Improved Measured Mile Analysis Technique

William Ibbs¹ and Min Liu²

Abstract: Quantifying lost labor productivity on construction projects is difficult and sometimes subjective. A widely accepted way to quantify losses is the “measured mile” approach. It compares periods of a project that have been impacted by change to those that have not been impacted. As currently practiced the measured mile relies on subjectively identifying that reference period. In this paper the measured mile and a variant, the baseline method, are analyzed and compared to a new, proposed statistical clustering method. This new approach is advocated because it determines its reference period using objective criteria. A case study is included to show how the three methods work, and advantages and disadvantages of each method are presented in this paper.

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Introduction

Diekmann and Nelson (1985); Semple et al. (1994); and Ibbs and Allen (1995), among many others, have written about the epidemic of claims in the construction industry. There are many different types of claims. Schedule delays, design issues, and differing site conditions are among the most common (Hester et al. 1991). The costs of such claims are rooted in various factors such as extra material costs and standby equipment time. One key factor is the lost labor productivity associated with such disruptions. No reliable estimates on the size or value of lost labor productivity could be found, but it is certainly a major portion of the $65 billion total claim figure reported by Ibbs and Allen (1995).

Supporting and evaluating cost overrun claims because a contractor has suffered labor productivity problems are difficult undertakings. Industry guidebooks (NECA 1976; USACE 1979; MCAA 1986) are one source. They are suspect though because parties with vested interests have developed them and their underlying research methodology is unclear.

Hanna (Hanna et al. 1999a,b); Ibbs (Ibbs and Allen 1995; Ibbs 1997; Ibbs et al. 1998, 2003); and Leonard (Leonard 1988) have tried to fill the gap by independently benchmarking projects. The result has been industry standard statistics, which are somewhat useful. These techniques are based on data collected from a large number of projects and deriving regression curves that show the impact that change has on labor productivity.

Another approach for computing lost productivity is the measured mile approach (Zink 1986). In this technique, periods of unimpacted production are compared to periods in the same project that have suffered substantial productivity loss strictly because of one party’s actions (say the Owner). That party (the Owner) is then assigned responsibility for this difference.

In cases where a pure, unimpacted portion of the project cannot be found, a baseline may be defined (Thomas and Sanvido 2000a). From the claimant’s perspective this is a conservative measurement because the baseline productivity may still include some lost productivity. But because responsibility for that lost productivity cannot be easily measured and clearly assigned to the respective parties, the claimant uses the baseline period as a reference, even though some lost productivity may still be intertwined in the baseline rate.

There are substantial limitations with these methodologies though. The measured mile method, as defined by Zink, requires that its reference productivity come from a continuous, uninterrupted period. That is not always available though. The baseline method has the shortcoming of using daily output to identify the reference period instead of daily productivity. The result is questionable because daily output may vary because of crew size, not just productivity.

A major problem with both these methods is that they use subjective methods to identify the unimpacted reference periods. The baseline method, as described by Thomas, multiplies the duration of a project by 10% (say 10% of a 100 day project duration= 10 days). Then the productivity of those “top 10%” days is computed by averaging the productivities achieved during those days. The basis for using 10% is clearly arbitrary.

To overcome these shortcomings a new statistically based methodology for baseline calculation is proposed in this paper. The mechanics of the procedure are explained through a case study as are the advantages and disadvantages. This new approach to labor productivity loss calculation is valuable to project managers because it provides a scientific basis for determining damages more fairly. Injecting more objectivity into the claims resolution process will, in turn, help stem the rising costs of such disputes because the litigating parties will have a more rational

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tool for evaluating the merits of their respective positions in the dispute.

A note about the definition of productivity as the term is used in this paper. In the research literature two inverse definitions are used: (1) input/output (workhours/units of work), and (2) output/input (units of work/workhours). The first definition is used in this paper to be consistent with Thomas and Sanvido (2000b). This choice is just a matter of personal preference, however, the concepts presented here are still relevant if the other definition is used.

### Previous Research

The measured mile method and its variant, the baseline method, are two methods routinely used to measure lost labor productivity claims.

### Zink's Measured Mile Method

Zink introduced the measured mile concept in Zink (1986, 1990). This method distinguishes itself from other methods because it allows specific impacts to be isolated while accounting for other inefficiencies inherent in the work being performed. It is not based on generalized industry averages (which may be inappropriate for a particular project), nor does it assume that all inefficiencies are attributable to the owner, as in the total cost method (Chitester 2003).

The measured mile method involves a comparison of productivity during an unimpacted period of time with productivity during an impacted period of time. The productivity is calculated for both periods of time and the difference between the two is the lost productivity attributed to the impact. Ideally the measured mile is a continuous period of time during the project when the labor productivity is unimpacted (Thomas and Sanvido 2000a).

According to Loulakis and Santiago (1999), the following guidelines should be followed in choosing a measured mile: (1) the work performed during the mile should be substantially similar in type, nature, and complexity to the work that was affected; and (2) the composition and level of skill of the crews should be comparable. The measured mile should also represent reasonably attainable labor productivity levels.

Zink (1986) proposes defining and calculating the measured mile using the following three-step procedure:

1. Plot the actual workhours expended on a project versus percent of work complete (workhours on the ordinate and percent complete and time frame associated with percentage complete on the abscissa); and
2. Because the first and last 10% are “build-up” and “tail-out” and are not representative of expected or average sustained cost, delete the first and last 10% and only deal with the intermediate 80%; and
3. Identify a reasonable linear or nearlinear portion in the 80% of the labor curve, which shows an unhindered segment defining the most efficient rate of progress. This will be the measured mile.

Though in theory the measured mile calculation is straightforward, in practice, it has the following difficulties:

1. Calculating losses attributable to a specific impact requires very detailed and reliable information. In other words, good productivity record keeping is essential for a measured mile analysis. It requires considerable time and effort to record and identify owner- or contractor-caused inefficiencies every day on every particular activity. Many contractors do not keep this level of detail, especially on projects that have extensive changes.
2. Some people argue that the measured mile should be a “continuous period of time when the labor productivity is unimpacted” (Thomas and Sanvido 2000a). However, in many projects the work disruptions are so pervasive that there is no consecutive stretch of unimpeded work, and hence no measured mile period.
3. The size of the measured mile sample should be “reasonable” (Zink 1986; Loulakis and Santiago 1999). But no unanimity or clearly defined standard exists about the meaning of “reasonable.” As will be seen later in the presented case study, some of the current guidelines yield sample sizes that are too small.

### Thomas’s Baseline Method

To address some of the measured mile’s weaknesses, Thomas introduced the baseline concept (Thomas and Sanvido 2000a). A baseline period is a period of time when the contractor performs his or her best productivity. It is not necessarily a continuous, unimpacted time frame, nor is it a purely unimpacted period; owner- and contractor-caused inefficiencies may be present throughout. When there is a continuous, unimpacted time frame the measured mile and the baseline periods are one and the same. However, there are many situations where a baseline period can be identified but no measured mile is apparent. Table 1 summarizes the important differences between the measured mile and the baseline period methods. According to the definition of measured mile (Zink 1986), the purpose of measured mile calculation is to find periods without owner-caused impacts. A measured mile has to be a consecutive set of time periods. Thomas’s baseline method does not require it to be a consecutive period. But it specifies the baseline size, 10% of project duration.

Thomas describes the mechanics of the baseline method in a

<table>
<thead>
<tr>
<th>Table 1. Comparison of the Measured Mile and Baseline Calculation Methods</th>
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</thead>
<tbody>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td>Causes of delay</td>
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<td>Consecutive time periods?</td>
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<td>Record of delay causes needed?</td>
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<td>Sample size</td>
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<td><strong>Baseline</strong></td>
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<td><strong>Sample size “Reasonable”</strong></td>
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<td><strong>Record of delay causes needed?</strong></td>
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<td><strong>Consecutive time periods?</strong></td>
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<tr>
<td><strong>Causes of delay</strong></td>
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<td><strong>Purpose</strong></td>
</tr>
</tbody>
</table>
4. For these days, make note of the daily productivity; and
3. The contents of the baseline subset are selected as the
Disadvantages of baseline method include:
Compared to the measured mile method, the baseline method has
1. Determine 10% of the total workdays;
2. Round this number to the next highest odd number. This
number should not be less than 5. This number \( n \) defines the
size of (number of days in) the baseline subset;
3. The contents of the baseline subset are selected as the \( n \)
workdays that have the highest daily production or output;
4. For these days, make note of the daily productivity; and
5. The baseline productivity is the median of the daily produc-
tivity values in the baseline subset. [Thomas is inconsistent
here though. In at least one case he uses the average, not the
median value of a baseline subset (Thomas et al. 2002). Statis-
tically, the average of a set of data is not always equal to
its median.]

Compared to the measured mile method, the baseline method has
certain advantages:
1. The baseline method does not require records with the same
level of detail as the measured mile method. The measured
mile requires a production period that is free or essentially
free of productivity disruptions. The baseline method, on the
other hand, does not require such fine filtering. Such filtering
will generally require much more detailed job records, so the
baseline method may be less onerous in this regard.
2. In the cases where no measured mile is apparent or available,
a baseline productivity rate can still be determined and used
to measure change.

Disadvantages of baseline method include:
1. It is highly subjective. There is no evidence that 10% of the
whole daily productivity is a reasonable or well-accepted
percentage to represent the best performance a contractor
could achieve. Every project is different. Although 10% of
the project’s duration might be a suitable reference period for
some projects, it is impractical to deem it a universally
applicable number for all the projects. Moreover, this 10%
percentage is presumably 10% of the time that similar work is
being performed, not 10% of the total project, which may
consist of a series of quite dissimilar work categories.
However, Thomas is unclear on this.
2. This procedure selects the contents of the baseline subset “as
the \( n \) workdays that have the highest daily production or
output.” Daily output might be maximized by crew size.
Therefore certain days could be selected as the baseline,
which are not truly indicative of the achieved productivity.

New Methodology—Statistical Clustering

Based on the shortcomings of those methods, a new method for
baseline calculation is proposed herein. The basic principle of
labor productivity loss calculation—comparing the unit produc-
tivity in an unimpeded time period to that achieved in the claimed
disrupted time period—is still used. The central idea of the sta-
tistical clustering method is to separate the data into different
groups. The basis for that dividing operation is the similarity of
the data points. In other words, all the data divided into the same
cluster group should have comparable productivity values. In this
easy we use the clustering method to assign the productivity
data points into one of two groups, either an “unimpacted” group
or an “impacted” group.

Statistical cluster analysis methods are pertinent for this type
of data analysis problem and can be divided into (1) hierarchical
and (2) nonhierarchical clustering techniques (Dillon 1984). The
hierarchical techniques organize data into a tree-like graph based
on similarity. All data points start in individual clusters, and at
each step of the clustering process the two closest clusters are
merged until only one cluster remains. For example, there will be
10 clusters at the first level if there are 10 data points in total. At
the next level the two closest data points (clusters) are fused, say
the sixth and eighth data points are fused because the distance
between these two points is the smallest among all the pair to pair
combinations of the 10 data points. Then at the third level a new
object joins the cluster containing the two previous data points, or
another two-object cluster is formed, with the decision resting on
some assignment criterion. This assignment criterion might be
reaching a point where incremental improvements in the analysis
become “very small” at each progressive stage of the analysis.

The process continues in a similar fashion until eventually a
single cluster donating all objects is formed. In the hierarchical
method, once two data points are fused into one cluster, they are
never able to move out and form a cluster with other data points
individually.

Alternatively, nonhierarchical clustering techniques form clus-
ters by optimizing around some specific clustering criterion.
K-means clustering is a special form of nonhierarchical clus-
tering. The kernel algorithm of K-means is to first divide all data
points into \( K \) groups with cluster centers as widely distributed as
possible. Then the data points should be moved between the clus-
ters based on the distance between that data point and the \( K 
\) cluster centers. After the first iteration is complete, new clusters
are formed and cluster centers are updated accordingly. This pro-
cess repeats until there is no more change of cluster means or a
predefined maximum number of iterations has been reached.
The calculation process of K-means method for productivity
baseline identification has three basic steps.

Step 1: Select Initial Cluster Centers

Choose the maximum and minimum productivity value and use
them as the initial cluster centers, dividing the whole data set as
widely as possible.

\[
c_{10} = \text{Max}(x_1, x_2, \ldots, x_n) \quad (1)
\]

\[
c_{20} = \text{Min}(x_1, x_2, \ldots, x_n) \quad (2)
\]

where \( x_1, x_2, \) and \( x_n \) = first, second, and \( n \)th data point; \( c_{10}= \) first
original cluster; and \( c_{20}= \)is the second original cluster center.
For example, if we have 10 daily productivity values and the maxi-
mum value is 12.6 \( \text{w h/m} \) and the minimum value is 3.4 \( \text{w h/m} \),
we will use these two data points as our initial cluster centers,
\( c_{10}=12.6 \) and \( c_{20}=3.4. \)

Step 2: Update Initial Cluster Centers

Starting with the first case, each case in turn is assigned to the
nearest cluster and that cluster mean is updated. In this K-means
algorithm, the distance between a data point and a cluster center
is computed as a Euclidean distance, which is defined by
(Dillon 1984)

\[
D_{x_{ij}}(x_i, c_{ij}) = \sqrt{(x_i - c_{ij})^2} \quad (3)
\]
updated new cluster centers.

classification cluster centers. The result of step 2 provides the

\[ J \]

where

\[ c \]

between

\[ xi \]

\[ j \]

th iteration. The updated cluster means are the

\[ c \]

th iteration and

\[ c \]

first cluster center of the

\[ j \]

th iteration.

\[ \frac{N_1}{N_2} \]

where

\[ C_1 \]

= first cluster of the

\[ j \]

th iteration and

\[ C_2 \]

= second cluster center of the

\[ j \]

th iteration.

\[ D_{x,j}(x_i, c_j) = \sqrt{(x_i - c_j)^2} \] (4)

where

\[ x_i \]

= ith data point; \( c_j \) = first cluster center of the

\[ j \]

th iteration; and \( c_2 \) = second cluster center of the

\[ j \]

th iteration. \( D_{x,j}(x_i, c_1) \) = distance between

\[ x_i \] and \( c_1 \); \( D_{x,j}(x_i, c_2) \) = distance between

\[ x_i \] and \( c_2 \).

If \( D_{x,j}(x_i, c_1) < D_{x,j}(x_i, c_2) \)

Then \( x_i \in C_1 \), and

\[ c_1 = \frac{\sum x_i}{N_1} \] (6)

Otherwise, \( x_i \in C_2 \), and

\[ c_2 = \frac{\sum x_i}{N_2} \] (7)

Step 3: Assign Cases to the Nearest Cluster

Repeat step 2 until there is no more change of cluster means or

the maximum iteration number has been reached. The K-means

clustering implementation for baseline productivity calculations

can be programmed in spreadsheet software or directly used in

commercial software packages such as SPSS (Rachad 2003). An-

dvantages of statistical clustering are

1. It is subjective. In the statistical clustering method all daily

productivities are divided into two groups according to the

value. The impacted daily productivities and unimpacted
daily productivities are partitioned into two different groups.

2. There is no arbitrary, one-size-fits-all 10% rule for baseline

productivity calculation. All the baseline productivities are

calculated based on the project’s actual performance and

characteristics.

3. It is a simple and quick calculation method. The calculation

process can be programmed in spreadsheet software or the

SPSS statistical software.

Case Study

Project Description

An example from Thomas and Sanvido (2000b) is now used to

compare the three labor productivity loss calculation methods.

This example consists of 37 daily productivity data points for

HVAC ductwork in a three-story reinforced concrete building.

Table 2 contains the daily productivity data used in this case study

analysis. The first step using the measured mile procedure is to

transform daily productivity and workhours into cumulative

workhours and cumulative percent work completed (Columns 3

and 6 of Table 2). Actual workhours expended versus percent

complete is plotted in Fig. 1. Using Zink’s (1986) rules, the first

10% and the last 10% of the total project workhours are excluded

from analysis. Analysis of the actual workhours deals only with

the intermediate 80% of the project workhours. Following this

criterion the unhindered, linear portion of the actual workhour

curve occurs between Day 26 (64.46% work completed) and Day

31 (81.57% work completed). The computed measured mile value

is (2.62+4.89+3.12+2.72+3.15+2.85)/6=3.22 w h/m.

Next the baseline productivity method can be computed using

Thomas’s approach. By this procedure, the appropriate size of the

baseline subset is “five,” computed by taking 10% of 37 days and

rounding 3.7 to the next odd number (and not less than 5, accord-

ing to Thomas). Then those five workdays with the highest daily

production are identified. Identifying those days and dividing by

the workhours per day yields hourly productivities of 1.57, 1.44,

1.80, 2.62, and 2.10 w h/m (see Table 2). The median value

1.80 w h/m would be the computed baseline productivity. (Using

the average value, it would be slightly higher, 1.90 w h/m.) Fig. 2

shows the daily and baseline productivity rates. The K-means

calculation process includes the following three steps.

Step 1. Select Initial Cluster Centers

First, identify \( K \)=2 and choose the maximum and minimum

productivity values, and use them as the initial cluster centers.
The initial cluster centers are 1.44 (Day 17) and 7.31 (Day 32),

which divide the variable values into the two most widely separated

clusters. The result of step 1 is shown in Fig. 3.

Step 2. Update Initial Cluster Centers

Starting with Day 1, the productivity rate of 2.79 is assigned to its

nearest center, 1.44. Each subsequent number is assigned in turn

to its nearest cluster, and that cluster mean is updated accord-

ingly. For example, after assigning 2.79 to the cluster center 1.44,

the new cluster mean is 2.12=(2.79+1.44)/2. Then Day 2’s produc-

tivity, 6.36, is assigned to its nearest center, which is 7.31. The

new center mean is 6.84=(6.36+7.31)/2. This process continues

until the last day productivity, 2.99 is assigned to its nearest.

At the end of this step the new center means are 2.90 and 5.58. The

result of step 2 is shown in Fig. 4.

Step 3. Assign Cases to the Nearest Cluster

In this step, all 37 variables are assigned to the nearest cluster

center, starting at 2.79. The means of two centers are then calcu-

lated and updated. They are 2.85 and 5.44. This process is re-

peated until the maximum change of cluster centers in two suc-

cessive iterations is equal to 0. In this case the calculation stops at

the fifth iteration, with the final cluster centers being 2.76 and

5.20. The end result is that there are 26 data points in cluster 1

and 11 data points in cluster 2. The results of this calculation are

summarized in Table 2.

Using this statistical approach, the computed baseline produc-

tivity is 2.76 w h/m. The resulting baseline productivity is shown

in Fig. 5. For this particular case study, the statistical clustering

technique value, 2.76 w h/m, is between those values computed

using Zink’s and Thomas’s methods.

Discussion

Through the case study it is found that both current measured

mile and baseline calculation methods have some significant dis-

advantages (see Table 3). In Zink’s measured mile calculation

approach, six consecutive daily productivities (Day 26 to Day 31)

are identified as the measured mile period and the resulting mea-

sured mile productivity is calculated to be 3.22 w h/m. Although
Table 2. Labor Productivity Loss Calculation Process (Boldface Indicates Workdays in Baseline Subset)

<table>
<thead>
<tr>
<th>Work day</th>
<th>Work hours (w h)</th>
<th>Cumulative work hours (w h)</th>
<th>Total output (m)</th>
<th>Percent</th>
<th>Cumulative percent</th>
<th>Daily productivity Zink (w h/m)</th>
<th>Daily productivity Thomas (w h/m)</th>
<th>Daily productivity K-means (w h/m)</th>
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<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>40-</td>
<td>14.3</td>
<td>3.63</td>
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<td>2.79</td>
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<tr>
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<td>80-</td>
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<td>6.36</td>
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Fig. 1. Measured mile calculation—Zink’s method

Fig. 2. Baseline productivity calculation—Thomas’s methods
it is a widely accepted method and the result is neutral to both the owner and contractor, the calculation is based on identifying a consecutive set of workdays where productivity was unhindered. In practice, it is very hard to find a work period free from disruptions. In addition, because there is no clearly defined standard about what constitutes a “reasonable” time period, the method is highly subjective. In this case, it was 6 days, out of 37. In this case, the computed baseline productivity is very close to the average productivity.

Thomas’s baseline method has significant shortcomings, as illustrated by this case study. One shortcoming is that it identifies the baseline sample according to the best daily output or production instead of the best daily productivity. This method ignores one of the most important factors in the productivity calculation, namely crew size. As an example, Day 26 in the case study (with a productivity of 2.62 w h/m) is chosen instead of Day 36 (productivity=1.94 w h/m) because Day 26 has a higher output (15.2 versus 12.4 m). As a result the baseline subset represents the days with highest outputs instead of the best productivity, which contradicts the definition of a baseline.

Another problem with this method is that the 10% requirement for the baseline sample size is arbitrary and not founded on scientific principles. Because each project has different productivity performance, a fixed percentage is inappropriate. There is also the problem of whether median or average values should be used. In this simple example, the difference between median and average values is notable (1.80 versus 1.90 w h/m). Also in this case the 10% selection method results in a measured mile productivity value of about half of the average productivity (51.72% for Thomas’s median method and 54.60% for Thomas’s average method). The disparity can undermine an objective analysis.

The proposed statistical method has the same advantages of the measured mile and baseline methods, yet avoids their shortcomings. As is the case with the other two methods, this proposed approach uses actual data from the subject project. It also has the advantage that a continuous, unimpacted period is not required. One of the main disadvantages of Zink’s method is thus avoided.

The prime advantage of this new method is that it is more objective and neutral than the baseline method because the reference period is selected using an impartial statistical clustering procedure. Using the K-means method, the daily productivities are divided into two groups, “unimpacted” and “impacted.”

Another advantage of the statistical method is that the sample size is defined by the characteristics of the data themselves, not an arbitrary, predefined rate, like Thomas’s 10%. In this case study, the statistical method has a much larger sample size (70.27% of the entire data set). Zink’s and Thomas’s methods use 16.21 and 13.51%, respectively. The statistical clustering productivity rate (2.76 w h/m) is in between that computed by Thomas’ method (1.80 w h/m using the median and 1.90 w h/m using the mean) and Zink’s (3.22 w h/m). Therefore the statistical method realizes the advantages of Zink’s and Thomas’ methods while avoiding their shortcomings.

Admittedly the statistical method has a somewhat more complicated calculation process. With the aid of SPSS or other statistical software packages the calculation process can be completed quickly and effectively.

<table>
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<th>Table 3. Comparison of Calculation Results</th>
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<tr>
<td>Method</td>
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<tr>
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<tr>
<td>Thomas (median)</td>
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<tr>
<td>Thomas (average)</td>
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<td>K-means</td>
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The suggested process to use the statistical method is illustrated in Fig. 6. After collecting the daily productivity data and identifying comparable periods of a project, we can use the K-means method to calculate baseline productivity based on different project performance.

Conclusions

The purposes of this paper are to (1) summarize the technical aspects of various measured mile techniques, (2) identify weaknesses with the existing methods, and (3) introduce a new method that overcomes such weaknesses. A case study analysis reveals that the proposed method is the best choice for productivity loss calculation because it calculates baseline productivity and disruption effects in a much more objective manner. The new method requires minimal extra computational effort.

It is hoped that this new method will make a positive difference in the world of claims. If used properly and proactively, parties may be able to resolve expensive and rancorous disputes in a way that is faster, less expensive, and less painful.

Notation

The following symbols are used in this paper:

\[ C_{1j} = \text{first cluster of the } j\text{th iteration}; \]
\[ C_{2j} = \text{second cluster of the } j\text{th iteration}; \]
\[ c_{1j} = \text{first cluster center of the } j\text{th iteration}; \]
\[ c_{2j} = \text{second cluster center of the } j\text{th iteration}; \]
\[ c_{10} = \text{first original cluster center}; \]
\[ c_{20} = \text{second original cluster center}; \]
\[ D_{x_i}(x_j, c_{1j}) = \text{distance between } x_i \text{ and } c_{1j}; \]
\[ D_{x_i}(x_j, c_{2j}) = \text{distance between } x_i \text{ and } c_{2j}; \]
\[ K = \text{number of clusters requested}; \]
\[ N_{1j} = \text{number of data points in the first cluster of the } j\text{th iteration}; \]
\[ N_{2j} = \text{number of data points in the second cluster of the } j\text{th iteration}; \]
\[ w/h/unit = \text{workhour/unit of work}; \]
\[ x_i = \text{ith productivity data point}; \]
\[ x_n = \text{nth productivity data point}; \]
\[ x_1 = \text{first productivity data point}; \]
\[ x_2 = \text{second productivity data point}. \]

Subscripts

\[ 1, 2, i, n, K, j, N = \text{positive integer indices}. \]

References


