The most common ways of assessing labor productivity loss in construction claims attempts to determine the reduction in productivity from what a contractor would have achieved but-for an owner-caused disruption. This is accomplished, in one form or another, by comparing actual performance to some measure of the productivity expected to be experienced by the contractor under normal operating conditions. To date, the various methods used to accomplish this typically rely on the best information available on a case-by-case basis. None of the methods accurately captures the baseline productivity in all cases, which represents normal contractor operating performance. There is a way, however, to use a single general approach for determining a productivity baseline that reflects a contractor’s normal operating performance against which productivity in a dispute can be consistently compared. This can be accomplished by using longstanding statistical techniques that specifically address this type of problem and traditionally have been applied to other areas. An essential element of these techniques is the explicit consideration of the variability in individual productivity values that is not considered by existing methods.

The purpose of this presentation is to introduce a general objective approach for establishing a productivity baseline in construction claim cases that reflects a contractor’s normal operating performance. In order to fully achieve this goal we explain the basis for the approach and provide an understanding of the underlying methodology. The discussion begins with a section that provides a brief background about the existing methods for assessing damages. Fundamentals associated with the behavior of data and the basic tool used, a process control chart, are then provided. The next section outlines the productivity baseline method, which is a special application of a process control chart and provides results associated with a specific numerical example. An additional section discusses the implications of the approach for assessing liability and other potential uses of the methodology introduced.

DAMAGE ASSESSMENT APPROACHES

Various methods for quantifying labor inefficiency or diminished productivity have been used. Commonly used approaches for determining labor inefficiency are given as follows:

- Total cost
- Modified total cost
- Measured Mile
- Jury verdict
- Quantum meruit

The total cost method is the most basic approach for calculating damages, and subtracts the estimated labor costs, or bid, from the actual labor cost plus profit. Causal factors for which an owner is not responsible are not considered. These factors are considered in the modified total cost method, which subtracts from the actual cost the contractor’s bid estimate and the costs due to contractor errors. In the case of the measured mile, the actual cost associated with a disrupted work period is compared to a projected baseline estimate based on a nondisrupted work period, which is selected by the contractor or its experts. In its basic form, the projection is obtained as a linear extrapolation of the cumulative cost as a function of cumulative work completed.

Under the jury verdict method, a fair and reasonable approximation, or best guess, is made based on available information in the absence of information which is more reliable. The quantum meruit method considers reasonable profits in addition to reasonable costs of performance. A description of the various methods can be found in [3]. In addition to the various methods, labor productivity ratios based on industry standards have also served as a basis for inefficiency claims.

All of the methods that attempt to quantify labor inefficiency basically utilize aggregate figures corresponding to segments of a project, whether they are for a disrupted period, a nondisrupted period, or for the entire project duration. Productivity ratios based on industry standards, of course, are aggregated over numerous projects and do not apply to any specific construction project about which a claim is made.

Of the methods cited, the total cost approaches and the measured mile explicitly incorporate a quantifiable baseline representing normal operating performance, of sorts, into the determination of loss. In the case of the total cost approaches, the baseline is the bid price or the bid price adjusted for contractor faults. In the case of the measured mile, the baseline is a projection based on an undisrupted period of performance. Of importance is the fact that variability in individual productivity values is not specifically considered and incorporated into the methodology for determining a productivity baseline that reflects a contractor’s normal operating performance. Since variability is a property of all meas-
measurements, it is fundamental and should be considered in order to develop a meaningful baseline.

**FUNDAMENTAL CONCEPTS**

In order to obtain a better appreciation of the last point and how it relates to the productivity baseline method, it is instructive to review certain fundamental properties of data. This can be accomplished by first considering the plotted data presented in Figure 1, which corresponds to hypothetically generated productivity values in the form of 35 weekly unit rates. The unit rate is defined as the number of hours to perform a particular work effort divided by the number of units of output (e.g., 6 hrs/ft). Higher unit rates correspond to lower productivity. The work effort could involve any repetitive construction activity, such as, for example, land-fill removal, caisson drilling, pouring concrete, pulling wire, or installing pipe or conduit.

The values underlying Figure 1 represent an idealized series that were randomly generated, meaning that they are based on a single causal mechanism and that there exist no patterns attributable to other than natural or normal causes. In other words, although the individual productivity values appear to be somewhat scattered or disparate, the variability in productivity from week to week relating to the same basic activity is an idealization of what the contractor will ordinarily or naturally experience in the absence of contractor changes, faults, or other impacts. In such a case, the behavior of the productivity values cannot be explained further and no extreme or unusual values exist that correspond to different productivity levels. Such a process is said to be stable, or one that is in a state of statistical control. A process that is in a state of statistical control, therefore, is performing under normal operating conditions, and the average level of performance of such a process represents the baseline productivity level. Individual productivity values for any given week will lie above or below this average with varying magnitudes. How much these vary depends on the amount of inherent or natural variation, which is different from process to process.

Two fundamental requirements for establishing a productivity baseline result from the above comments: (1) a baseline productivity level should be determined on the basis of construction project values that correspond to a state of statistical control, and (2) a method is needed to determine which productivity values correspond to a state of control in an actual construction project in order to establish a productivity baseline. Clearly, the methods currently in use do not satisfy these requirements.

In order to meet the stated requirements, it is essential to explicitly consider variability in productivity. This is accomplished with the aid of a process control chart, which is a graphic device with limits representing the point beyond which values are considered as unusual and do not correspond to normal operating conditions, or are considered to be due to factors other than chance [1]. A process control chart applied to the original data depicted above is presented in Figure 2.

The control chart is comprised of three lines imposed on the graph: (1) a center line, CL, (2) an upper control limit, UCL, and (3) a lower control limit, LCL. The center line corresponds to the average, or arithmetic mean productivity level, and when typically constructed limits are used, the limits are set at three standard deviations above and below the mean. That is,

\[
\text{Center Line, } CL = \text{Arithmetic Mean Productivity} \tag{1}
\]

\[
\text{Upper Control Limit, } UCL = \text{Mean} + 3 \text{ Standard Deviations} \tag{2}
\]

\[
\text{Lower Control Limit, } LCL = \text{Mean} - 3 \text{ Standard Deviations} \tag{3}
\]

The standard deviation is the most commonly used measure of variability in statistical work.

Points falling within the control limits are said to be in control, and are attributed to natural or common causes of variation. Points falling outside the limits are attributed to assignable causes of variation, or factors affecting the process that cause the average to change. Although there appears to be variation in productivity evidenced by high and low spikes about the center line in Figure 2, all points, in fact, fall within the control limits, which is to be
expected since we already know that the series behaves in control. It should be noted that in the case of a productivity claim, values above the upper control limit are mainly of interest since these correspond to unusually low levels of productivity.

In summary to this point, we have introduced the concept of variation in individual productivity values, which has not been explicitly considered in existing baseline determination methods associated with productivity loss claims. By illustrating this in terms of an idealized series, a clearer reference frame has been established for the use of a process control chart. The process control chart is the basic tool that can be used to uncover unusual productivity values in order to isolate those representing a contractor’s normal operating performance and to establish a productivity baseline.

THE PRODUCTIVITY BASELINE METHOD

Productivity data are not automatically available in the form described above. In addition to normal operating performance on the part of the contractor, other factors affect productivity, some of which may be attributed to the contractor while others may be attributed to the owner or to other external factors. The process control chart can be used to identify productivity values that are unusual; however, it does not automatically indicate where the responsibility lies. This must be obtained from construction project records or other available information.

In order to illustrate how the control chart is used to establish a productivity baseline, let us consider another simplified productivity series resembling the data presented in Figure 1, but with clearly impacted productivity values, not specifying any reason or causal basis for the impacts. This series is displayed in Figure 3. We see from the figure that eleven values corresponding to weeks 11-15 and 26-31 vary about higher levels than the rest of the series, which possibly is evidence that something unusual with respect to productivity is occurring relative to the rest of the project. What is needed is an objective method for identifying points such as these in any series of productivity measures, which then can be eliminated in order to isolate the baseline productivity level from which damages would be measured.

The method for determining the productivity baseline is to employ a process control chart successively in stages to the data, eliminating points out of control at each stage until no points fall outside the control limits. At the first stage, the mean and standard deviation of all the project data are calculated and used to obtain the control limits. Points outside the control limits are eliminated, and the calculations are performed with the remaining data. This process is repeated until no additional points fall outside of the control limits. The center line of the resulting control chart, or final chart, is the productivity baseline. The method is discussed in more detail in [2]. Since high unit rates are of primary concern, those above the upper control limit are the ones mainly of interest to remove.

### Table 1—Summary of Successive Stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Week Number of Productivity Values Removed</th>
<th>Unit Rates</th>
<th>UCL</th>
<th>LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27, 30, 31</td>
<td>10.3, 9.7, 9.3, 8.75</td>
<td>2.07</td>
<td>5.41</td>
</tr>
<tr>
<td>2</td>
<td>11, 15, 26, 28</td>
<td>8.2, 8.1, 8.0, 8.5</td>
<td>7.90</td>
<td>2.10</td>
</tr>
<tr>
<td>3</td>
<td>12, 13, 14, 29</td>
<td>6.7, 6.9, 7.1, 7.5</td>
<td>6.45</td>
<td>2.64</td>
</tr>
<tr>
<td>Final</td>
<td>--</td>
<td>--</td>
<td>6.17</td>
<td>2.09</td>
</tr>
</tbody>
</table>
Figure 4 depicts the final control chart based on four applications of the control chart applied to the data underlying Figure 3. Based on Figure 4, we see that the impacted points indicated above fall outside the upper control limit. The values of the control limits in the diagram represent the limits calculated on the basis of the productivity data with these points eliminated. The corresponding center line, CL, is equal to 4.13 units of labor per unit of output is the productivity baseline. That is,

Baseline Productivity = Center Line of Final Control Chart = Arithmetic Mean of Productivity Values in Control

(equation 4)

A summary of the results at the successive stages is provided in Table 1.

APPLICATIONS

Once the final control chart is obtained and values indicated as out of control have been isolated, an assessment of these individual productivity values can be made on the basis of project records and field information regarding the underlying cause associated with the impact. Since the method described does not indicate why the values are unusual, one cannot automatically conclude that they are as a result of an owner-caused event. Consequently, in addition to establishing a baseline, by identifying unusual values the final control chart may be used to assess potential owner liability on a week by week basis, in this case. If owner responsibility is associated with particular productivity values, each can be individually compared to the baseline productivity and converted to total hours and corresponding dollar values to obtain a total productivity loss amount.

The methodology introduced is retrospectively applied to construction project data in order to establish a baseline productivity level. The approach has a longstanding history in manufacturing, and more recently within the past 15 or so years in service industries, to establish targeted levels of performance and as a basis for process improvement. Applications of the control chart concept, therefore, may also be used prospectively for purposes of process monitoring and control in construction. On a prospective basis, the control chart can be used to anticipate impacts of all kinds, and possibly minimize their potential effects on productivity by taking early remedial action to overcome the cause of disruption and its adverse impact on productivity.

The primary goal of this presentation is to introduce a more scientific approach for determining a baseline that can be used in productivity loss disputes in construction. Our intent is to provide a single overall approach that may be applied in many, if not all, cases and overcomes limitations of existing methods by measuring the productivity baseline under normal conditions of performance. The baseline productivity level is found by successively applying a process control chart to the actual project productivity data directly until a set of productivity values results that represents what the productivity data should look like under a normal pattern of operating performance in the absence of impacts. Of importance is the fact that the method allows one to isolate individual productivity values, rather than aggregate and summary quantities, which may be used as inputs into loss determinations.

Second, the proposed method provides a basis for assessing whether or not liability exists, and if so, the extent of the liability. Also, once the extent of liability is established, productivity values are identified that become the basis for loss determinations. In addition, the result of the procedure introduced can be used prospectively for construction project monitoring in order to possibly prevent or mitigate adverse impacts.

Although the data required to use the control chart approach is similar to that used in some of the other approaches to loss determination, more attention must be given to database management. With the ever more frequent use of computerization in construction, this should not pose a problem for even the smallest of subcontractors. Finally, the example employed in this presentation was simplified in order to convey the main ideas underlying the methodology introduced. More complex data configurations that would be encountered in construction might require modifications to the method presented here; however, the basic underlying principles and procedures still would apply. Additional statistical techniques may be required to meet the needs of specific individual cases.

REFERENCES


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