CONSTRUCTION PRODUCTIVITY AND PERFORMANCE MEASUREMENT

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Abstract—*By whatever name—work sampling, activity sampling, or productivity measurement—the process of analyzing the activities of a construction workforce to establish the percentage of time craft workers spend in various productive and nonproductive activities provides a project team with valuable information. Using work or activity sampling as a cornerstone of a productivity evaluation program, the project team obtains an objective measure of the success of the execution effort.*

This paper describes a programmatic approach to evaluating productivity. In doing so, it discusses various methods of using activity sampling to gather project data, ways to present data for analysis, data interpretation, evaluation frequency, the statistical basis for activity sampling (including margin of error), and steps to minimize bias. The paper also discusses the desired characteristics of the personnel gathering the data, as well as the advantages and limitations of this programmatic approach to activity analysis and the results obtained.

Keywords—*activity analysis, activity sampling, construction productivity, craft productivity, productivity measurement, work sampling*

INTRODUCTION

Work or activity sampling has been used for years as a means of measuring time spent "working" during the work shift. By defining a set of productive and nonproductive work categories to use as measures, the process provides a statistically valid set of data about a work environment. Observers collect random data points or observations during randomly conducted workplace data collection tours. Once the data have been collected and percentages calculated, the project team can evaluate the data to identify any impediments to work completion. The team can then act to eliminate or ameliorate the impediments.

This programmatic approach to improving productivity, commonly referred to as *activity analysis*, incorporates activity sampling as one phase of the analysis cycle. Using a standard set of work categories, activity analysis addresses the methodology for determining sample size and collecting observations, as well as strategies to implement during the data collection process to facilitate data evaluation. Because activity analysis is dynamic, sample results change throughout a project's lifecycle. Barriers created during the various phases of the construction process can be identified, and the project team may take steps to resolve the issue, fulfilling the role of a continuous improvement process.

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BACKGROUND

Work or activity sampling has been used as a process evaluation tool since the early part of the twentieth century. During the late 1920s, L.H. Tippet's application of statistical models to equipment used in the textile industry eventually led to improved production and utilization efficiency. [1] Over time, the application of statistical models became a standard technique of industrial engineering practice.

In the mid 1970s, it was determined that statistical methods could be used in the construction industry to aid in evaluating workforce activity and provide management with a tool to identify and remove productivity barriers.

The term *work sampling* is generally used in the industrial engineering field. Because the actual practice involves observing individuals or equipment and categorizing them by the activity they are performing at the time, the term *activity sampling* is used in this paper. [2]

The value of activity sampling lies in its flexibility. Categories can be designated to measure specific activities in the work operation. The results are statistically accurate as long as the sampling rules and criteria are consistently followed. One item to note is that the flexibility of the process has, over time, led to variations in work category definitions among the different organizations that have implemented the process. This variation limits the ability to compare the results of one sampling system to those of another.

A sample taken at random from a large population tends to have the same distribution as the large population.

Activity sampling is based on the laws of probability. A sample taken at random from a large population tends to have the same distribution as the large population. If the sample is of adequate size, the characteristics of the sample mirror those of the large population. Therefore, if the activities of a worker or machine are observed and recorded at random times during the work shift, the percentage of the time recorded as spent in each activity during the data collection tour is representative of the time actually spent in each activity during the entire work shift. At a summary level, the overall time spent during a work shift is characterized as either working versus not working or, as shown in **Figure 1**, productive versus nonproductive.

Activity sampling lends itself to further partitioning because the general activities routinely engaged in by the population being observed may be subdivided into various categories of productive or nonproductive work. These categories may then be applied to the specifically observed activities. A typical distribution of time spent on a set of activities is shown in **Figure 2**. In this case, the productive work activities consist of direct work, preparatory work, tool and equipment activity, and material handling, while the nonproductive work activities consist of waiting, travel, and personal.

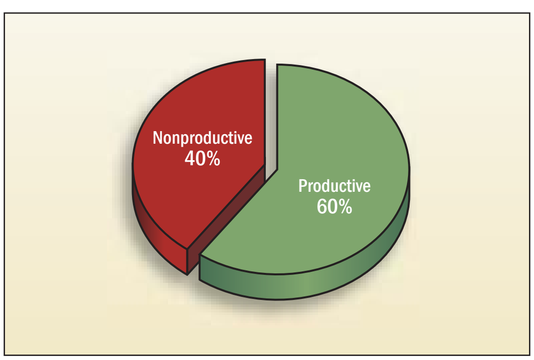

Figure 1. Distribution of Productive Time vs. Nonproductive Time During a Typical Work Shift

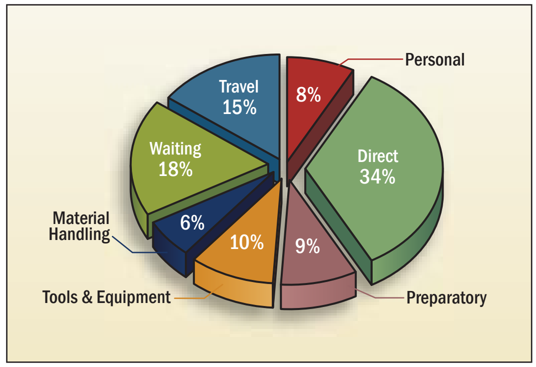

Figure 2. Distribution of Activities in a Work Shift

ACTIVITY SAMPLING THEORY AND SAMPLE SIZE

Initially, it is necessary to determine the level of confidence desired in the final activity sampling results. Assuming normal distribution, the most common level is 95%. As shown in **Figure 3**, the area under the normal curve encompassed by two standard deviations (2σ) on either side of the mean (μ) is 95.45%, which rounds to 95%. This means that there is a 95% probability that the results from the random observations—in this case, activity sampling—are representative of the entire population, and there is 5% probability that they are not. [1]

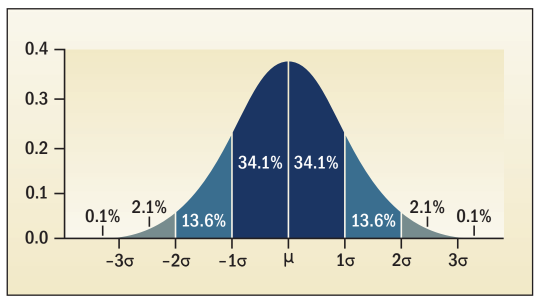

Figure 3. Area Under the Normal Curve

Another major factor to be determined is the desired confidence interval, or degree of accuracy, of the activity sampling results because it affects the number of observations that need to be made. For illustrative purposes, consider a confidence interval of ±5% as reasonable, with a 95% confidence level. Assuming that normal distribution is used as the basis for determining the sampling error, then the number of observations required is based on the following formula [1]:

$$S_p = 2\sqrt{\frac{p(1-p)}{N}}\,, \qquad (1)$$

where S = desired degree of accuracy, p = percentage expressed as a decimal, and N = number of random observations (sample size).

If 60% productive work versus 40% nonproductive work is taken as the initial target, then, from Equation 1, with p = 60% = 0.60 and S = ±5% = 0.05,

$$N = \frac{4\,(1 - p)}{S^2\,p} = \frac{4\,(1 - 0.60)}{0.05^2\,(0.60)} \approx 1{,}067\,.$$

Thus, the initial target number of observations required is 1,067. As the study progresses, the actual sample size needs to be validated based on the actual results from the sampling, as discussed later.

ACTIVITY ANALYSIS: A PROGRAMMATIC APPROACH TO EVALUATING PRODUCTIVITY

In construction, work or activity sampling is useful because the data help identify conditions that may be hindering the ability of craft workers to complete the work. Once the conditions are identified, the project team can take action to eliminate or ameliorate these hindrances to craft worker productivity.

As illustrated in **Figure 4**, activity analysis, as a programmatic approach to evaluating productivity, incorporates a cyclical process of measuring performance. Steps in this process include planning a productivity study, conducting activity sampling, analyzing results to identify conditions affecting productivity, identifying and implementing improvements or changes to address these conditions, and then following up with another study to evaluate the effects of the implemented changes. [3]

Planning the Study

The first step in the activity analysis cycle, planning the study, includes:

- Notifying the craft workers of the upcoming study
- Characterizing the workforce
- Defining the activity categories
- Formatting the data collection sheets

Activity analysis incorporates a cyclical process of measuring performance.

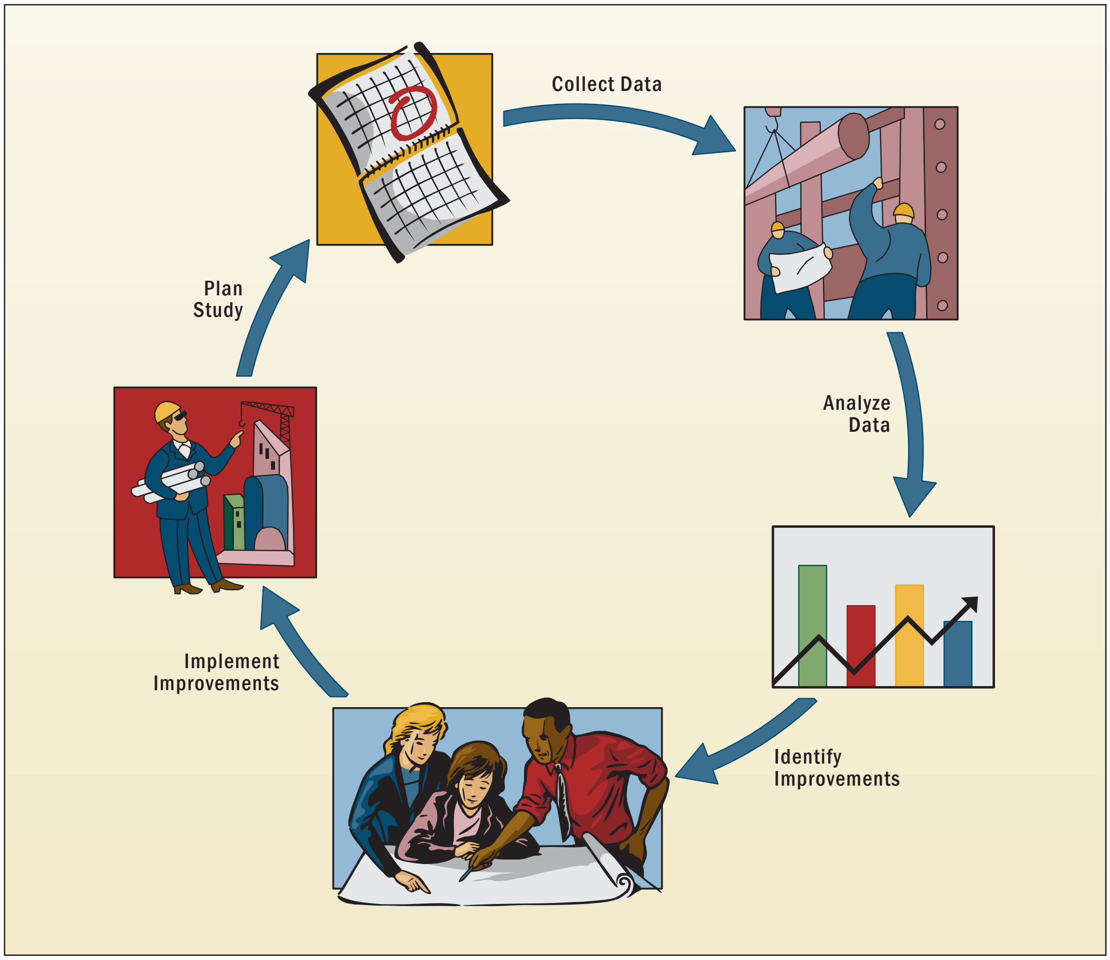

Figure 4. Activity Analysis Cycle

Notifying the Craft Workers of the Upcoming Study

Individuals generally react negatively to surveillance, since it is sometimes perceived as an issue of mistrust. Notification may be cascaded down through normal communications means, such as toolbox meetings. Cascading information about the upcoming study, the anonymity of the process, and the true purpose of the study serves to allay misgivings regarding the study. When workers understand that it is a measurement of the project team's ability to manage the project and identify conditions that hinder work performance, and not a prosecutorial attempt to weed out the population, their apprehension dissipates.

Activity sampling is not a new process—various organizations and companies have implemented variations of it along with variations in activity category definitions.

Characterizing the Workforce

The makeup of the workforce needs to be reviewed to determine the limits of the final results. Items that need to be considered include:

- Worker population
- Craft mix
- Methods of differentiating craft workers by discipline

Because the target population is the pool of individuals engaged in productive work activities that support the completion of commodities, individuals in nonmanual supervisory roles are normally excluded. Foremen, general foremen, superintendents, field engineers, and other nonmanual personnel fall into this exclusion group.

The worker population needs to be reviewed to assist the study planner in defining the study length. Craft mix and current work plans need to be reviewed to determine primary areas for data collection tours. A method of differentiating craft workers by discipline is critical because the results cannot be similarly separated (nor can supervisory personnel be excluded) unless the observer is able to identify craft types and supervisory personnel. On some projects, craft workers wear numeric identification or color coding to differentiate the disciplines and supervisory levels. Whatever means is used, the observer needs to understand the methodology before beginning the sampling effort.

Defining the Activity Categories

Because activity sampling is not a new process, numerous organizations and companies have implemented variations of it along with variations in activity category definitions. Regardless, as long as the process is consistently applied by unbiased observers, the data provide valid results.

In general, there are two main categories of activities—productive work and nonproductive work:

- **Productive work** may be defined as any activity on which an individual or a machine expends effort to complete a task or commodity. Examples of productive work include gathering and positioning tools or equipment in preparation for completing a task, gathering or transporting material, reviewing a drawing or receiving instructions, completing a weld, and performing a lift with a crane.
- **Nonproductive work** may be defined as the opposite of productive work, i.e., activities that do not contribute to the completion of a task or commodity. Examples of nonproductive work include idleness while waiting for coworkers or a piece of equipment to arrive at the workface, moving an unburdened truck around the jobsite, driving a front-end loader with an empty bucket to a new location, walking around the jobsite without tools or materials, and engaging in nonwork-related conversations or eating or drinking during the normal shift.

A significant amount of thought must be given to defining the categories of productive work because, once defined, they should not be changed. Changing category definitions renders previous sampling sets invalid since they can no longer be compared to subsequent sampling sets. This situation adversely affects the cyclic nature of activity analysis.

Several sets of categories developed by various companies subdivide productive and nonproductive work into subcategories. Within Bechtel, there are seven subcategories, as shown in **Table 1**.

Table 1. Bechtel Definitions of Work

Productive Work	Nonproductive Work
• Direct • Preparatory • Tools & Equipment • Material Handling	• Waiting • Travel • Personal

Direct work involves exerting physical effort toward completing an activity or physically assisting in completing the activity.

Preparatory work pertains to receiving a work assignment and determining its requirements before performing the task. It is nonphysical and includes safety-related activities such as stretching, completing job hazards analyses, and participating in safety and toolbox meetings.

Tools and equipment work refers to activities related to gathering, transporting, repairing, or setting up tools and equipment in preparation for commodity completion.

Material handling work pertains to activities related to moving materials from one location to another or actively seeking materials in a storage area. Normally, this subcategory does not include moving materials into final position for installation, since this action constitutes an effort toward commodity completion and, thus, is categorized as direct work.

Waiting, per the dictionary, is defined as inactivity. For activity sampling purposes, this subcategory is consistent with the dictionary definition; waiting is viewed as a temporary pause in work activity, such as waiting for instructions, waiting for a truck to arrive, or waiting for a coworker to complete a task.

Travel describes unburdened movement, such as moving a forklift or crane around the jobsite without a load, walking around the jobsite empty handed, or riding in the passenger seat of a truck.

Personal is the subcategory that accounts for time spent on individual private activities during a work shift. Personal activities include such things as engaging in a private conversation; drinking and eating during the work shift; and donning, doffing, or adjusting personal clothing.

Formatting the Data Collection Sheets

Once the work categories have been defined, observation worksheets are prepared for use by the observer(s) during data collection tours. The sample sheet shown in **Figure 5** is divided by activity categories in the second column and sorted by craft head count; craft; and, in this case, color coding identifier, as shown in the upper rows.

The observer fills in the date, the tour number, and the tour start and end times (typically an hour's duration). As the observer makes each observation, he or she records it with a hash mark in the box aligned with the appropriate craft column and with the appropriate row for the observed activity.

Activity sampling is a statistical method of studying the work pattern of a group.

Collecting the Data

Desirable Characteristics of the Observer

Because activity sampling is a statistical method of studying the work pattern of a group, the quality of the sampling program results depends on objective (unbiased) observations of categories and a random pattern of observations.

To be able to understand and classify the activities being observed, individuals performing observations should have backgrounds and experience in the industry. For example, an individual with minimal construction

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TYPICAL OBSERVATIONS (1-hour increments)

Date: ______

Tour #: ______ Start Time: ______ Stop Time: ______

OBSERVATION WORKSHEET

CATEGORY	CRAFT											
Head Count	82	77	31	28	23	14	6	6	2	1	0	0
Craft Identifier	PF Red	EL Grey	IW Grn	CP Blk	LB Org	OP Brn	CM Or/Wh	TM Mag	PA Bl/Rd	MW Bk/Ah	0 0	0 0
Direct Work												
Preparatory Work												
Tools & Equipment												
Material Handling												
Waiting												
Travel												
Personal												

Figure 5. Typical Observation Worksheet

experience may have difficulty understanding fire-watch activities or pipefitters witnessing a hydro test and be tempted to classify them as nonproductive.

During data collection tours, the observer must record his or her instantaneous first impression or "snapshot" of each activity observed. In some cases, it may be necessary to wait a few seconds to ensure that the first impression is correct before recording it. The observer must not anticipate when a worker will start or stop any category and must record the activity as it is observed.

Eliminate bias from the sampling process by selecting observation routes randomly and varying them during successive tours by entering the work area from different points or entrances.

When it is not clear what category appropriately classifies an activity, the observer may need to attempt to clarify the observation by moving to a new vantage point. However, the observer must recall the initial activity observed and avoid recategorizing it based on a change of state or new activity observed. If the observer is unsure about an activity (which can sometimes occur due to the observer's level of experience in the construction industry), then the observation should not be recorded.

Basic criteria for observers to follow include:

- Be impartial and unbiased at all times. The validity of the results depends on the randomness and accuracy of the observations.
- Eliminate bias from the sampling process by selecting observation routes randomly and varying them during successive tours by entering the work area from different points or entrances.
- Move to a new vantage point if unsure of what is being observed.
- Observe craft workers and equipment wherever they are encountered on the jobsite.
- Do not attempt to take observations from a concealed position.
- Make intelligent decisions about categories as appropriate; however, if there is any doubt, do not record uncertain observations. Much of the validity of activity sampling depends on obtaining good data. While sufficient data are needed to make the study statistically valid, the data collected must be accurate.
- Adjust tours during unusual shift events (such as extended safety meetings, training exercises, morale and recognition luncheons) by either moving to another area away from the influence of the shift event or curtailing sampling.
- Suspend data collection tours during rain or other inclement weather and during emergency drills.
- Do not reveal information or personal opinions about the work habits, performance, etc., of any crew or individual to anyone. Management should never question observers about these items.

Data Collection

Using the initial sample size, which is based on an assumed target productivity level, the sample is divided by the number of hours in the work shift to establish the number of observations needed per hour; for the example presented previously, for an 8-hour work shift, $1,067 \div 8 = 133.4 \approx 133$. The observer should be able to meet or exceed the required minimum number of observations per hour without too much effort unless the population is small (i.e., fewer than 200 personnel). Throughout the day, the observer should make notes about any events, conditions, or concerns that occur during tours. These notes help during the data analysis phase and assist as references during the preparation of any required final report.

Typical Data Collection Tours

Typical observations focus on individual worker activity and are taken throughout the regular shift on a per-hour basis. The observer walks random routes or tours through the work areas, categorizing the observed worker activities. The observer uses the time between observation rounds to summarize and analyze the observations made up to that point in the day. To provide sorting capability during data analysis, each sheet should be used for only 1 hour.

Data Compilation

Once the tours for a given day are completed, the collected data are compiled, either manually or in a spreadsheet program. The observation counts are totaled by hour, and the day is totaled by the end of the work shift.

An example of a completed observation worksheet is shown in **Figure 6**. This example shows the results from a data collection tour conducted between the hours of 3:00 PM and 4:00 PM. In this case, the observer was able to gather 156 observations, which exceeds the minimum number of required hourly observations.

Observers should be instructed not to exceed the minimum hourly sample size by a large margin. One of the goals of sampling by the hour is to establish a representative sample throughout the work shift. A particularly large

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TYPICAL OBSERVATIONS (1-hour increments)

Date: 10/19/10 | Tour #: 8 | Start Time: 3:00 | Stop Time: 4:00

OBSERVATION WORKSHEET

CATEGORY	CRAFT											
Head Count	82	77	31	28	23	14	6	6	2	1	0	0
Craft Identifier	PF Red	EL Grey	IW Grn	CP Blk	LB Org	OP Brn	CM Or/Wh	TM Mag	PA Bl/Rd	MW Bk/Ah	0 0	0 0
Direct Work	11	13	16	9	9	8	5					
Preparatory Work	5	1	4	1		1						
Tools & Equipment	5		5	3	3							
Material Handling	6	1	1				1					
Waiting	6	6	1	1	3	2						
Travel	3	4	1	2	3	5			1			
Personal	2	4	2			2						

Figure 6. Observation Worksheet After a Completed Tour

Information collected during the study and the percentages of time spent in each category are analyzed to identify problem areas.

group of observations in one tour may skew the results, and final data may not be representative, since various categories of activity may be more prevalent at different times during the work shift. Observers gathering data should be advised to limit observation collection rates to keep the total tour count to less than 25% over the target minimum number of observations per hour.

Regardless, once an overly large number of observations have been taken in any given hour, the options are to either discard that data and re-sample, or increase the minimum sample size required for the rest of the tours. Because increasing the sample size increases the relative accuracy of the final results, it is generally advantageous to do so. For the example provided in Figure 6, the new target would be about 150 observations per hour.

After 500 to 600 observations have been taken, the sample size needed to achieve the desired sampling accuracy should be checked in case the sample size needs to be adjusted based on the actual observed productivity level. In this example, the actual cumulative productive work percentage is 52%. Using Equation 1, with p = 52% = 0.52 and S = ±5% = 0.05, the required sample size N can be calculated as

$$N = \frac{4(1-p)}{S^2 p} = \frac{4(1-0.52)}{0.05^2(0.52)} \approx 1{,}477\,.$$

Based on the observed productivity, the new target number of observations required is 1,477; thus, the new hourly target for an 8-hour shift is 185 observations.

Analyzing the Data

The work sampling study is continued until the desired accuracy is obtained. At this point, the information collected during the study and the percentages of time spent in each category are analyzed to identify problem areas. Initial results should be compared to target benchmarks, as shown in **Table 2**, with the objective of increasing the direct work percentages by reducing the time spent in other activities.

Table 2. Comparison of Observed Productivity Against Target Benchmarks

Activity	Target	Your Project	Variance
Direct	34.7%	31.5%	–3.2%
Preparatory	8.9%	15.2%	6.3%
Tools & Equipment	9.8%	13.6%	3.8%
Material Handling	6.1%	4.7%	–1.4%
Productive	**59.5%**	**65.0%**	**5.5%**
Waiting	18.2%	13.8%	–4.4%
Travel	14.8%	15.6%	0.8%
Personal	7.5%	5.6%	–1.9%
Nonproductive	**40.5%**	**35.0%**	**–5.5%**

In the example shown in Table 2, the preparatory work percentage is elevated, and the tools and equipment percentage is slightly elevated as well. Because preparatory work involves receiving a work assignment and determining requirements before performing the task, an elevated level could indicate confusion on the part of the worker or that a particularly complicated task requires additional discussion time with supervisory or field engineering personnel. An elevated level of tools and equipment activity could be indicative of tool program or tool room issues; broken, lost, or insufficient numbers of tools and equipment; or tool or tool room location issues.

> *The initial activity analysis should be done fairly early in the schedule—at around 10% to 15% of construction complete.*

As with tools and equipment, a higher percentage of time spent in material handling activities could be related to material location, lost materials, or material program issues.

Waiting could indicate overstaffing. If work group size is too large for the task assigned, one or more crew members may be unable to participate fully. Other possible contributors to waiting include poor supervision or a shortage of supervisory personnel, complicated designs or engineering issues, and poor planning.

Personal activities are closely related to waiting. Idle workers tend to engage in personal activities because they have nothing else to do. Alternatively, higher levels of waiting and personal activity could indicate poor management during the critical times of the day (shift start, before and after breaks, and shift end).

Travel activities are primarily related to jobsite layout. The locations of break areas, entry control points for badge access, tool rooms, and welding rod dispensaries, for example, all affect the percentage of time spent on travel. Travel could also be affected by frequently changing work assignment priorities because the craft workers have to disengage from the current activity, travel to a new location, and re-engage in a new activity.

If it is possible to differentiate crafts and gather data by craft discipline, it is useful to evaluate individual craft results. Comparisons such as those shown in **Figure 7** may be made to identify the challenges to a particular discipline. Further research into the conditions causing a particular category to be above or below a target may be necessary. The example in Figure 7 indicates that the carpenters are spending 21 percent of their time in material handling. In this case, the project team should review factors that could be behind this result, such as material storage locations relative to the workface.

For data collected on a per-hour basis, a graph may be prepared that illustrates the variability of productivity over the entire shift. A representative stacked percentage graph of the results from a set of data collection tours is shown in **Figure 8**.

Completing the Activity Analysis Cycle

Once the analysis is completed, the remaining steps in the activity analysis cycle are implemented. Changes may be identified to correct or improve a particular issue or condition. Once changes have been identified and put into action, planning should begin for a follow-up study. This study should be completed for two reasons:

- To determine if the changes have had the desired effect
- To determine if the changes have possibly created other issues

EVALUATION FREQUENCY

Although site conditions, temporary facilities, and site layout that can affect worker productivity should be reviewed and assessed before contract award and before site mobilization, these reviews do not involve activity sampling. Normally, the initial activity analysis should be done fairly early in the schedule—at around 10% to 15% of construction complete. This initial analysis should focus on site logistics and work site flow.

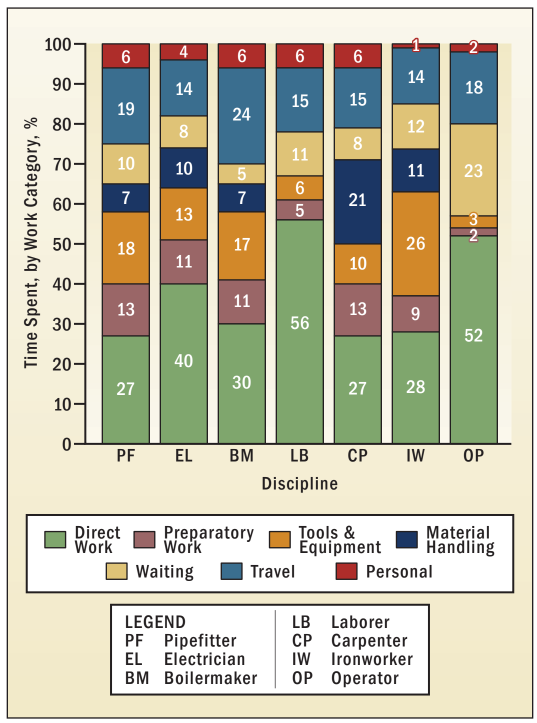

Figure 7. Comparison of Craft Performance, by Discipline

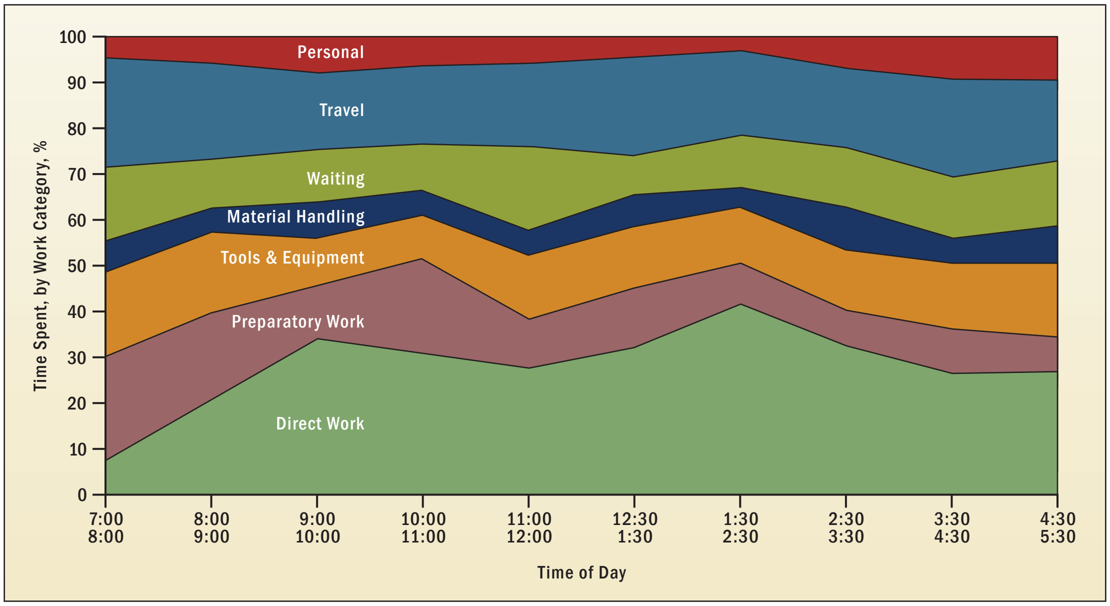

Figure 8. Overall Hourly Productivity

The activity analysis process described here provides a measure of the level of activity, not the effectiveness of the project's commodity completion effort.

A second analysis should be performed before 30% complete, with a focus on improving work processes in the field. It may be beneficial to implement additional evaluation tools during this analysis, such as a foremen delay survey. This survey involves interviewing approximately 10% to 20% of the foremen on the jobsite in an effort to identify the types of issues they encounter and the frequency with which the issues occur. The list of possible delays is developed in advance and may include items such as waiting for inspections, drawing problems, work package problems, material delays, material loss, tool availability, equipment availability, breakdowns, absenteeism, changing priorities, and rework.

Each foreman interviewed is asked to provide feedback on the frequency of delay due to each item on the list. The interviewer assigns a numeric value (0, 1, 2, or 3) based on the response, with delays that occur daily or weekly scored as 3; delays that occur a couple of times a month, as 2; delays that occur a couple of times a year, as 1; and delays that have never occurred, as 0. The numeric average of each delay category indicates which category occurs with the greatest frequency.

A third analysis should occur before 50% complete, and a fourth and final should be made before punch listing and system completion begin. Both of these activity analyses should be conducted in a format similar to that of the second.

The recommendations here are based on a minimum frequency of evaluation. Follow-up activity analyses may be conducted throughout a project's lifecycle as needed to review specific processes and evaluate the effectiveness of implemented improvements.

CONCLUSIONS

Implementing a programmatic approach to evaluating productivity is not a substitute for using standard project controls tools to measure commodity completion. The activity analysis process described here provides a measure of the level of activity, not the effectiveness of the project's commodity completion effort. For example, a worker observed grinding out a bad weld would most likely be credited by the observer as performing direct work. However, the actual time allocated for completing the weld would be increased (jobhours required for original weld plus jobhours for repair) and would, therefore, negatively affect the unit rate or jobhours allocated per weld.

In the early 1980s, work or activity sampling was inappropriately promoted as a means of correlating labor output or commodity completion to the percentage of time spent in direct work activity. This led to the imprudent use of work sampling results in legal cases. [4]

Another pitfall often encountered in the use of activity analysis is attempting to compare the results of one study to those of another that employed a different set of defined categories. This leads to confusion and misunderstanding with regard to a project's performance.

The primary advantage of activity analysis is that it helps identify factors affecting or hindering a workforce's ability to engage in direct work. Increasing the time available to the workforce to complete commodities gives projects the chance to improve performance; however, the effectiveness of taking this action depends on proper planning and execution by the project team.

Other advantages of activity analysis include:

- Overall project work activity is observed at randomly selected areas and times, not by specific area or worker.
- Activity sampling is less disruptive to work activity and, thus, causes less stress and anxiety to the workforce.
- The process may be adapted to various project execution types, such as direct hire or construction management.
- A project may be compared to itself in subsequent analyses. The effects of varying manpower levels and the project percentage complete may be taken into consideration when reviewing the results.
- Observers with construction experience can conduct observations with a minimum of specialized training.
- Activity sampling collects data not normally collected by any other means.
- Activity sampling is more cost effective than continuous monitoring techniques.

Using activity analysis on a construction project enables the project team to understand the barriers to productivity so that steps may be taken to eliminate them.

Implementing an activity analysis is an extension of performing simple work or activity sampling and is part of a continuous improvement program. Using activity analysis on a construction project enables the project team to understand the barriers to productivity so that steps may be taken to eliminate them. The cyclical nature of the process aligns with the changing environment of a construction project so that barriers to productivity not present in the initial studies can be identified and addressed in a more timely manner as they evolve. ■

REFERENCES

[1] R.M. Barnes, *Motion and Time Study: Design and Measurement of Work,* 7th ed., John Wiley & Sons, 1980, pp. 406–440, see http://www.amazon.com/Motion-Time-Study-Design-Measurement/dp/0471059056#_.

[2] K.G.R. Heinze, "Performance Measures by Means of Activity Sampling," *1984 AACE Transactions, D.4, AACE International,* Morgantown, WV, 1984, see http://www.aacei.org/cgi-bin/litsearch.pl.

[3] C.H. Caldas; D.D. Christian; P.M. Goodrum; M.C. Gouett; R. Granger; C.T. Haas; G.M. Stofega, Jr.; and S.A. Toon, "Guide to Activity Analysis," Craft Productivity Research Program Research Team, Construction Industry Institute, [Implementation Resource] IR252-2a, Austin, TX, July 2010, access via https://construction-institute.org/source/Orders/index.cfm?section=orders.

[4] H.R. Thomas, "Labor Productivity and Work Sampling: The Bottom Line," *Journal of Construction Engineering and Management,* Vol. 117, No. 3, ASCE, September 1991, pp. 423–444, access via http://scitation.aip.org/coo/.

BIOGRAPHY

Steven Toon leads the productivity engineering effort for Bechtel Construction Operations as part of the Construction Engineering and Technologies group. He supports Bechtel's various business lines and projects by performing productivity studies, including data collection, analysis, training, and interpretation. Steve has over 30 years of management, supervision, design, and construction engineering experience related to direct hire work, subcontracting, quality management, telecommunications, nuclear power, and the federal government.

Steve began his construction engineering career with Pullman Power Products at Diablo Canyon nuclear power plant in California and then at Vogtle nuclear power plant in Georgia. He joined Bechtel at the Department of Energy's Savannah River Site in 1989 and, during his 11 years there, held a variety of progressively more responsible positions, including lead field engineer, area superintendent, field design group lead, and project manager. In 2000, Steve moved to the Communications business line as the project field engineer and, subsequently, the project construction manager for a major project with Cingular. He joined the Bechtel Construction Operations staff in 2007 to guide and foster the growth of productivity engineering within the company.

Currently, Steve serves on a Construction Industry Institute (CII) Research Team on Craft Productivity Research, RT-252. In 2010, he spoke on craft productivity at the Construction Business Forum jointly sponsored by *Engineering News-Record (ENR)* and the Construction Users Roundtable (CURT) and at the CII annual conference. Steve is also a member of the American Society for Quality and the American Institute of Constructors.

Steve has a BS from California Polytechnic State University, San Luis Obispo, and an AS in Agricultural Engineering from Modesto Junior College. He is a Six Sigma Yellow Belt.