborators did not offer a consistent criteria for use of average productivity or median productivity for the baseline set, and either of them has been presented in different publications [4][5][6][7][8][9][10]. Thomas's baseline procedure is applied to the 15" VCP replacement work described in the section of case study. By Thomas's procedure, the appropriate size of the baseline subset is five, the maximum of 10% of 35 days and 5. Five reporting periods with the highest production or output are selected as the baseline set, as shown in Table 2, which both the average and median productivity as calculated to be 3.23 hr/lf and 3.33 hr/lf. One weakness of Thomas's procedure is that it could include heavily impacted reporting periods in the baseline set. In the baseline set selected using Thomas's procedure, Day 7 appears more heavily impacted compared to most others, because the productivity of Day 7 is worse than the overall average. Because it uses production instead of productivity to identify the baseline, Thomas's procedure makes sense when the input in each reporting period is uniform or almost uniform because then the reporting periods with the highest productivity would be among the ones with the best production. When the input in each reporting period is not uniform, and the reporting periods with high production happen to be heavily impacted, Thomas's approach could either fail to determine a viable baseline or selects a baseline that includes significant productivity loss, which could be unfavorable and unfair to the claimant.

Work Day	Labor Hours	Output (lf)	Calculated Productivity (hr/lf)	Notes in Daily Reports
22	220	86	2.56	
31	220	73	3.01	
5	200	60	3.33	Utility conflict
7	245	59	4.15	Muddy site
24	200	58	3.45	
	Average Productivity		3.23	
	Median Productivity		3.33	

Table 2— Baseline Set Selected Using Thomas's Procedure

Applying Gulezian and Samelian's Control Chart Based Method

Gulezian and Samelian proposed a statistical approach based on a process control chart for establishing a productivity baseline that reflects a contractor's normal operating performance [11]. A control chart consists of:

- Points representing a statistic of measurement in samples taken from the process at different times;
- The mean of this statistic using all samples is calculated;
- A center line (CL) is drawn at the value of the mean of the statistic ;
- The standard deviation of the statistic is also calculated using all samples;
- Upper control limit (UCL) and lower control limit (LCL) that are drawn typically at three standard deviations from the center line.

To use the control chart to determine a productivity baseline, the metric on the vertical axis is productivity value, and the metric on the horizontal axis is time. The individual productivity values in corresponding reporting periods are plotted on the chart to create a time-series plot of productivity values for corresponding reporting periods. Since a portion of the data points may fall out of the control limits, they are eliminated; and the control chart is reapplied with a recalculated center line and control limits. The process repeats until no points fall out of the control limits. Then the mean productivity of the points falling within the control limits after the last iteration is used to define the baseline productivity level.

This method usually returns a very conservative baseline that may not reflect the attainable sustained productivity, especially when the disruptions are pervasive, and thus would discourage the productivity loss claim. When the data points are evenly spread across the initial mean, the method would return a meaningless baseline close to the mean, and no productivity loss can be reported. In this case, it is counterintuitive. A control chart is plotted for the 15” VCP installation data in the case study, as shown in Figure 2. It can be seen that no points fall out of the control limits, and Gulezian and Samelian’s method cannot even find a baseline for this case study.

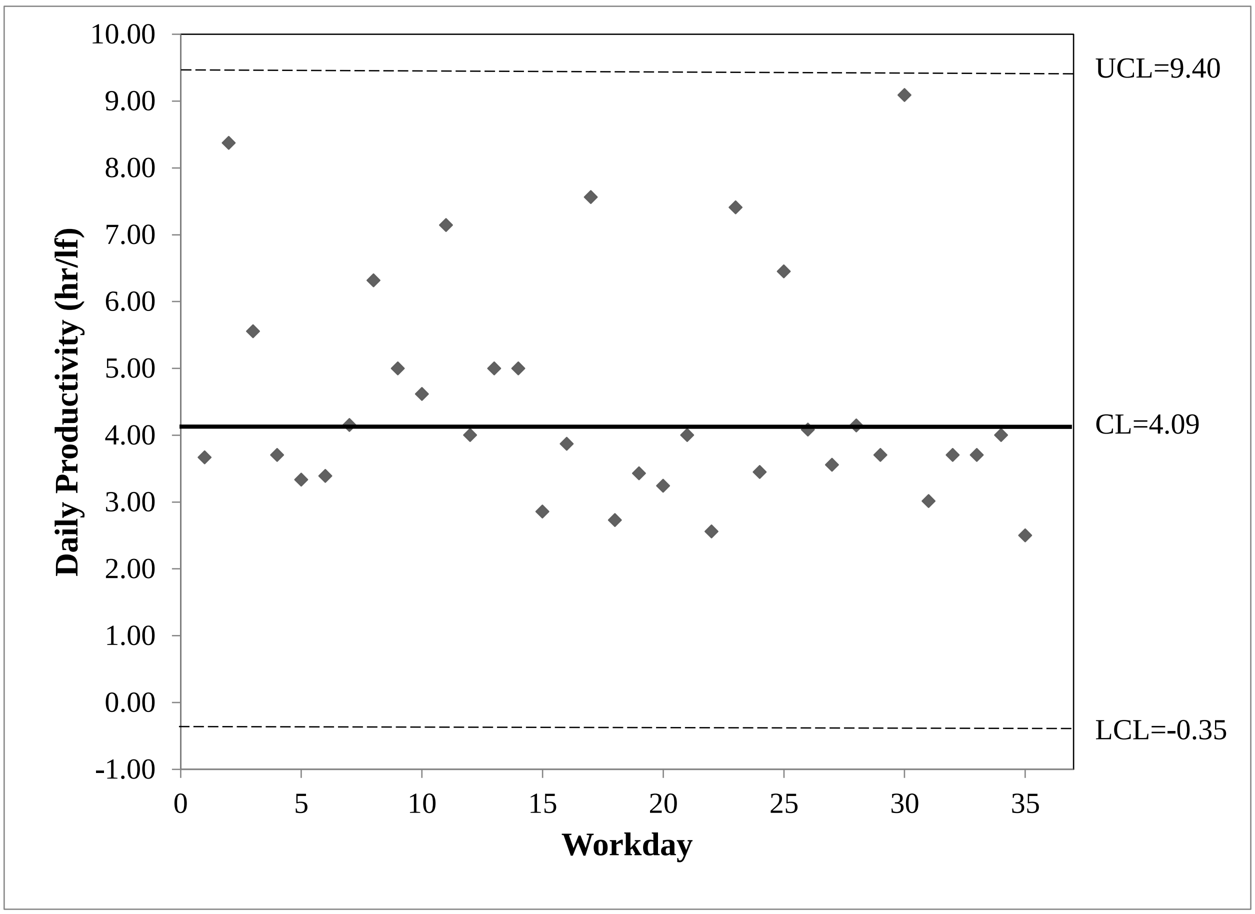

Figure 2 — Process Control Chart for the 15” VCP Installation Productivity

Applying Ibbs and Liu's K-Means Clustering Technique Based Procedure

In an attempt to address issues in Thomas's procedure, Ibbs and Liu proposed a K-means clustering based method to separate the productivity data into different groups [2]. K-means clustering is a method of cluster analysis, which aims to partition observations into K clusters in which each observation belongs to the cluster with the nearest mean. Although Ibbs and Liu did not clearly specify how to determine the value for K, they appeared to allude to K equaling 2 for their procedure. Ibbs and Liu's procedure can be summarized as follows:

1. The two cluster centers are first set to the highest and lowest productivity among all the reporting periods.
2. The distances to the two cluster centers are calculated for each reporting period, and the reporting period is assigned to the cluster to which it is closer.
3. Calculate the mean for each of the two clusters. If it is different from the cluster center, the cluster center is updated by it, and go to 2; otherwise, go to 4.
4. The cluster with higher productivity is then the baseline set, and its cluster center is determined to be the baseline productivity.

Using the K-means clustering technique, the productivity data can be divided into two clusters, good and bad. The good productivity cluster, which may not be continuous in time, is the baseline subset determined by Ibbs and Liu's method and the mean of the baseline subset is then selected as the baseline productivity. This method will always include the best reported productivity in the baseline subset, whether or not it is attainable and sustained.

Another flaw in using the means clustering based method to identify a productivity baseline is the presence of multiple solutions even with the same K value [13]. Different solutions sometimes can be reached from different initial conditions, which may create hurdles to resolve a productivity loss claim, especially when different commercial software packages are employed to perform the K-means clustering calculation by the opposing parties.

The application of Ibbs and Liu's K means clustering procedure to the 15" VCP installation case study is demonstrated in Figure 3. First, the maximum and minimum productivity values are chosen as the initial cluster centers. The initial cluster centers are 2.50 hr/lf of Day 35, and 9.09 hr/lf of Day 30. Starting from Day 1, the distances to the two cluster centers are calculated for each day, and it is assigned to the cluster the center of which it is closer to. After this step, all the workdays with a productivity value no less than 5.56hr/lf have been assigned to the upper cluster, and the others are in the lower cluster. The cluster centers, calculated as the mean productivity of the cluster, are 3.78 hr/lf and 7.48 hr/lf, respectively. Then the step of distance calculation and assignment for each workday repeats, until the cluster centers between two iterations remain the same. In this case, the calculation stops at the second iteration, with the final cluster centers being 3.78 hr/lf, the baseline productivity, and 7.48 hr/lf.

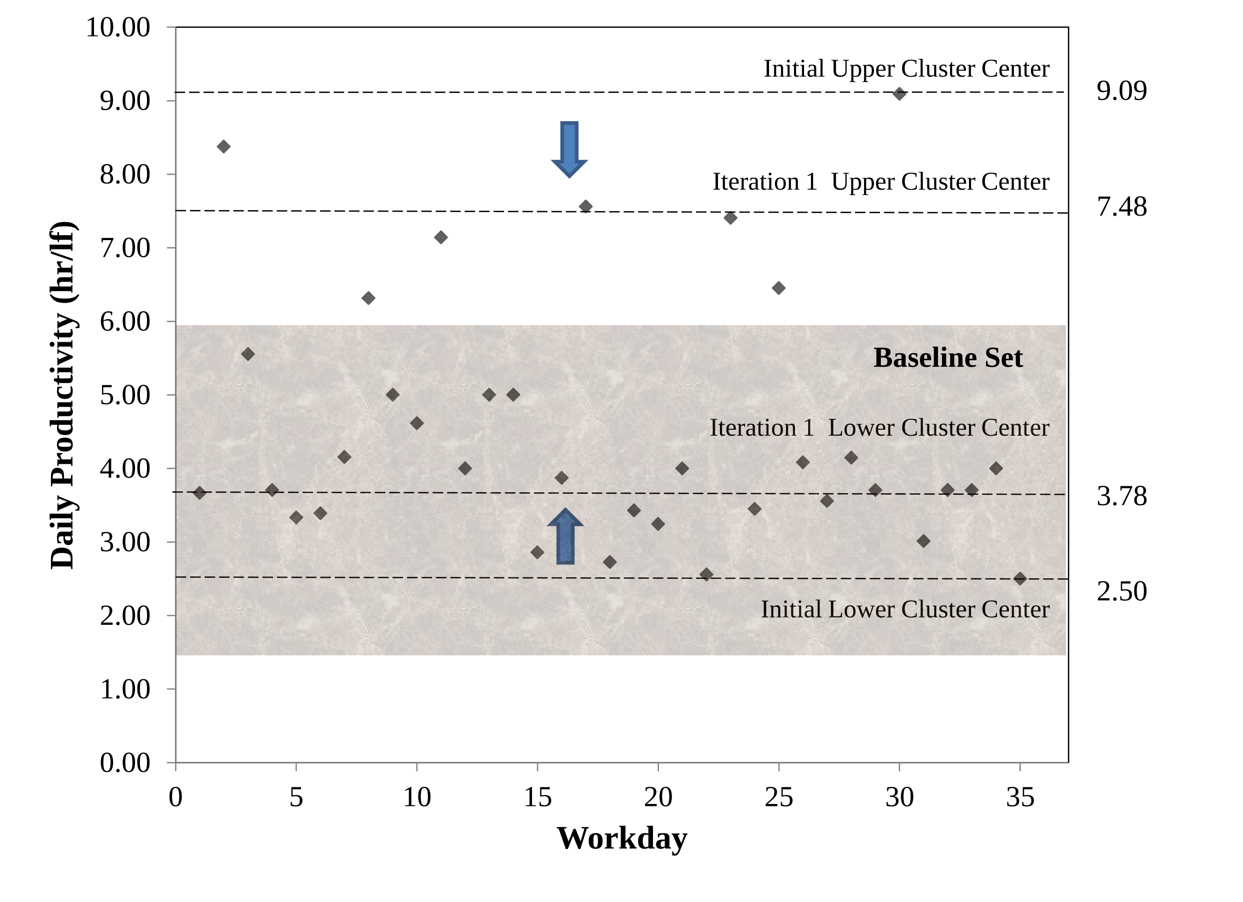

Figure 3—K Means Clustering Implementation for the 15" VCP Installation

Applying Zhao and Dungan's Improved Baseline Method

In order to address the weaknesses in the above methods, Zhao and Dungan proposed the IBM, published in Journal of Construction Engineering and Management [13]. In the IBM, the baseline subset is defined as the periods or sections where the productivity reflects the contractor's normal operating performance, or the productivity that is attainable and sustained. The baseline subset does not have to be continuous in time. There are two basic steps to determine the baseline productivity:

- Step 1, use the overall average productivity to divide the data into two groups, the good productivity group (GPG) and the bad productivity group (BPG) In lost productivity claims, the establishment of the cause and effect relationship is one of the most important steps. The causal relationship between disruption and productivity governs the extent that lost productivity can be proven. It is generally accepted that with other conditions kept the same, the more heavily the construction is impacted, the worse the productivity would be. Good productivity is normally experienced where there are either no disruptions or light disruptions. Therefore, it is a reasonable assumption that the productivity experienced in the periods/sections without any assignable disruptions or with light disruptions is generally better than the overall average productivity.

- Step 2, refine the baseline subset from the good productivity group using statistical techniques. Zhao and Dungan [13] used a revised control chart technique by adopting the average productivity as the center line instead of the arithmetic mean of the individual productivity values from different reporting periods/sections, which can address the production differences among reporting periods/sections. Contemporaneous project information is useful to refine the selection of productivity baseline.

Work Day	Labor Hours	Output (lf)	Calculated Productivity (hr/lf)	Notes in Daily Reports
1	198	54	3.67	
4	200	54	3.70	Muddy site
5	200	60	3.33	Utility conflict
6	122	36	3.39	Utility conflict
12	200	50	4.00	
15	120	42	2.86	
16	120	31	3.87	Utility conflict
18	120	44	2.73	
19	120	35	3.43	Utility conflict
20	120	37	3.24	
21	200	50	4.00	Come back work
22	220	86	2.56	
24	200	58	3.45	
26	200	49	4.08	Muddy site
27	160	45	3.56	
29	200	54	3.70	
31	220	73	3.01	
32	200	54	3.70	Come back work
33	200	54	3.70	Come back work
34	120	30	4.00	Come back work
35	120	48	2.50	Come back work

Table 3 — The Good Productivity Group for 15" VCP Installation

The IBM is applied to the example. The overall average productivity for this example is 4.09 hr/lf. All the work days on which the productivity is less than 4.09 hr/lf are assigned to the GPG, which is summarized in Table 2, and the remainder is then assigned to the BPG. Then the revised control chart technique applied to the GPG. The average productivity and standard deviation for the initial control chart data set are calculated to be 3.41 hr/lf and 0.48 hr/lf respectively. Correspondingly, the LCL is 1.96 hr/lf while the UCL is 4.86 hr/lf. As demonstrated in Fig. 4, the calculation stops because no extreme points need to be eliminated. Therefore, the baseline subset contains 21 data points (reporting periods), the same as the GPG, and the baseline productivity is 3.41 hr/lf.

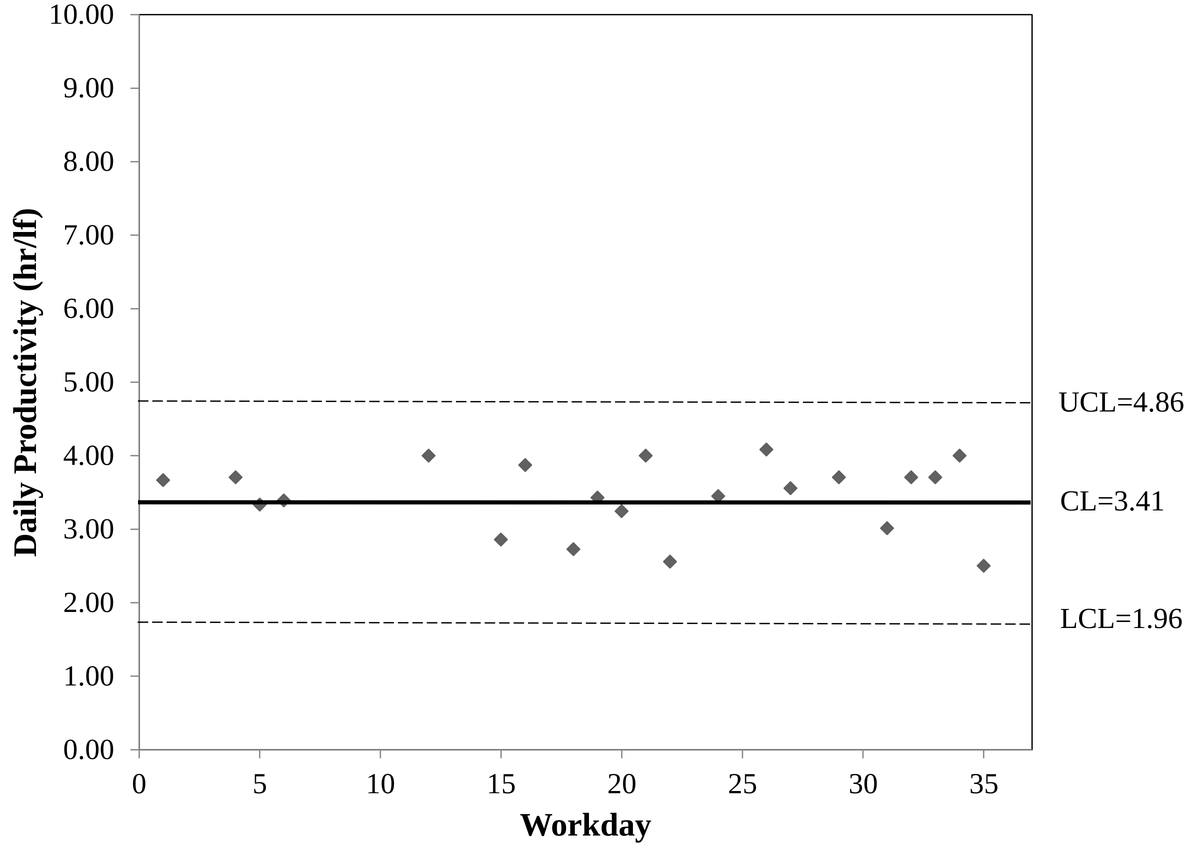

Figure 4—The Revised Control Chart for the GPG

In the IBM, the first step significantly narrows down the range for the data set that contains the baseline subset. Even without the second step, the first step would provide a reasonable approximation for the baseline productivity. The second step is for fine-tuning purpose to eliminate extreme data points, which do not represent the contractor's normal productivity from the GPG. Some of the extreme data points may be caused by clerical errors, data update delays, or the inclusion of dissimilar work and/or assignable disruptions on some data points.

Considerations for the Build-Up and Tail-Out Effects

Productivity is commonly impacted by the effects of build-up and tail-out during construction. In Zink's procedure, the first and last 10% of the reporting periods are deleted due to the effects of build-up and tail-out. There is, however, no evidence that 10% is a reasonable percentage. In some instances, the productivity decline at the end of construction may be due to the come-back work attributable to the owner, and thus it may not be reasonable to impose an arbitrary tail out period. In this paper, the following rules are proposed to eliminate the use of the arbitrary figure of 10% for the cases without any other assignable causes at the beginning and end of construction:

1. If some of the first 10% reporting periods are members of the GPG, the build-up effect should end before the earliest of them. In other words, once the productivity reaches the normal level, the build-up effect is deemed to have been overcome.
2. If some of the last 10% reporting periods are members of the GPG, then the tail-out effect should not start until after the latest of them.

The explanation is that if a reporting period is in the GPG, it and its successors should not be in the build-up period; similarly, it and its predecessors should not be in the tail-out period, because the productivity reaches a level near the normal operating process and the effects of build-up and tail-out can be neglected.

Although it is not uncommon that build-up and tail-out effects are encountered during construction, the rule of thumb to use 10% should not be considered as a general rule, as those effects vary from project to project. The duration and impact of those effects for a project should be determined based on the cause and effect analysis specifically for that project.

For the case study, the data points of day 1 and day 35 are in the GPG. According to the proposed rules to identify the build-up and tail-out periods, the build-up and tail-out effects can be ignored in this case study because the productivity of days 1 and 35 are within a range of normal operating performance.

Conclusions

This paper has compared various methods to perform the measured mile/baseline calculation through a case study, in which the advantages and weaknesses with the existing methods are demonstrated:

Zink's method was the first systematic procedure to determine the measured mile. It requires the measured mile to be impact free and continuous in time, which may not be applicable in many projects. The 10% build-up and tail-out periods are arbitrary and the details for selecting the linear or near linear portion that represent the most efficient rate of progress have yet to be refined to reduce subjectivity.

Thomas made great contributions to the improvement of the measured mile methodology by introducing the baseline concept, which overcomes the restrictions of impact free and continuously measured mile. But Thomas's procedure selects baseline using production instead of productivity, and includes the arbitrary 10% requirement for the baseline sample size.

Gulezian and Samelian's method is a useful tool to identify extreme data points. When the productivity value of a reporting period falls out of the control limits, it can be viewed as unusual compared to all others that are within the control limits. However, when the majority of the reporting periods experienced disruptions, it is not surprising to expect that no data points would be beyond the control limits, like the case study in this paper. Therefore, Gulezian and Samelian's method may not work well for the cases with pervasive disruptions throughout the reporting periods.

Ibbs and Liu's method uses the K-means clustering technique to divide productivity data into two groups, "unimpacted" and "impacted." As reported in the literature [13], there could exist multiple competing productivity baselines using K-means clustering technique. This certainly would undermine an objective analysis. Ibbs and Liu's method did not evaluate whether the data in the baseline set falls in contractor's normal productivity range.

Zhao and Dungan's IBM not only combines the advantages of the above methods, but also avoids their weaknesses. It does not require a continuous, unimpacted period for the baseline subset which is similar to Thomas's and Ibbs and Liu's methods. But the definition of the baseline set is revised to be the periods in which the productivities reflect the contractor's unimpacted or least impacted normal operating performance to eliminate the inconsistency between baseline definition and method implementation in Thomas's method.

Since a unique baseline subset is determined using impartial, basic statistical techniques, the IBM is more objective than other methods. The productivity data are first divided into two groups, the GPG (which could be used as a reasonable quick approximation for the baseline) and BPG, according to the overall average productivity value, and then the GPG is refined to be the baseline subset by eliminating the extreme data points.

In the IBM, the sample size of the baseline subset is not decided by an arbitrary percentage; it relies, instead, on the characteristics of the productivity data itself. This is similar to Ibbs and Liu's method, but the IBM's solution on the baseline productivity is unique which is different from Ibbs and Liu's method. Further, the IBM eliminates extreme data points that do not represent the normal operating performance, while Ibbs and Liu's method does not.

As presented above, this paper discussed various methods to help determine the measured mile for productivity analysis, especially on projects where the measured mile is not readily observable. Each of the methods has its underlying premises and assumptions. Applying these procedures without considering the underlying premises and assumptions may lead to erroneous measured mile calculation. Further, a cause and effect analysis is still needed to establish the causal link between the disruption and declined productivity, and verify that the measured mile determined by those methods is reasonable.

References

1. AACE International, 2004, **AACE International Recommended Practice No. 25R-03, Estimating Lost Labor Productivity in Construction Claims,** Morgantown, WV
2. Zink, D. A., 1986, *The measured Mile: Proving Construction Inefficiency Costs,* **AACE International Cost Engineering Journal, 28(4),** Pages 19-21, AACE International, Morgantown, WV
3. Zink, D. A., 1990, *Impacts and Construction Inefficiency,* **AACE International Cost Engineering Journal, 32(11),** Pages 21-23, AACE International, Morgantown, WV
4. Thomas, H. R., and Zavrski, I., 1999, *Construction Baseline Productivity: Theory and Practice,* **Journal of Construction Engineering and Management, 125(5),** Pages 295-303, ASCE, Reston, VA
5. Thomas, H. R., Riley, D. R., and Sanvido, V. E., 1999, *Loss of Labor Productivity due to Delivery Methods and Weather,* **Journal of Construction Engineering and Management, 125(1),** Pages 39-46, ASCE, Reston, VA
6. Thomas, H. R., and Sanvido, V. E., 2000, *Quantification of Losses Caused by Labor Inefficiencies: Where is the Elusive Measured Mile?,* **Construction Law and Business, 1(3),** Pages 1-14, Aspen Law & Business, New York, NY
7. Thomas, H. R., and Sanvido, V. E., 2000, *Role of the Fabricator in Labor Productivity,* **Journal of Construction Engineering and Management, 126(5),** Pages 358-365, ASCE, Reston, VA
8. Thomas, H. R., Horman, M. J., Minchin, R. E., and Chen, D., 2003, *Improving Labor Flow Reliability for Better Productivity as Lean Construction, Principle,* **Journal of Construction Engineering and Management, 129(3),** Pages 251-261, ASCE, Reston, VA
9. Thomas, H. R., Minchin, R. E., and Chen, D., 2003, *Improving Role of Workforce Management in Bridge Superstructure Labor Productivity,* **Journal of Management in Engineering, 19(1),** Pages 9-16, ASCE, Reston, VA
10. Thomas, H. R., 2007, *Quantification of Economics Losses Caused by Labor Inefficiencies,* **Proceedings of 2007 Construction Super Conference,** San Francisco, CA
11. Gulezian, R. and Samelian, F., 2003, *Baseline Determination in Construction Labor Productivity-Loss Claims*, **Journal of Management in Engineering, 19(4),** Pages 160-165, ASCE, Reston, VA
12. Ibbs, W., and Liu, M., 2005, *Improved Measured Mile Analysis Technique,* **Journal of Construction Engineering and Management, 131(12),** Pages 1249-1256, ASCE, Reston, VA
13. Zhao, T., and Dungan, J. M., 2014, *Improved Baseline Method to Calculate Lost Construction Productivity,* **Journal of Construction Engineering and Management, 140(2),** Pages 06013006-1 - 06013006-4, ASCE, Reston, VA

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