CONSTRUCTION PROCESS MEASUREMENT AND IMPROVEMENT

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ABSTRACT

Production management is an integral part of the industrial construction process. The process lends itself to measurement by means of statistical tools – to help control the process. Reducing the variation or variability in a process is considered a sign of improved quality of the construction process.

To quantify variability and distinguish the "vital few, trivial many" causes, control charts are used, that are constantly updated and communicated for timely feedback on process performance. Site-level experience on hundreds of projects suggests key construction performance measures include the variability and mean (average) percentage level of value-adding, productive work activity.

The purpose of this paper is to submit that process metrics provides useful insight for constructing 'lean,' i.e., producing value efficiently. Measurement of the construction process involves statistical monitoring and analysis of value- and non-value-added work activities during project execution, using cost-effective random sampling of work activity combined with observation of the workflow.

Effective application of the technique of work process measurement and continuous improvement includes elimination of non-value-added activity and waste, and 'just-in-time' manpower scheduling. Using the correct approach and the proper mindset, work process improvement is saving a major U.S. utility significant contractor labor cost on construction, plant overhaul and modification projects.

Construction process sampling is a useful 'diagnostic' tool for understanding right action by management, supervision and workers alike – to optimize the work environment and create customer value at all times. Experience demonstrates that the quality of the tactical implementation of sampling is as important as the quality of the strategic planning of its use to transform the construction industry.

KEY WORDS

Construction process variability, construction process work sampling, construction process benchmarking, construction process improvement, construction productivity.

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INTRODUCTION

The concept of production in construction – up to now mostly unfamiliar to the industry – provides new access to greater efficiency and effectiveness of the construction process. This paper conveys how the application of construction process measurement provides quantitative information to reduce variability – and thus reduce risk and cost to customer and society.

As a rule, past practices and historical results dictate labor and time estimates for project completion. New planning tools or information technology to better manage construction may be helpful, but individually are incomplete – as is any strategy that fails to consider how variability of the complex, dynamic construction process affects project performance. It's not that managers are necessarily "old school." The new tools often don't provide information they need for their own tasks (Drucker 1999). Variability (and accordingly, uncertainty) is inherent in any process affected by people, equipment, work methods, management practices, and the environment. The challenge is to understand the construction process and obtain useful information from it by measuring and quantifying its variability and level of performance.

Koskela (1999) put forward that production theory could explain the "inherent variability of production in construction." On a macro level, there is much qualitative evidence of the link between variability and project performance, yet too few managers appreciate the importance of process variability – and manage it – in their immediate environment.

In "Out of the Crisis" Deming (1986) wrote: "What is needed is improvement of the process, by reduction of variation, or by change of level, or both." This is as applicable to construction as it is in manufacturing: reduce the 'noise' in the process and raise its performance level. Statistical process control (SPC) has had a large impact on suppliers to the automotive industry (Womack 1990), as has 'six sigma' at GE and other companies. The construction process, similarly, lends itself to measurement by statistical means – to help control and improve it. Indeed, field experience shows how a systematic approach of construction process measurement for process control can significantly reduce causes of under-utilization and waste of resources.

A variable of primary importance in construction is the effective, productive utilization of the workforce. It is a major construction cost and time variable and can be considered as a practical, partial measure of productivity of the production process. It can be readily measured, benchmarked, managed and improved by the proper use of statistical tools – and with a progressive, collaborative viewpoint. Process improvement then consists of making work more convenient by engaging the workforce and removing roadblocks, allowing for greater productive utilization of labor hours.

MEASUREMENT OF CONSTRUCTION PROCESS VARIABILITY

Perhaps the oldest and most widely used 'measures' of construction project performance are the ratio's of actual vs. plan (estimate), i.e., cost vs. budget, progress vs. schedule. If these ratios are 'out-of-line,' they indicate a problem. But if not, they don't provide much insight about causative factors and opportunities for improvement. A more comprehensive, compatible approach is to also measure whether the activities of the construction process are in control and add value, where the constraints are and what actions to take to improve.

There's a widely held adage: "If you can't measure it, you can't manage it" – it holds true for the construction process. Understanding variability is not only a key to process control, it is important to improving the quality of the process, i.e., meeting or exceeding expectations in terms of productive utilization of labor hours.

The universal measure of variability is the standard deviation (sigma), which quantifies the range around the mean (average) level of a set of data. In statistical process control (SPC), a process is said to be "in statistical control" if it behaves in a random fashion, is stable and predictable. Variability in such a process is due to what Deming called 'common causes,' i.e., chance, and random, unspecific causes. But, a process that is 'in control' may not be meeting expectations. Conversely, a process that is 'out of control' may be meeting them. When a process produces unacceptable results – even as it is statistically 'in control', control charts enable quick corrective changes to improve the quality of the process and therefore its subsequent performance.

In evaluating a construction process, its performance can be described by both the average level and the variability of the productive utilization of the labor resources made available during the project. This information provides project managers with a more complete and balanced picture – "wholeness," as Kaydos (1999) calls it, "so that performance won't look better or worse than it is."

Experience on hundreds of industrial construction projects has demonstrated the direct relationship of the value-adding, productive utilization of labor hours and project performance (Picard and Seay 1996; Seay 2000). Applying continuous, systematic sampling of workforce activity in the construction process enables managers to quickly draw valid conclusions – as opposed to erroneous perceptions because of delayed, or inaccurate information, or disposition.

For over two decades, my associates and I have used graphical means (such as pie charts, trend charts and scatter diagrams) to depict construction process performance and variability, analyze constraints to the workforce, and identify causes and opportunities for improvement. Among lessons we learned on the way is that the construction management 'philosophy' is key to the credibility and success of the work activity sampling and analysis methodology. We find that, to create and maintain an optimal work environment, the work process or production system must be aligned with the workers' needs – i.e., work is made more convenient for the worker – as much as workers must align themselves with the system.

TWO CASE EXAMPLES OF CONSTRUCTION PROCESS VARIABILITY

The construction process represented in Figure 1 shows its variability and changes in level of productive utilization. The data represent continuous measurement during green-field construction (civil work, steel erection, installation) of a combined-cycle power plant with a workforce of about 200 crafts. Data points are average productive workforce utilization measured during random sampling tours. The trend line (a 2^{nd} order polynomial regression) shows how the value-adding activity level varies, suggesting specific, assignable causes such as slow starts due to schedule changes or lack of information, and slow-downs towards end of shift due to workers leaving work early, e.g., to return tools to central tool storage.

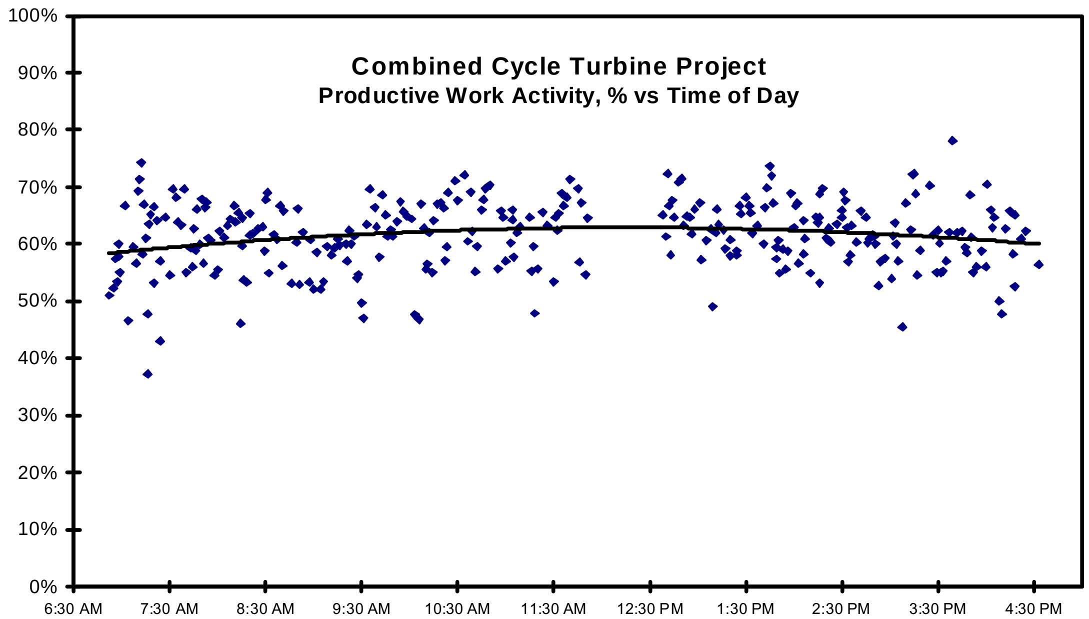

Figure 1: Variability and trend of average effective workforce utilization of construction production system. Data points are average effective workforce utilization measured on random sampling tours of all work areas, plotted by start time, over the course of the shift (no measurement on lunch break).

The productive utilization of the construction process varies up and down but regresses toward its mean (average) level. For the overall process, average productive utilization (*p*) of the workforce on this project is 61.5. %. Assuming a 'normal' distribution, a standard deviation (σ) of 6.00 %-points can be calculated.

In practice, average workforce utilization is monitored and analyzed for daily, varying constraints to the workforce and opportunities to eliminate them. Causes of problems can be identified and accountability for action established. Appreciating the quantitative impact on progress and cost of crews waiting, e.g., for information, workable assignments, tools and equipment, or need for walking long distances from work area to tool supply, material lay-down areas, facilities, etc. provides valuable insight for management decisions.

Workforce utilization as a process performance measure, made visible graphically, is easily understood at all project levels, enables managers to quickly identify key issues, and involve crafts to bring to the fore roadblocks they encounter in carrying out their assigned tasks. Productive utilization performance goals can be set, using external or internal benchmarks, and included in contract language (Picard, Seay 1996). To compare the performance of different projects, the average productive workforce utilization of their respective work processes can be used, in addition to the conventional variances against budget and schedule.

Hopp and Spearman (2000) classify factory processes based on variability, and propose as a coefficient of variation as a "relative measure of variability". Applying a similar ratio to the variability of the productive utilization of a construction process, this coefficient of variation is: C = σ/p, where σ is the standard deviation (in % points) and *p* the mean (average) productive utilization measured (in %). Thus, the coefficient of variation for the Combined Cycle Project construction process is 6.00/61.5 = 0.10. Experience suggests this process could be considered one of relatively 'low variability'.

The second example of construction process variability (Figure 2), showing much greater variability, is the construction process achieved on a Clean Air Act 'selective catalytic reduction' (SCR) installation at an existing coal-fired power plant – as can be seen, with more widely varying productive workforce utilization than that in Figure 1.

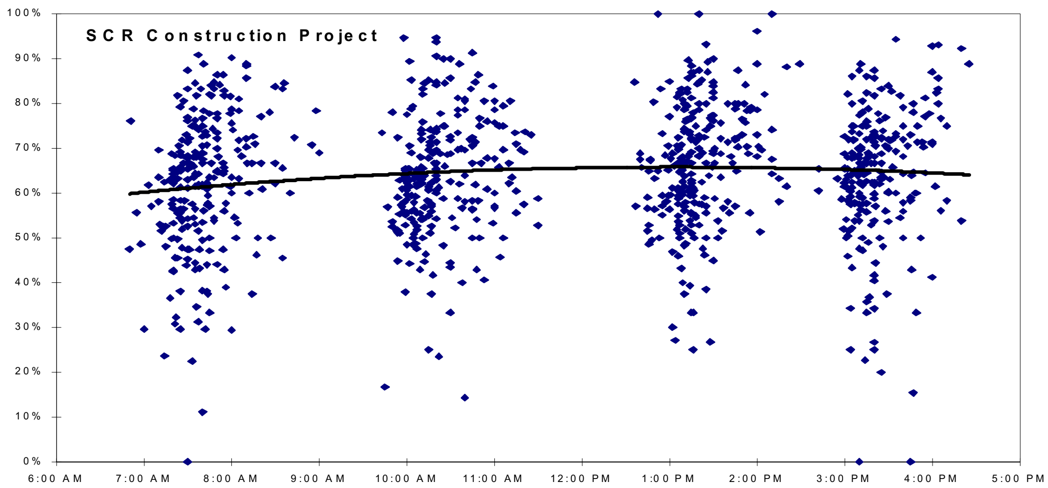

Figure 2: Variability of productive workforce utilization. Data points are average productive utilization of overall workforce of approx. 350. The shift had 3 organized break periods (during which no data were gathered).

Overall, this SCR construction process averaged 64.2% productive utilization with a standard deviation of 14.34. The coefficient of variation therefore is: 14.34/64.2 = 0.22, observably representing relatively 'high variability'.

In assessing process performance levels, a single 'magical' number such as the coefficient of variation, might appeal, but could mislead. Nevertheless, it would seem useful to look at ways of classifying construction processes based on their variability of effective workforce utilization.

The two projects are dissimilar in many ways. Looking at the process, however, the main difference is that in the first project (Figure 1), lower variability was achieved by a pro-active team of management and supervision, including the foremen. A "process improvement taskforce" was established with representatives of labor, supervision and management meeting regularly to review 'how' the work was going (not 'what'). Good communication and feedback led to participation in problem solving by members of the craft workforce, including foremen. The project encountered numerous engineering and delivery delays – contributing to the lower level of average productive workforce utilization.

The second case (Figure 2) achieved a somewhat higher average productive utilization, did not suffer the delivery delays, but had relatively less effective project planning and control. Whereas the first case was a 'process-driven' project, the second was more on the opposite side of the scale, i.e., was more 'planning-driven' A final note: the goal for average productive workforce utilization on each of these above projects – set jointly by owner and constructor management – was 70%.

STATISTICAL PROCESS MEASUREMENT METHODOLOGY

Process control works when there is adequate information – accurate, actionable and timely. Measurement and improvement of the construction work process involves ongoing observation and analysis of value-added and non-value-added work activities during project execution using statistical sampling of work activity. It is sometimes misunderstood because of inappropriate applications, sometimes in the attempt to solve "labor problems" in contentious project conditions. Overcoming resistance to measuring the work process can be a big hurdle. The obstacle often is management, more concerned about possible negative reaction by the workforce than about consequences of an inefficient work process. Properly applied, work sampling is a useful technique that serves process measurement and improvement well.

Work sampling is broadly defined as the application of statistical sampling techniques to the study of work activities. It is typically used to estimate the proportion of workers' time that is devoted to different elements of workforce activity

The data collection procedure used in our construction process measurement approach follows standard random work sampling procedures, such as described e.g., in DCAA Contract Audit Manual (DCAA 2002). Site-level sampling tours are randomized as much as practicable during work periods, and are conducted openly without interfering with workers or need for asking questions. At no time are individuals' names or other identifiers required – the purpose is to study the overall construction process.

Aided by the analysis of work sampling data, separate observation tours of the workflow are conducted to study specific constraints, identify root causes of obstacles, and derive recommendations for action. Participation in problem solving is elicited from field supervision, and foremen, and, at their discretion, also from select crafts or technicians.

CONSTRUCTION PROCESS IMPROVEMENT

Understanding the capability of a construction process is important for planning and control, but no matter what it is, it is likely that improvement is possible. Even though we cannot, at this point, predict accurately how variability of the construction process affects the project's performance, the ability to manage the variability of the work process must be considered a core management competence.

In "Construction Workers, USA," Applebaum (1999) writes "construction workers will determine how to do the work, depending on the job conditions." He declares, "labor output is considered beyond control, other than the journeyman." Experience shows that the construction work process can be improved significantly by simply reducing or eliminating factors that interfere with crafts and technicians, and contribute to variability while diminishing the level of performance.

One of a project manager's objectives must be to achieve the smallest possible variability that the process is capable of – eliminating or minimizing all undesirable effects or specific causes – and cause it to perform at the maximum possible level of effective labor utilization. Labor utilization measurement provides needed, estimateindependent information, i.e., new insight that enables quick corrective management action and strengthens project controls.

Changing the rules or providing more planning or training do not necessarily constitute process improvement. The key to ensuring business-driven change is to measure results in terms of efficiency and effectiveness by assessing the contributions of managerial personnel and information on achieving goals. This aims at “measuring the measurer”, is more demanding and discerning, but has big expected pay-off (Schoderbek 1990).

The bulk of opportunities for improvement of the industrial construction process is subject to management action (Macklin and Picard 1992). The management question is: “What constrains the workers in doing their assigned tasks – and can be eliminated by supervision or management decision?”

A visible consequence of poor process control is a high variability, due to workers frequently moving or waiting, which consumes valuable time that could be utilized productively. What makes workers unproductive, and the work process fluctuate downward, is the unreliable availability of a combination of varying production factors such as correct information, right tool supply (and re-supply), correct parts and materials, proper supplies, supervisory support, nearby conveniences, and actual, do-able work. Other major factors limiting productivity of the work process are changeable site conditions, such as safety, housekeeping, weather.

Process-based competencies have historically provided important competitive advantages to companies that had them. The technology to measure the construction delivery process is cost-effectively available. Using it enables customer and constructor both to quickly verify that value-adding activity is optimal. In case of important variation in the construction delivery process – discernible from random trivial ones – problems can be solved and adjustments made on a timely basis. But, optimal process solutions deteriorate over time (Dettmer 1997) as project conditions change frequently. Continuous improvement is thus required to maintain and increase the performance of the process.

Benchmarking construction process performance provides an added means to specify and verify the quality of the delivery process, and allows for contract language that includes objective, quantifiable performance measures, especially important in ‘partnering’.

CASE OF CONTINUOUS PROCESS IMPROVEMENT

The disciplined application of the technique of construction process measurement, analysis and improvement at a major U.S. utility since 1993 is producing annual contractor labor cost savings of around $23 million (Seay 2000). Figure 3 shows the continuous improvement trend of construction work processes, worked by thousands of craftsmen of as many as 15 different trades.

The strategic approach to drastically improve construction cost-effectiveness led the organization to its current focus on efficiency of the construction work process. Major contributing factors in its work process improvement effort are:

Long-term ‘partnering’ relationship with constructors

Incentive clauses reward contractors with shared labor savings

Continuous sampling measurement, learning and improvement

Up-date labor estimates and ‘raise the bar’ on future projects

The key features of construction work process improvement are

Management takes responsibility for the capability of the work process – managers, supervisors and foremen are ‘active.’

A system is in place for continuously monitoring and correcting process performance – i.e., the process is measured and the workforce is engaged and enabled to participate.

Make job conditions as convenient as possible for the workers.

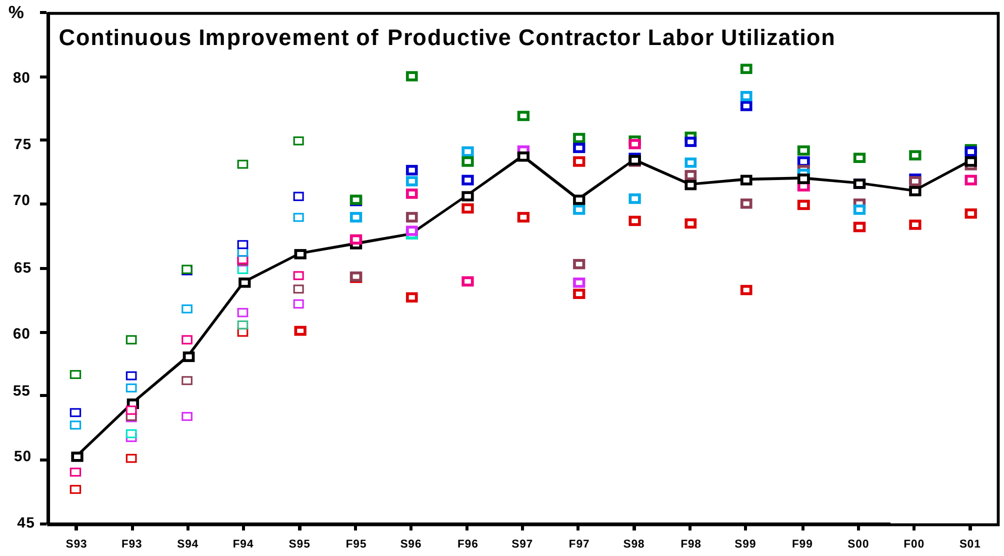

Figure 3: Continuous work process improvement at major utility from 1993through early 2001. Data points represent average productive labor utilization achieved at major plant modification and outage construction projects. Trend line shows system-wide average; the sudden drop in 1997 corresponds to a change of contractor.

Established practices and procedures are not automatically taken for granted. Previously planned manpower staffing schedules are not typically “lean”, based, as they are, on historical data – nor adhered to, if, as indicated by daily labor utilization data, non-value-added activity exceeds agreed-upon, un-acceptable levels. Manpower levels are increased only as needed, ‘just-in-time’, as work becomes available, and are maintained as long as non-value-added activity does not exceed the target. The net effect is an average 30 percent less manpower required to complete work – with corresponding cost savings and early facility availability.

The quality of the tactical implementation of this technique is as important as the quality of the strategic plan to improve construction performance. Company and contractor personnel are always briefed prior to measurement, receive daily feedback, and learn how to interpret resulting data. Significantly, also, field supervisors are learning to provide pro-active support to their crews, and to ensure working conditions are as convenient as possible so that productive activity can be maximized without greater effort.

CONCLUSIONS

The construction process provides the foundation of performance measurement, which, combined with conventional project measures, provides a more completely balanced, "whole" picture of project execution. The ability to manage process variability must be considered a core project management competence.

Much is written about construction variability but consistent, direct measurement data have been lacking. A process-based discipline of statistical work sampling measurement, analysis and continuous improvement is available that integrates with conventional project measures, such as cost, and schedule.

While evaluating project performance on the basis of results is customary, the new focus on the process reduces variability and raises the overall performance level through quick corrective action – saving money and time through more effective, productive utilization of available labor hours, creating greater customer value in an optimal work environment.

Continuously removing or minimizing systemic process constraints makes task accomplishment easier and more convenient for the workers, but the implementation of process measurement must be management supported, effectively planned and communicated, and worker input elicited in process improvement.

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