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DIRECT LABOR PRODUCTIVITY MEASUREMENT – AS APPLIED IN CONSTRUCTION AND MAJOR MAINTENANCE PROJECTS

TCM Framework: 9.2 – Progress and Performance Measurement

Acknowledgments:
Hans E. Picard, (Author)
Charles E. Bolyard, Jr.
Robert C. Creese, PE CCE
Earl T. Glenwright, Jr.
Stephen M. Jacobson, CCC
Richard A. Selg, CCE
Ronald M. Winter
James G. Zack, Jr.

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INTRODUCTION

This recommended practice of AACE International describes a direct method to measure, monitor and optimize construction and maintenance project labor productivity. The method described is statistical sampling of the work process, or: work sampling. The work process is made up of steps and activities that take input resources, add value, and produce the completed project. Understanding the capability of the process, or 'management system,' to produce efficiently is important for project planning and control. Sampling is a cost-effective way to provide information about the performance of the work process, i.e., about 'how' the work is done, and how to do it better. Work sampling complements conventional project management methodology, which typically tracks 'what' work is done.

Sampling provides project managers, supervisors, and the workforce with objective feedback re: the efficiency of the work process (not of individual workers, which is part of the foreman's job) – and the ability to respond quickly to adjust. In addition, it provides a measure of management's ability to effectively plan, coordinate, and control project execution. Analysis of the sampling data allows for prompt removal or reduction of roadblocks, optimizing the construction work process through redesign and innovation. Streamlining the work process ensures that performing productive work is made more convenient for the workforce, ensuring that, at all times, crafts and technicians have all the necessary tools, materials, parts, supplies, information, supervisory support and personal needs readily available. Work sampling, properly applied, recognizes that productivity results from an optimal work process, i.e., from 'managing smarter,' not from people working harder.

Construction labor productivity is a measure of work process efficiency. It can be defined as the ratio of the value labor produces to the value invested in labor. Productivity increases as needed labor resources are minimized and wasted efforts eliminated from the work process. This definition and the practice covered here treats productivity as a direct, absolute measure to be optimized.

PURPOSE OF DIRECT MEASUREMENT

The purpose of construction and maintenance project work sampling is to measure and assess the work process, and provide useful, (near) real-time information about the process. It is a tool to enable more efficient, safe completion of the work scope so that fewer labor-hours will be expended than customary.

Systematic statistical observation of general work activity on the project site is useful to:

1. determine the proportion of direct labor hours being wasted in non-productive activity and delays, and productive work activity;
2. analyze factors that cause non-productive activity and delays; and
3. identify opportunities to reduce non-productive activity and delays.

As part of its discipline, work sampling enables cost management to affect productivity improvement on labor-intensive construction and maintenance projects. Work sampling on a project helps monitor the work activity to obtain an overall picture of the utilization of the workforce. With statistically sound samples, inferences can be made regarding constraints to the flow of work and resulting inefficiencies in the process. Consistent application of sampling over a period of time provides project managers ongoing information about the effectiveness of actions taken to continuously improve the work process.

Analysis of the (estimate-independent) data quantifies non-productive activity and identifies possible causative factors, suggesting corrective action. Work sampling provides managers and supervision quick, actionable feedback on work process performance – insight that cannot be obtained by conventional project control metrics. Conventional productivity measures tell when productivity problems occur, but work sampling also tells why – the methods complement each other.

The actual, project-specific, quantitative data obtained by work sampling ensures objective assessment of the work process. As such, the data supports benchmarking and continuous improvement of efficiency and productivity. Properly applied, it is effective in getting more construction or maintenance work done with fewer labor-hours, and with greater worker safety and satisfaction.

BACKGROUND ON PRODUCTIVITY, EFFICIENCY AND WORK SAMPLING

Construction and maintenance project performance is an important concern of project owners, constructors, and cost management professionals. Project cost and schedule performance depend largely on the quality of project planning, work area readiness preparation – and the resulting productivity of the work process made possible in project execution. Labor productivity is often the greatest risk factor and source of cost and schedule uncertainty to owners and contractors alike.

Construction and major maintenance projects are commonly managed and controlled through oversight and coordination. At intervals, progress is tracked against agreed-upon schedules and budgets – which are estimated, based largely on historical performance data. This method may be effective for highlighting when performance is not on track with plans. But it does not show why productivity is lagging or out of control, nor does it support decisions on corrective actions and improvement of the work process. As such, traditional project control measures do not fully address the objective of improving cost and schedule performance. For meaningful cost and schedule optimization, direct productivity measurement must be used to complement the indirect, relative control measures that compare performance to the estimate.

Breakthrough lessons learned by US manufacturing in the 1980s showed that managers must take responsibility for the majority of work process (‘system’) performance problems. It is management's job to plan, develop, and continually ensure an efficient work process – the workforce works within the boundaries of the process.

These lessons also apply to the construction industry – raising the productive use of labor-hours by applying process measurement, analysis and improvement results in better productivity, efficiency and cost effectiveness. Using statistical techniques, such as statistical process control (SPC), and Six Sigma (focus on process variation) many firms were able to radically increase productive efficiency and quality – theirs and their vendor’s.

Work sampling is a statistical technique that can be effectively used for analyzing the construction and maintenance work process. Proportions of time devoted by crafts and technicians to the variety of work activities, and the variability of the work process are measured. The application has proven effective on hundreds of construction and maintenance projects, achieving labor cost savings of 20 to 30 percent, and more.

Work sampling has been widely used to periodically make studies of industrial operations. Originally used in the textile industry in the U.K., it was introduced in the US during the World War II effort to obtain information about men or machines. A fact-finding tool, it was called "snap-reading" method – referring to the instantaneous recording of observation of activities being studied. The method provides process information quickly and at less cost than other means. The technique has been used in one form or another by different groups for different reasons, although sometimes unfortunately misused, e.g., as a way to ‘blame’ the workforce for low productivity.

Observations must be random and free of bias, or systematic observation errors that tend to run in the same direction. Consistently carried out according to definitions and procedures, sampling results will differ from actual conditions only in a random manner and will be unbiased. The greater the number of observations, the more accurately will sampling results approximate actual conditions.

Advantages of the work sampling method are:

1. Random observations are made of overall project work activity of groups of workers, collectively observed at randomly selected areas and times, not of specific individual workers.
2. Sampling causes less anxiety and tension among workers than continuous observation (such as with a stopwatch).
3. There is no, or minimal, interference with the worker's normal activities.
4. Observers with minimal specialized training can conduct random work sampling.
5. The number of observations can be adjusted to meet desired levels of accuracy.
6. Work sampling is an effective means of collecting useful facts during project execution that are not normally collected by other methods.
7. Work sampling is less expensive than continuous observation techniques.

WORK SAMPLING THEORY

Work sampling is based on probability theory. This means that activity samples observed at random from a large group of craft activities on a project tend to have the same pattern of distribution as that of the large group. The ratio of the number of observations (samples) of a given activity to the total number of observations of all activities approximates the percentage of time that the work process spends on that activity. If the number of observations is large enough, the percentage of time found by work sampling spent on an activity will differ little from the actual time spent on that activity in the work process developed on the project site.

A sufficient number of observations must be taken to ensure accuracy. Although the procedure is easy to learn, it is important that sampling tours are conducted randomly, without bias. Every worker on every assignment during each work period should have an equal chance of being observed on each work sampling tour.

A fundamental principle of work sampling is that the number of observations is proportional to the percentage of time the work force is engaged in an activity such as, for example, 'working'. A sample of size N is taken to estimate the proportion P. According to elementary sampling theory, we cannot expect the proportion based on a sample (p) to be the true value of P. But we can expect the value of p to be within the range of $P \pm 2\sigma$ ('sigma' is the symbol for standard deviation) approximately 95 percent of the time at a (selected) 95 percent confidence level. With P as the true percentage to be determined, the p of any sample can be expected 19 times in 20 to fall within the limits of $P \pm 2\sigma$ by chance alone.

As the number of observations N increases, the sampling error diminishes, i.e., the value p gets closer to the true value of P. The absolute accuracy is the difference between the observed percentage p and the true value P (relative accuracy is this difference expressed as a percentage of the observed percentage). Absolute accuracy of resulting data can be calculated with this formula:

$$A = Z\sqrt{p(1-p)/N} \qquad (1)$$

Where:
A = absolute accuracy
Z = number of standard deviations **σ** (for the 95 percent confidence level, the value of Z = 2)
p = the observed percentage, obtained by work sampling
N = the total number of work sampling observations made.

DATA COLLECTION AND TREATMENT METHODOLOGY

Work sampling requires routine data collection by trained construction or maintenance analysts observing the entire workforce on-site (with some exceptions discussed later). Random-walk observation tours must be conducted at randomly selected times during all work periods, excluding periods when no work takes place, such as end-of-shift clean-up periods, or break periods (if crews all break at specifically scheduled break times), and tour starting points must be varied to the extent possible.

Craft activities are manually recorded according to specific activity category classifications, which are pre-defined and may be customized for the specific construction or maintenance project. Covering the entire labor workforce on-site, each worker is counted as one sampling observation. A sampling observation is an observation of work activity at the very instant the analyst observes the activity on a work sampling observation tour.

Before the start of each observation tour, the analyst determines and documents crew size(s), their foreman, and their work area(s) to ensure the entire workforce will be observed. An analyst impersonally observes and records all craft and foreman activity occurring on the project by placing tick marks on a data collection form (such as the "Data Collection Form" in Appendix B), and also records the number of craft workers not observed on-site ('un-accounted for').

Using statistical software, the percentage of observations of each activity category is computed. The resulting data shows the overall crew utilization for the period work sampled and may be printed out graphically, e.g., in pie chart format. By applying the proportions of value-added and non-value-added activity to the total labor-hours available, the time spent on each category can be determined. A print-out of a scatter diagram of, e.g., the percentage of productive utilization ('direct work') versus the tour start times, is a practical way to graphically verify randomness and determine variation of the work process. The software will calculate the mean (average) level of productive activity and the standard deviation for the overall process.

Improvement constitutes raising the level of efficiency of the work process and reducing its variability. Analyzing the work process measurement data allows decision-makers to take prompt appropriate action and remove systemic constraints and obstacles that interfere with best possible, productive utilization of the craft labor resources.

Working in support of owner and/or contractor project management, cost management helps identify opportunities to cause improvement and recommend streamlining and/or re-design of the work process, and establishing guidelines for project-specific best practices including:

1. On-going measurement, analysis and optimization of productive labor utilization;
2. Prompt feedback (e.g., no later than end of shift) on work process efficiency;
3. Analysis of process trend and variability data taken over time;
4. Assessment of work process performance vs. baseline and industry benchmarks;
5. Up-front planning and preparation with the objective of most efficient workflow;
6. Updating historical estimating databases for future 'lean' estimating;
7. Regular review and audit of soundness of implementation of this practice.

GETTING BUY-IN OF WORK SAMPLING

Before starting work sampling, the use of the method must be 'sold' to all personnel at all levels of organizations affected, including top management, supervision and, if present, union representatives. Work sampling is a tool to make it more convenient for crafts to carry out assigned tasks by streamlining procedures and removing roadblocks. It is management's responsibility to eliminate or minimize factors that limit productivity on the project.

Typically, 15-minute briefings of field supervision and union representatives are effective. Craft workers can be briefed on basic work sampling procedure during hiring-in procedure, e.g. by means of a short, custom-prepared video which ensures consistency of presentation. It is important to explain the impersonal data collection procedure, the activity definitions, and how the sampling results are used to show the efficiency of the work process.

Focusing on the efficiency of the construction work process introduces a new, effective way of managing construction projects at improved cost-effectiveness.

PLANNING IMPLEMENTATION OF WORK SAMPLING

After briefings to explain the work sampling procedures and activity definitions, and obtaining buy-in by management, supervision and workforce, a detailed plan is needed before conducting work sampling tours of the site.

1. Determine desired accuracy of the results and specify the level of confidence, e.g. a relative accuracy of ± 5% at a 95 percent confidence level is practical and usually adequate.
2. Next, determine the required number of observations to achieve the desired accuracy, e.g., by using a statistical accuracy look-up table, an example of which is included in Appendix H.
3. Based on the anticipated observation tour time to cover the workforce on-site, determine the daily number of work sampling tours needed to achieve the required number of observations.
4. Subsequently, design the work sampling form on which to record the observations. An example is included in Appendix B.

IMPLEMENTING RANDOM WORK SAMPLING

Implementation on construction or maintenance project sites includes the following activities and deliverables:

1. Conduct up-front briefings to ensure management, supervision and workforce buy-in before starting measurement of work activity.
2. Determine which jobs on the site to exclude from the work sampling. It may not be cost effective to observe a small crew working in a remote area, requiring a great deal of travel time to observe. In such case it may be more practical to keep this small number of workers out of the sampling. (Note that the resulting data only reflects actual observations made in work areas included in the sampling).
3. Measure workforce utilization by observation of the entire workforce on-site (except jobs that are excluded because of distance from the main work area).
4. While conducting work sampling observation tours, it is useful to ask the question: "What can be done to improve productive utilization, reduce wasted time, minimize travel, and streamline workflow?"
5. Communicate regularly with field supervision, asking about job locations, manning, existing procedures such as breaks, tool control, safety meetings, and any constraints or interferences.
6. Regularly produce easy-to-read graphic labor utilization reports, e.g. pie charts, trend charts, scatter diagrams.
7. Prepare action recommendations (e.g. an "action item list") to reduce non-value-added activities (avoiding "finger-pointing" or "blaming") for presentation to site project management.
8. Offer and be prepared to facilitate team problem solving with select craft and foreman participation, producing recommendations to management to improve the work process. Include a determination of the cost-benefit of recommended work process improvement opportunities.
9. Review and update historical estimating database with latest data.
10. On request, conduct continuous improvement training workshops.

Supported by top management, improvement of the work process can cause significant labor cost and time savings. And, through communication and emphasis on "working smarter", labor representatives typically respond well to the continuous work process improvement approach that makes working more 'convenient' for the worker.

KEY TERMS AND DEFINITIONS

1) **Confidence Level.** The probability that the true value that is being estimated by the sample is included in a specified range. The desired confidence level is specified by the analyst and the precision or accuracy range is calculated or looked up in a table. For example, if the desired confidence level is 95 percent and the 'productive utilization' (or 'direct work') is 56 ± 2.5 percent, then there is a 95 percent chance that the true 'productive utilization' is between 53.5 and 58.5 percent.

2) **Accuracy.** A range of possible values determined according to the confidence level. When calculated from sample results, the accuracy range has an upper and lower limit within which the sample estimate might differ from the true value. In work sampling a recommended accuracy range is typically at least ±5 percent ('relative accuracy') at a confidence level of 95 percent. The accuracy of the sampling measurement that is achieved depends on the sample size N and the percentage of observations of an activity p.

3) **Standard Deviation (sigma, σ).** A measure of variability, that is, of the deviation of an activity percentage average, according to the formula:

$$\sigma = \sqrt{p(1-p)/N} \tag{2}$$

Where:
σ = standard deviation
p = percentage occurrence of observed activity (e.g., 'productive utilization')
N = total number of observations obtained on work sampling tours.

4) **Randomness of observation tours, both of start-time and analyst's path of observation tour ('random time/walk').** With a computer-based random times generator or a random times table (see Appendix G), the analyst randomly selects the start time for an observation tour. Tour start points are randomized by selecting different start locations and paths taken on the project site. Sampling tours must be conducted randomly and without bias over the course of all work periods. Every worker on every assignment during each work period should have an equal chance of being observed on each work sampling tour.

   The scatter diagram of tour start times during work periods (sample diagram included in Appendix F, showing average direct, productive work percentages and start-times of observation tours, plotted for a specific shift during the course of a construction project) can be used to verify randomness of observation, as well as to analyze work process variability.

5) **Data Collection Form and Foremen Sheet.** Samples are observations obtained by observing workforce activities, either as groups of workers simultaneously or as individuals working separately on the project during observation and classifying the observed activities, impersonally, into pre-defined activity categories. The Data Collection form included in Appendix B is an example of a form the analyst uses to record observations. The Foreman Sheet in Appendix C is used to record foremen's work area location and crew size information, and is used by the analyst to ensure covering all work areas, foremen and entire workforce.

6) **Work Sampling Activity Category Definitions.** Workforce activities are distinguished, essentially, in three major categories: "Productive Work (Utilization)," "Non-productive Work," and "Downtime". Each

of these has its sub-categories, as shown in the pie chart of Figure 1. Work sampling definitions are often customized to provide actionable information specific to a project or facility. An example of construction work activity definitions is presented in Appendix A. A daily printout of craft labor-hour utilization for a shift would show actual measured percentages in a pie chart format, as shown in Appendix D.

In addition, the percentage of un-observed workers ('Un-accounted For'), as well as the total number of observations (N) can be shown in the daily report.

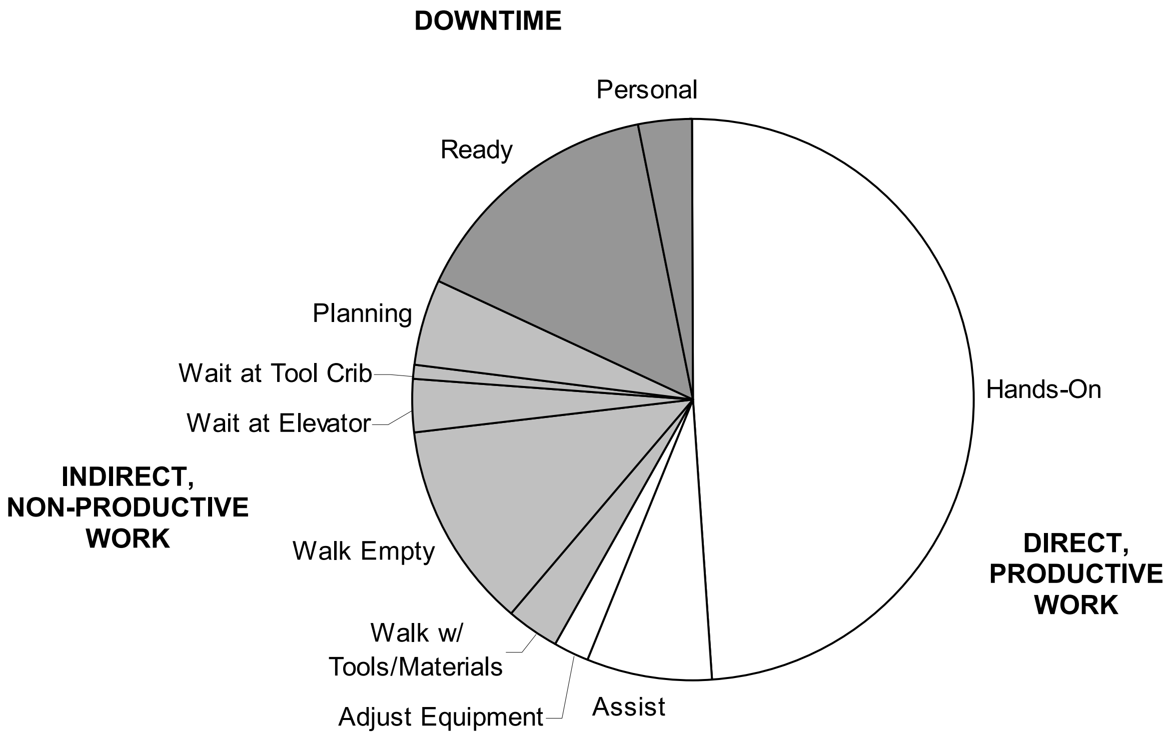

Figure 1 — Example chart of proportions of labor hour utilization by work category

7) **Reports.** To be useful and effective, work process measurement data must be reported on a timely basis. For example, at the conclusion of each shift, a pie chart showing labor utilization for that shift can be prepared and presented to project management and supervision, and include posting at craft areas. The pie chart in Appendix D shows some of the possible causative factors that affect activity categories. An Action Items List can be included, i.e., short notes on the perceived cause and effect of interaction of work activities in the system and interferences in the workflow. The list is regularly updated with obstacles or constraints to efficient workflow, observed by the analyst on work sampling tours, or on tours conducted with the specific purpose of identifying workflow problems (when time permits, between work sampling tours).

8) **The Action Items List.** Can also describe 'undesirable' work activity, i.e., activity that is classified as working but can possibly be eliminated or reduced by improved process. Examples include certain types of walking, waiting, cleaning, etc.

An example Action Item List format is included in Appendix I.

Footnote:
1. The definition of productivity in AACE International Recommended Practice No. 10S-90 "Cost Engineering Terminology" is a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm…". That definition applies to productivity ratios such as used in earned value project control practices rather than in the direct measurement of productive workforce utilization for work process improvement purposes.

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CONTRIBUTORS

Hans E. Picard, (Author)
Charles E. Bolyard, Jr.
Robert C. Creese, PE CCE
Earl T. Glenwright, Jr.
Stephen M. Jacobson, CCC
Richard A. Selg, CCE
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APPENDIX A. WORK SAMPLING DEFINITIONS APPLICABLE TO CONSTRUCTION PROJECTS

Direct, Productive Work Activity: using tools or effort at a designated work location to perform an assigned task that makes a direct, productive contribution to completing the work scope. There are three sub-categories within Direct Productive Work Activity:

1. **Hands On**
   a. **Using tools or equipment**
      - Operating air or electrically driven power tools
      - Welding, cutting, brazing, or heating (arc or torch)
      - Turning/pulling on a wrench, screwdriver, or other hand tool
      - Hammering, filing, sawing, sanding, or polishing
      - Sweeping, wiping, buffing, brushing, or applying paint/coating
      - Placing or positioning chain falls/slings or scaffolding
      - Aligning or positioning parts or materials onto equipment, supports, etc.
      - Getting or putting aside tools or parts at the job site
      - Feeding wire, cable, line, etc.

   b. **Inspecting**
      - Observing the operation or condition of equipment to ensure proper functioning
      - Using gauges, calipers, meters, or other instruments to measure or test the condition or operation of equipment, the facility, or circuits
      - Using diagrams or schematics for instructional purposes in the work area
      - Inspection of quality of completed work, e.g., checking welds, threads, alignments etc.

   c. **Using equipment or vehicle (e.g., tugger, crane, forklift)**
      - Lifting, lowering, or positioning load
      - Driving/operating rolling equipment (assigned task)

   d. **Support Activities**
      - Tool crib attendant or tool runner when bringing or handing a tool to another
      - Tool crib attendant or tool runner when working on, adjusting, or repairing equipment
      - Actively waiting on a weld bead to be passed when tandem welding
2. **Assisting**
   - Passing tools or materials
   - Positioning materials, parts, or equipment for another
   - Signal man
   - Safety related activities such as holding a ladder for another, fire or hole watch, tag line attendant, etc.
   - Holding, supporting, or pulling on pipe, part or structural piece for another to perform a task
   - Tool crib attendant or tool runner activity when not directly working on tools or helping another
3. **Adjusting Equipment**
   - Replacing a cut-off disk or grinding wheel on a hand grinder
   - Adjusting a torch or arc type welder before making a cut or weld
   - Adjusting a torch or arc type welder for another
   - Standing by to fix problems during start-ups or difficulties
   - Repairing or modifying tools or equipment

<u>Indirect, Non-Productive Work Activity</u>: support activities that are not directly contributing to completing a job or project. These activities include:

1. Walking with tools or materials: transporting (also: walking or riding in vehicle with) parts, tools, materials, or equipment, inside or outside the plant or project.
2. Walking empty: walking or riding (as a passenger in vehicle) empty-handed, inside or outside the plant or project.
3. Waiting for the elevator
4. Waiting at the tool crib or stores: Waiting at a store room or tool room/crib for parts, materials, tools, or supplies.
5. Planning/getting job-related information
   - Studying drawings, diagrams, manuals, or notes to obtain job related information (out of the work area).
   - Performing calculations (out of the work area).
   - Job-related discussion with foreman/between craftsmen.
   - Making sketches.
   - Using plant paging systems, plant phones, or walkie-talkies.

<u>Downtime</u>: non-activity, including:

1. Ready: ready to assist co-worker in a work activity or ready-to-work but “on hold’.
2. Personal: all unexplained non-utilization or personal idle time

<u>Additional Data</u>: includes:

1. Un-accounted For: the percentage of craftsmen not observed during a sampling observation tour. It is the difference between the correct headcount obtained from supervision or staff and the actual number of observations made by the Analyst.
2. Total Observations: the total number of actual observations made plus the number of 'unaccounted-for'; this should equal the headcount.
3. Foreman Availability (%): on each tour, the number of foremen observed in the work area with their crews (visible to crew, within shouting distance, available and ready to assist any crew member) is counted. Foreman Availability is calculated as a percentage by dividing the number of foremen observed with their crews by the total number of foremen assigned on the project. The Foreman Availability percentage is a rough indicator of first-line supervision’s effectiveness; typically, a direct, positive correlation is found with the Direct, Productive Work percentage.

APPENDIX B. DATA COLLECTION FORM

Project:						LABOR UTILIZATION – DAILY RESULTS							Date:				
	Tour Time		Direct, Productive Work Activity			Indirect, Non-Productive Work Activity					Downtime		Additional Data				Comments
Tour No.	Start	Finish	Hands On	Assist	Adjust Equipment	Walk w/ Tools / Materials	Walk Empty	Wait at Elevator	Wait at Tool Crib	Planning	Ready	Personal	Total Observations	Un-accounted For	Foremen Available	Foremen Possible	
Shift Totals / Avg.																	

APPENDIX C. FOREMAN SHEET

Technician:______________________________

Partner: _________________________ Date: _______________________________ _

Location: ________________________ Shift: _______________________________ _

Weather Conditions

☐ Clear
☐ Cloudy
☐ Rain (How Long ____ hrs)
☐ Raining Ice, Sleet, Etc. (How Long _____hrs)
☐ Snow
☐ High Winds Temp ____° F

Foremen Information

Foreman	#Men	Where	Foreman	#Men	Where

Miscellaneous Notes

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____

____

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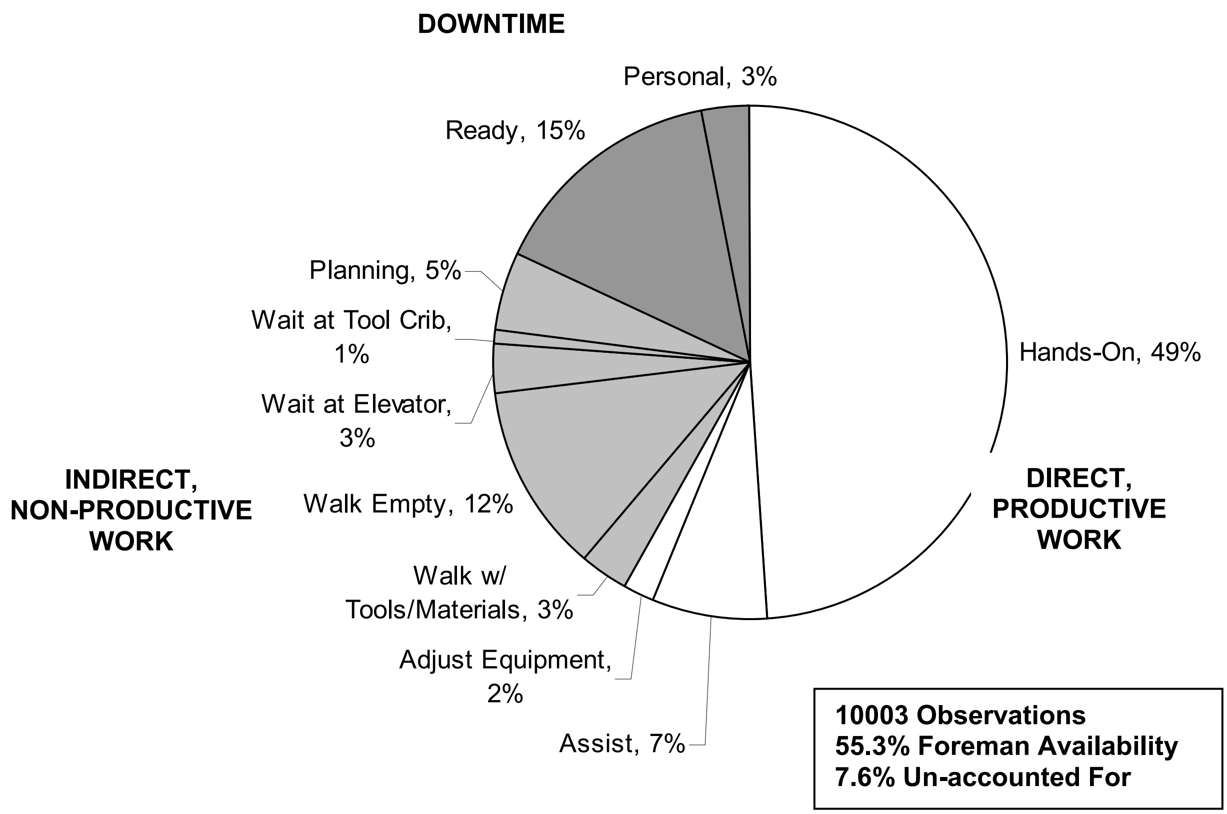
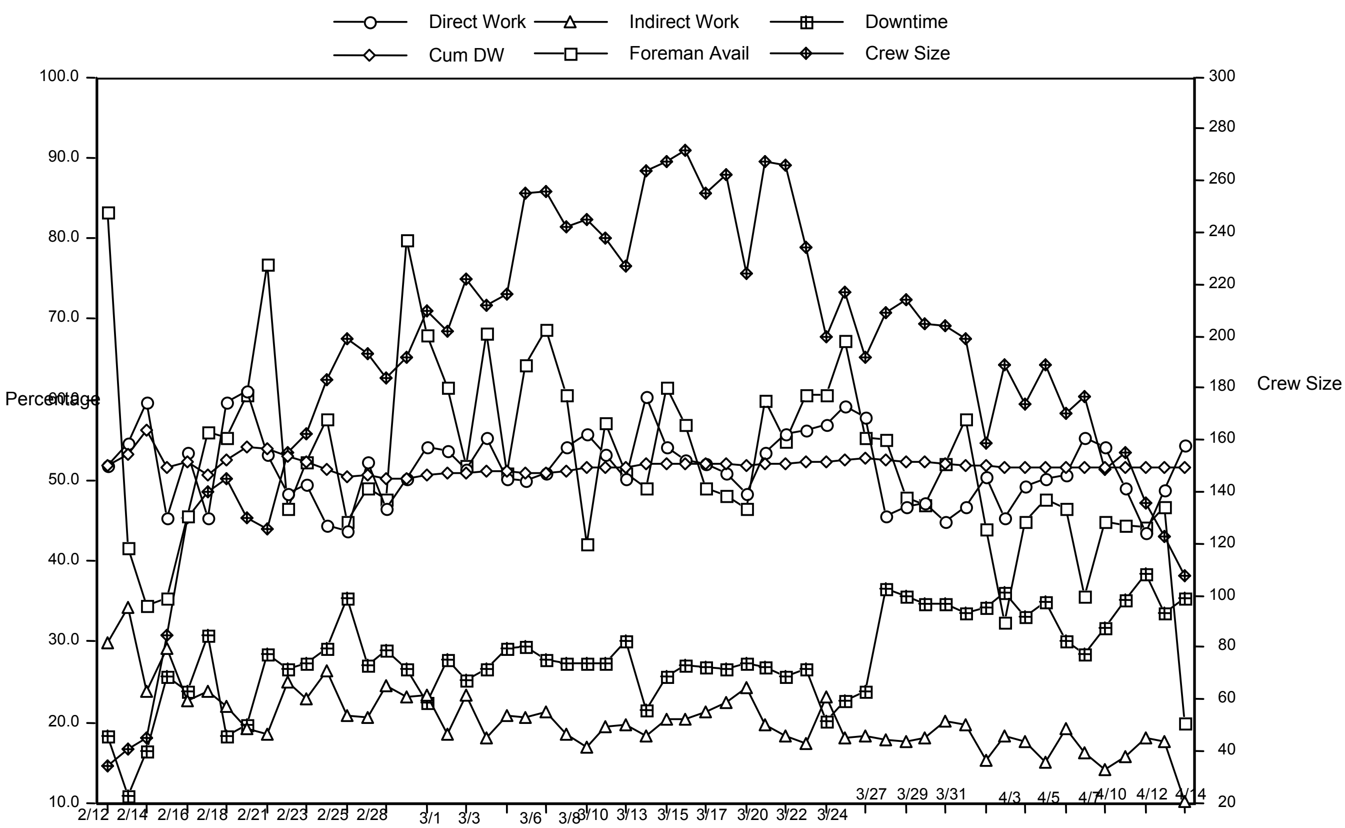
APPENDIX D. SAMPLE DAILY PIE CHART REPORT FORMAT

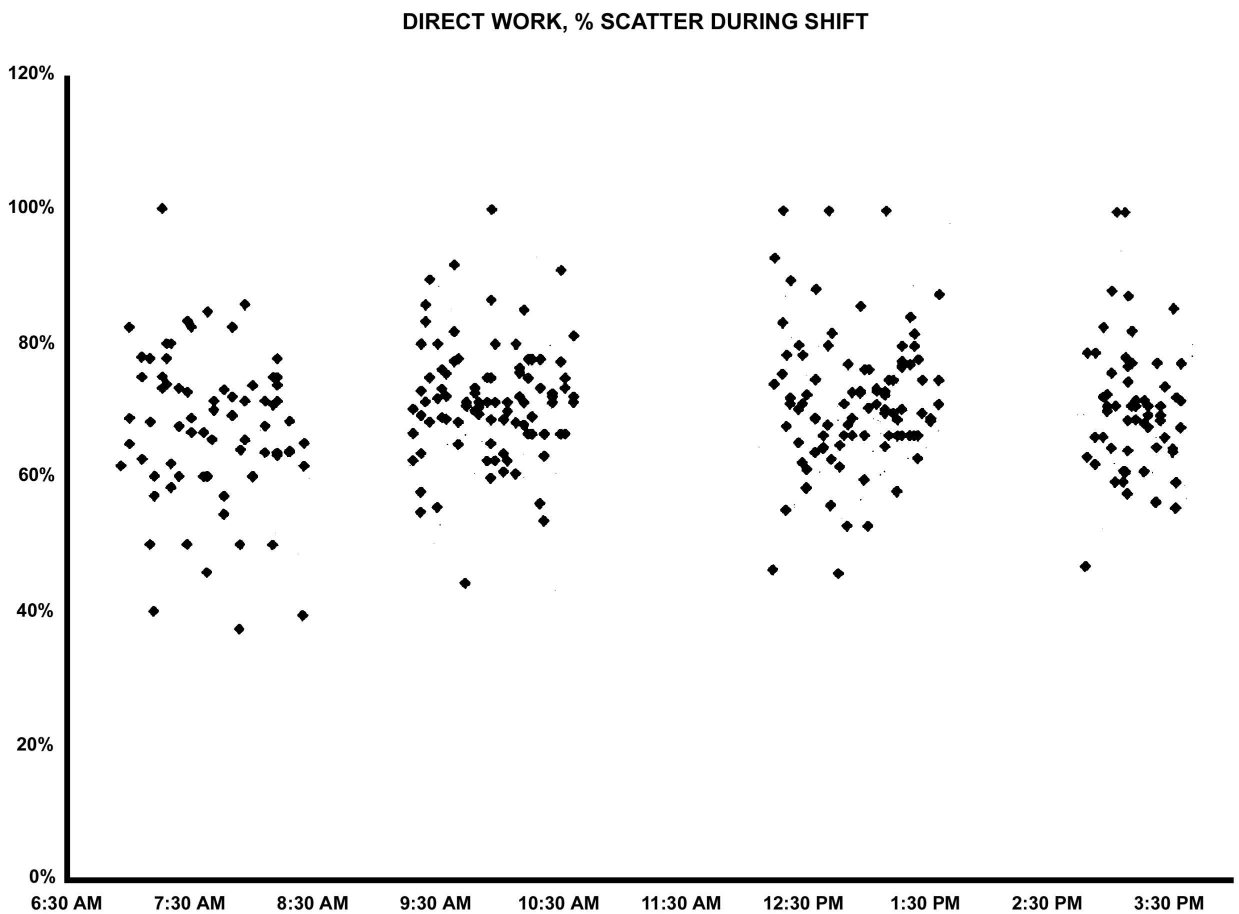


Example chart of labor hour utilization by work category with actual observed percentages as might be used for a daily report.

APPENDIX E. SAMPLE TREND CHART



APPENDIX F. SAMPLE SCATTER DIAGRAM OF PRODUCTIVE WORK PERCENTAGE MEASURED ON TOURS VS. TOUR START TIMES



APPENDIX G. SAMPLE RANDOM TIMES TABLE

RANDOM TOUR START TIMES (5 min. intervals - hours/mins. from shift start)

0:20	0:10	0:25	0:15	0:25	0:20	0:15
0:55	0:55	0:45	1:00	0:30	0:25	1:10
2:30	1:10	1:05	1:25	0:40	0:55	1:25
3:05	1:45	2:20	1:55	1:00	1:20	1:40
3:25	2:05	2:30	2:45	1:40	1:35	1:45
4:00	2:50	3:40	3:50	2:15	1:55	2:40
4:10	3:20	5:00	4:25	2:20	2:30	2:55
4:55	3:30	5:45	5:10	2:30	2:45	3:45
5:00	4:45	5:55	6:20	2:45	3:35	4:55
5:55	4:55	6:00	6:25	3:35	4:05	5:15
6:45	5:00	6:45	6:50	4:00	5:00	5:45
6:50	6:05	7:45	6:55	4:15	6:25	6:25
7:10	7:10	7:55	7:15	6:25	7:20	6:35
7:25	7:35	8:25	7:40	7:30	7:40	7:50
8:20	8:15	8:40	8:25	8:05	8:20	8:10
9:55	8:25	9:10	8:30	8:15	8:30	8:20
10:00	9:40	9:20	9:05	8:40	9:30	9:35
10:30	9:55	9:30	9:25	9:30	9:50	10:40
10:40	10:00	10:25	10:20	9:45	10:25	10:55
11:10	10:30	10:35	11:25	10:25	11:10	11:35
11:50	11:10	10:40	11:45	12:15	11:50	12:35

APPENDIX H. ABSOLUTE ACCURACY AT 95% CONFIDENCE

To determine absolute accuracy A_a% at values of proportion p % and number of observations N, at 95% confidence level, according to the formula $A_a = 2\sqrt{p(1-p)/N}$

p%	± 1%	± 2%	± 3%	± 4%	± 5%
1/99	396	99	44	25	16
2/98	784	196	87	49	31
3/97	1164	291	129	73	47
4/96	1536	384	171	96	61
5/95	1900	475	211	119	76
6/94	2256	564	251	141	90
7/93	2604	651	289	163	104
8/92	2944	736	327	184	118
9/91	3276	819	364	205	131
10/90	3600	900	400	225	144
11/89	3916	979	435	245	157
12/88	4224	1056	469	264	169
13/87	4524	1131	503	283	181
14/86	4816	1204	535	301	193
15/85	5100	1275	567	319	204
16/84	5376	1344	597	336	215
17/83	5644	1411	627	353	226
18/82	5904	1476	656	369	236
19/81	6156	1539	684	385	246
20/80	6400	1600	711	400	256
21/79	6636	1659	737	415	265
22/78	6864	1716	763	429	275
23/77	7084	1771	787	443	283
24/76	7296	1824	811	456	292
25/75	7500	1875	833	469	300
26/74	7696	1924	855	481	308
27/73	7884	1971	876	493	315
28/72	8064	2016	896	504	323
29/71	8236	2059	915	515	329
30/70	8400	2100	933	525	336
31/69	8556	2139	951	535	342
32/68	8704	2176	967	544	348
33/67	8844	2211	983	553	354
34/66	8976	2244	997	561	359
35/65	9100	2275	1011	569	364
36/64	9216	2304	1024	576	369
37/63	9324	2331	1036	583	373
38/62	9424	2356	1047	589	377
39/61	9516	2379	1057	595	381
40/60	9600	2400	1067	600	384
41/59	9676	2419	1075	605	387
42/58	9744	2436	1083	609	390
43/57	9804	2451	1089	613	392
44/56	9856	2464	1095	616	394
45/55	9900	2475	1100	619	396
46/54	9936	2484	1104	621	397
47/53	9964	2491	1107	623	399
48/52	9984	2496	1109	624	399
49/51	9996	2499	1111	625	400
50/50	10000	2500	1111	625	400

APPENDIX I. EXAMPLE ACTION ITEMS LIST

ACTION ITEMS LIST
SITE/PROJECT NAME:
CURRENT DATE:

Item No.	Date Reported	Obstacle to Productive Worker Utilization	Action Plan	Responsible Person	Due Date	Status	Completion Date
1	01/08	Craftworkers walking w. materials; lay-down area distant(ft)	1) Assign expediters to bring materials to crafts in work areas 2) Review workflow planning procedure	Site Superintendent	02/08	Assigned expediters	02/08
2	03/08	Long waits at start/end shift as crew size increases	1) Open additional service window 2) Add assistants when needed 3) Review tool control policy	Site Superintendent	05/08	Done	07/08
3	04/08	Craftworkers waiting while equipment is refueled	Fuel equipment in evening for next day	Fuel Truck Operator	04/08	Being done as of today	04/08
4	04/08	Craftwokers waiting in work areas for unknown reasons	1) Review manpower scheduling procedure 2) Balance with do-able workload	Site Superintendent	05/08		
5							