FRAMEWORK FOR ANALYSIS OF PERFORMANCE

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ABSTRACT: The construction process involves the interaction of equipment, manpower, and material. Each construction project begins with performance goals for cost, schedule, safety, etc. When actual performance differs from exected performance, the cause of the deviation must be determined. The analysis of construction performance has typically been performed in a shotgun fashion. The paper presents a framework for the rationalization of the analysis of construction performance that will improve the effectiveness and efficiency of the analysis. The framework provides a decision tree that will guide construction engineers as they analyze performance. Five major issues are addressed in the framework: adequacy of actual performance; presence of organizationally imposed constraints; worker possession of required knowledge, skills, and ability; worker possession of necessary motivation; and whether the estimate is realistic. Use of the framework requires answering a series of questions. Data are suggested to allow the questions to be answered.

INTRODUCTION

The performance of a construction organization is a function of the performance of the members of that organization. High performance by individual members of the organization will result in high performance by the organization. Organizational performance, as well as individual performance, is multidimensional. Many people operate with an extremely limited view of performance and consider the productivity of the firm's work force and the profitability of the firm as the only criteria of performance. An examination of productivity provides a very narrow perspective on performance in a construction organization, while focusing on profitability does not ensure long-term survival of the firm. Profitability and productivity are necessary, but not sufficient, conditions for survival. It is possible for a firm profitable in the short run to go out of business for a variety of reasons. A productive firm is not always a profitable firm. Before proceeding to an examination of a performance analysis framework, it is necessary to develop an understanding of the multidimensional nature of performance.

PERFORMANCE DIMENSIONS

One author has stated that performance consists of seven dimensions: effectiveness, efficiency, quality, productivity, quality of work life, innovation, and profitability (Sink 1985). Each of these dimensions must be of interest to the construction organization. Effectiveness encompasses the attainment of the organization's objectives. Every construction organization functions at two levels. The first is the corporate or home-office level, and the second is the project or field level. At the corporate level, the organi-

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zation must accomplish specific tasks and attain specific objectives to survive. For example, the business development function is charged with generating new business opportunities for the firm. This entails identifying potential leads or prospects, calling on them, and securing the opportunity to bid or negotiate for work. The firm may establish an objective that *X* new bidding opportunities be developed per month. The effectiveness of this activity is the degree to which the objective is met. Similar objectives can be established at the corporate level for such activities as the number of bids prepared, the number of personnel hired, and the amount of working capital obtained. Corporate-level performance, while of importance and interest, will not be addressed in this paper. However, the concepts to be examined are equally applicable at the corporate level as the project level. Objectives at the project level are much easier to establish because of the finite nature of the project. What is to be built is known, as are the schedule and budget. These all become objectives. A four-story commercial office building containing 100,000 sq ft of floor space is to be constructed within nine months at a cost of $2,000,000. Objectives may be set for other types of performance as well. For example, an objective may be established to have no lost-time accidents on the job or to keep absenteeism less than 3%. The degree to which these objectives are met indicates the degree of effectiveness.

Efficiency, which involves the utilization of resources, may be represented by the ratio of the resources expected to be consumed divided by the resources actually consumed. Labor productivity is a measure of efficiency. However, because of the labor-intensive nature of construction, it is treated as a separate dimension. Efficiency, therefore, will be limited to the utilization of equipment, fuel, material, and tools. Assuming that the quantities required to be installed did not change, the use of 10,000 feet of 1-in. conduit to attain a requirement of 7,500 installed feet is extremely inefficient. Similarly, the expenditure of $10,000 for small tools on a project when the budget was $5,000 is also inefficient, assuming there were no changes in the project or size of the work force. Another example of a measure of efficiency, which would be of interest to an earth-moving contractor, would be gallons of fuel consumed per cubic yard of earth moved.

Quality involves doing things the right way the first time. The work performed must conform to the specifications established for the project. If the specifications call for the use of a particular type of paint and another type is used, quality was not attained because of the lack of conformance with the specifications. Similarly, if the specifications called for soil to be compacted to a density of 110 lb/cu ft, but it was only compacted to a density of 100 lb/cu ft, quality was not attained. The overriding question becomes whether the completed work possesses the attributes desired by the owner and designer. Poor quality performance results in increased rework, which has significant cost and schedule implications.

As stated previously, productivity is treated as a separate dimension of performance because of the labor-intensive nature of the construction process. The process involves workers expending effort using tools and equipment to transform materials into finished products. Productivity can be defined in a variety of ways depending upon the work being performed. It is typically defined as output/input, with output expressed in terms of physical units and input as man-hours required to produce the output. For this paper, productivity will be defined as the number of man-hours expended in a period divided by the number of units produced during that period, i.e., man-hours/unit. The smaller this number the better the productivity. Thus, 0.75 hr/sq ft of formwork construction is better than 1.00 hr. Project estimates are based upon anticipated productivity rates. Considerable management efforts are expended to ensure that actual rates are close to those used to develop the estimate. The term "labor factor" is often used to denote the actual productivity rate divided by the expected rate. A value less than one indicates productivity is better than expected, while a value greater than one reveals productivity is worse than expected. Actual productivity has a significant influence on the ability of the firm to complete the project within the estimated time and budget.

Quality of work life is concerned with the response of organizational members to the sociotechnical aspects of the work and the organization. Quality of work life includes, among other issues, the autonomy people are granted in the performance of their work, the participation they are allowed in making decisions that affect them, and the social interaction allowed by the job. A positive quality of work life leads to positive organizational outcomes, e.g., reduced absenteeism and turnover, greater job satisfaction, etc. The quality of work life is a major determinant of an organization's ability to recruit, motivate, and retain skilled workers. As the construction industry moves into a personnel-shortage period, the quality of work life will play a major role in a firm's success in developing and retaining a skilled work force and, consequently, its ability to compete for work.

Innovation is the use of creativity by members of the organization. The identification and utilization of new and better materials, methods, procedures, etc., has positive benefits for the organization. Innovation allows a firm to remain competitive and provide a source of jobs. The inability to innovate results in organizational stagnation and, eventually, decline. Value engineering is a process that depends heavily upon innovation. Modularization is a process that has led to innovation in industrial construction.

The last of the dimensions of performance, and certainly not the least important, is profitability. Long-term survival of the construction organization depends upon the revenues generated by the firm exceeding the costs of producing the revenues. If the firm is not profitable, it will eventually consume the owner's investment in the organization and cease to exist. Profitability may be expressed in a variety of ways from the simple profit margin to return on net worth to a variety of financial ratios.

Each of the seven dimensions of performance is important to construction organizations. However, the relative importance of each dimension will differ within and between organizations at any point in time and over time. A firm performing a project that has an extremely tight schedule with heavy liquidated damages for failure to complete the project by a certain date will probably assign effectiveness a relatively high importance. Getting the project done on time will have the highest priority. Similarly, another firm performing work on a nuclear facility may assign quality the highest priority. Quality may also be given a higher priority on a project being constructed using a reimbursable price contract as opposed to a fixed price contract.

It is important to understand that neglecting any of the dimensions for a significant period of time will have negative consequences for the organization. For example, emphasizing on-time performance while ignoring the quality of work life may result in increased turnover and difficulty in hiring necessary personnel. An emphasis on profitability while neglecting quality may result in short-term profits, but imperil long-term survival as poor quality is manifested in significant warranty problems. Thus, it is important to understand the dimensions of performance and how their relative importance changes over time.

Contractors are in business for a variety of purposes, the primary one being to make money. To accomplish this, the objective of every construction manager (defined broadly to include anyone who manages the construction process at any level) must be to manage the process in a way that results in desired levels of performance. It is important that performance on any project be evaluated in terms of the seven performance dimensions presented. The specific project and organization will determine the relative importance of the dimensions. Historically, project performance has been evaluated in terms of cost, schedule, and quality. Poor performance on one or more of these dimensions creates significant problems for the firm. Poor performance in terms of costs results in decreased profits and, potentially, a financial loss on the project. In terms of schedule, poor performance may result in the failure to meet the contractural completion date and the requirement to pay late completion penalties or liquidated damages. Finally, poor quality performance results in increased rework to remedy the lack of quality. Rework also directly influences cost and schedule performance.

Performance Analysis

It is imperative that management respond quickly to evidence of poor performance and take action to eliminate its causes. Two factors inhibiting management's ability to do this are management's extremely limited time resources and the finite, often short, duration of construction projects or a contractor's time on a project. Contractors, because of the extremely competitive nature of the construction business, use a minimalist approach to project management. Except for large, cost-reimbursable industrial projects, there are very few people employed on a construction project above the foreman level. Consequently, the management personnel are extremely busy. They normally have one paramount set of objectives: get the project completed and accepted within the schedule and the budget. For the most part, they do not worry about innovation or the quality of work life. They are too busy just getting it done to worry about whether there is a "better" way of doing it. Solving problems or "putting out fires" takes up the great majority of their time. As a result, construction managers often become enmeshed in issues that consume significant amounts of their time, but often have little return. The second factor is the finite and often short duration of the contractor's presence on the project. By the time the construction manager obtains the necessary information to improve performance, the activity may have already been completed. The window of opportunity to influence performance during the actual construction process is extremely limited. Thus, the time to significantly influence performance is during the planning stage, particularly if craftsmen are allowed to become involved in the planning.

There is a need for a rational, analytical framework with which construction managers can analyze performance to determine potential causes of unacceptable performance. The framework would be used to establish hypothesized causes of the unacceptable performance. There are a variety of techniques that may be used to gather data to test the hypotheses. These techniques should be employed in a rational manner. This is necessary for both cost and time considerations. It makes little sense to employ these techniques in a shotgun approach to performance analysis. Each of the techniques has advantages and disadvantages and is particularly suited for analyzing specific aspects of worker performance. No one technique can provide a complete understanding of worker performance. Therefore, the availability of an analytical framework together with an understanding of the various techniques will allow management to address causes of unacceptable performance more quickly.

Performance Model

Maloney and McFillen have presented a model of worker performance and reported research that validates the model within a construction context (Maloney and McFillen 1983, 1986). The model identifies four variables that influence the level of worker performance: (1) The worker's motivation as evidenced by the worker's effort; (2) the degree to which the worker possesses the requisite job-specific knowledge and skills; (3) the degree to which the worker possesses the requisite innate mental and physical abilities; and (4) the effectiveness of management in organizing the work and providing the necessary resources.

Motivation is the physiological or psychological drive of a worker to obtain the means of satisfying his needs. An individual's needs may be placed into one of three categories: existence, relatedness, and growth (Alderfer 1970). Existence needs are those that involve the functioning and survival of the individual as a human being. Thus, needs such as those for food, air, water, and security fall within the existence category. Relatedness needs are those that are social in nature. The needs involving relationships with family, coworkers, and others are relatedness needs. Growth needs are those that involve the development and utilization of a person's skills and abilities. Motivated behavior is behavior with the objective of obtaining the means of satisfying an unfulfilled need. Getting into a car, driving to a restaurant, and ordering a meal is behavior with the objective of obtaining food to satisfy one's hunger. Joining in a discussion of the previous weekend's football game with a group of coworkers is behavior designed to satisfy a social need. Participating in a skills upgrading program and utilizing the new skills allows a person to satisfy one of his growth needs.

A person's motivation level to perform a task is a function of three variables: (1) The likelihood that if he exerts the effort, he will be able to perform the task; (2) the likelihood that if he performs the task, he will receive a specific reward or outcome for that performance; and (3) the anticipated satisfaction that he associates with the reward or outcome. A person must believe he has a reasonable likelihood of being able to perform a task before he will try it. If the likelihood is too low, the person will believe the task is too difficult to perform and will, most likely, not attempt to perform it. Conversely, if the likelihood of performance is too high, the person will see the task as being too easy and may not be very motivated to perform it. To be motivated, the worker must perceive a likelihood of his receiving a reward or outcome for his performance of the task. People do what they are rewarded for and they do not do what they are not rewarded for. The absence of rewards reduces motivation. Therefore, for a person to be motivated to perform a task, he must perceive a likelihood of receiving a reward. This does not mean that, for example, a carpenter building forms must receive a reward each time he builds a form. What it does mean is that the carpenter should believe he will be rewarded for his performance and that he is rewarded. The frequency and magnitude of the reward will vary from simply being told by the superintendent that he is doing a good job to being told that as a result of his good performance, he will be moved to another project with the firm when the current project is completed. The last variable influencing a person's motivation is the anticipated satisfaction he associates with the potential rewards he may receive. If this anticipated satisfaction is low, the worker will perceive the reward as not very desirable, and he will, therefore, not be very motivated to obtain it. On the other hand, if the anticipated satisfaction is high, the worker will want the reward and be motivated to obtain it. In summary, people are motivated to perform a task if they perceive themselves as having a reasonable probability of being able to perform the task and perceive a reasonable probability of receiving desired rewards or outcomes as a result of task performance.

Motivation is intangible. It cannot be touched or felt, but it can be seen. Effort is the physical manifestation of motivation. A motivated person will engage in physical or mental effort to perform the task for which he is motivated. The more motivated the person is, the more effort he will expend. The absence of effort indicates a lack of motivation.

A second variable influencing performance is the worker's possession of the requisite job-specific knowledge and skills. Each task requires specific skills and knowledge of how to use those skills. A scheduling engineer preparing a critical path schedule needs to understand activity durations, activity logic, the different types of float, etc. Without this knowledge, he will be unable to prepare the schedule. Similarly, a welder preparing to weld pipe spool pieces must have knowledge of the welding procedure to be employed, the welding rod to be used, any preheat requirements, the metallurgy of the pipe to be welded, etc., as well as the skills necessary to do the actual welding. Without the knowledge and skills, the worker's performance will be significantly reduced. Trial and error may result in the eventual acquisition of the knowledge and skills, but performance during this learning period will be very poor. Formal training programs allow a worker to obtain the knowledge and skills necessary to perform the task and avoid the performance impact resulting from trial and error.

A third variable having a significant influence on performance is that of the requisite mental and physical abilities necessary to perform the task. Mental and physical abilities are innate, i.e., people are born with them. They are not acquired through training programs. Some may be increased, such as physical strength, but, for the most part, people have them or they do not. Mental abilities are those such as numerical aptitude, spatial reasoning, etc., while physical abilities include manual dexterity, hand-eye coordination, and physical strength. Tasks have a minimum level of ability required for their performance. Workers possessing abilities above that level will be able to perform the task, while people below that level will not. The job of selection in an organization is to identify those people with the abilities required to perform the tasks constituting the job in question.

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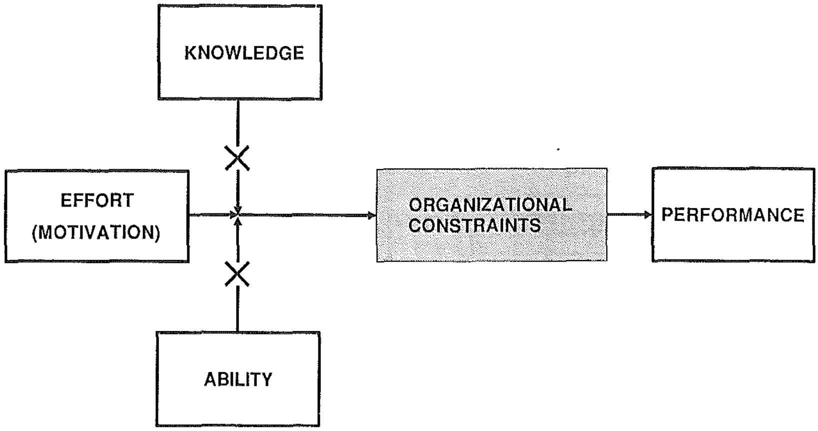

FIG. 1. Performance Determinants

The first three variables combine in a multiplicative fashion, as shown in Fig. 1, such that the absence of one precludes performance. Management's performance is an intervening variable, i.e., it may facilitate or constrain the worker's performance. To facilitate performance, management must provide workers with the resources necessary to perform the assigned tasks. The workers must have the equipment, instructions, material, and tools to do the work. In addition, the workers must be given access to the work area and be free from interferences from other work teams if performance is to be high. Management is responsible for ensuring this.

Performance Analysis Framework

The performance analysis framework is shown in Fig. 2. It is in the form of a flowchart or decision tree. The framework provides a logical means of addressing performance analysis. Organizational constraints are the first area examined because motivated workers possessing the requisite knowledge, skills, and abilities cannot perform up to their potential without the necessary resources. Thus, the first stage in improving performance is to identify and eliminate any organizational constraints. Once any constraints have been removed, the analysis shifts to uncover any inadequacies in terms of knowledge, skills, and abilities. A worker may be motivated and have the necessary resources to perform an assigned task but be unable to do so because of a lack of knowledge, skills, and abilities. A worker may possess the knowledge, skills, and abilities and have the necessary resources, but lack motivation. The unmotivated worker will still perform at higher levels than the worker without the knowledge, skills, and abilities. Therefore, the second stage in the performance analysis framework is to identify the lack of knowledge, skills, and abilities. If a worker has the resources and the knowledge, skills, and abilities, the primary determinant of his performance will be his motivation. The third stage of the framework focuses on the identification of factors causing a poor motivational environment. Once it has been determined that workers have the resources, the knowledge, skills, and abil-

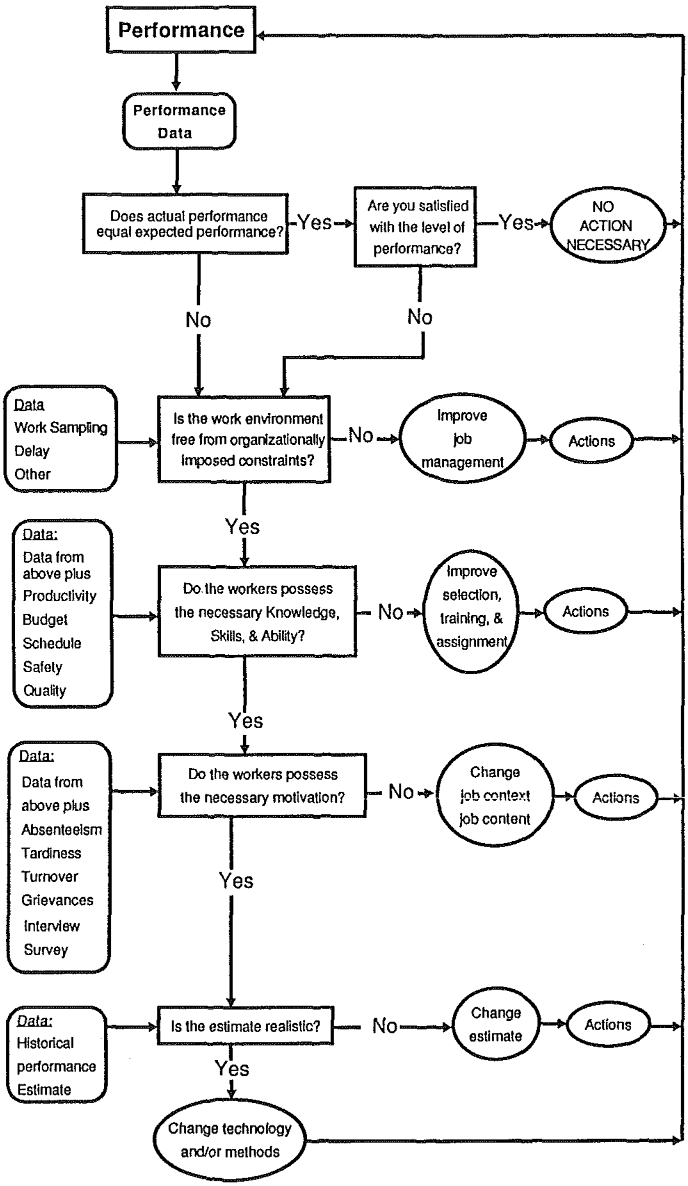

FIG. 2. Performance Analysis Flowchart

ities, and the motivation, the analysis proceeds to determine whether the performance objective is realistic or whether there must be change in the technology and/or methods used in the work process. Questions are asked to guide an individual through the analysis of worker performance. The answers to the questions, which identify the causes of the unacceptable per-

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formance, are obtained using various data-gathering techniques and lead to various action plans.

Step One

Successful performance management is dependent upon effective performance measurement. A performance measurement system is a prerequisite for performance analysis. The analysis of performance begins with a comparison of actual performance with the expected performance, as is the case in all control situations. Performance may be measured in terms of any of the dimensions presented. Typically, construction project personnel are most concerned with labor productivity. To illustrate the use of the performance analysis framework, performance will be defined as labor productivity. Consequently, the measure of performance must include physical output, i.e., some measure of productivity or unit output. The concern is with how much is produced with a specific amount of effort, with effort typically being expressed in man-hours. Some prefer to define productivity as man-hours required per unit of output or unit rates (Thomas and Kramer 1989). For performance analysis, these unit rates are much easier to understand. Thus, the measurements that are of interest are ones such as man-hours per cubic yards of concrete placed or linear feet of cable installed. Labor costs, in terms of dollars expended, are a function of wage rates and productivity and are, therefore, a poor measure of worker performance because of the need to control for wage rage changes. Similarly, substitution of one craft for another with a different wage rate or contractually mandated wage increases make cost a poor surrogate for worker performance. An examination of site performance measurement systems is beyond the scope of this paper. For an excellent discussion of this topic, see Thomas and Kramer (1989).

The concept behind the performance analysis framework is that there is an ideal productivity rate. This would be the rate obtained if management did a perfect job in planning the work and providing the resources necessary to carry out the work. To obtain this rate, it would also be necessary for the proper motivational environment to have been created by management and no external factors, such as weather or strikes, to have arisen that could influence productivity. Fig. 3 shows this concept. The ideal productivity rate is shown as the bottom curve and the hypothetical effects of various factors causing the productivity rate to worsen are added to this rate. The top curve shows the predicted productivity rate, which is based upon the historical performance obtained by the firm adjusted for anticipated conditions on the project.

The first question asked in the flowchart is: "Does the actual performance or productivity rate equal the expected or predicted performance?" It is readily answered if the firm has implemented a performance or productivity measurement system. For example, if the activity of interest is pipe erection, the expected performance may be 0.75 man-hours/foot of pipe erected. If the actual is 0.85, the answer is no, i.e., it is taking 0.1 man-hours more than expected to erect the foot of pipe.

If the actual rate is less than 0.75 man-hours/foot of pipe, the answer is yes and we are led to a second question, one whose answer is much more complex than the first. If the actual performance equals or betters the expected performance, the manager must decide whether the level of performance is acceptable. The answer to this question is dependent upon several

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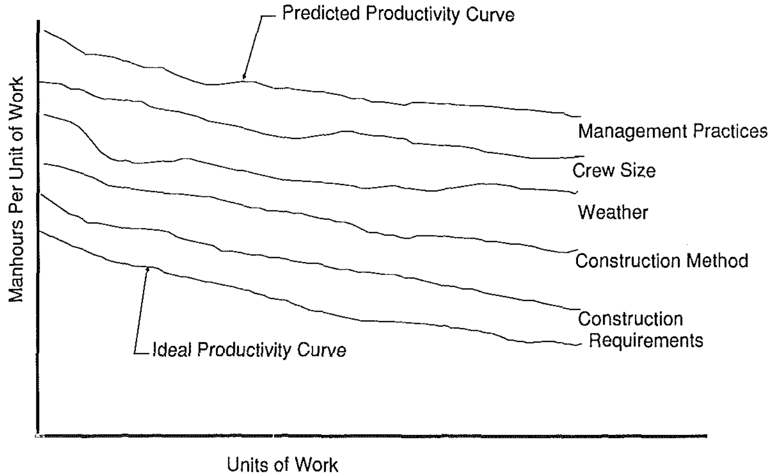

FIG. 3. Productivity Factors

factors. Probably the most critical is the current standing of the project in terms of cost and schedule. If the project has no float, the schedule is being exceeded, or an activity is on the critical path, management may not be satisfied with attaining the level of performance that was expected if, by improving performance, the project could be returned to its schedule. The same rationale would apply if the project were beginning to exceed its budget. Another factor influencing the answer to the question is the manager's perceptions of the capabilities of the workers performing the task. He may perceive that the workers are capable of performing at a higher level. If, after all factors are considered, the manager is satisfied with the level of performance and it is deemed acceptable, no further analysis or corrective action is necessary. If the level of performance is not acceptable, the manager must initiate the process of identifying the causes of the unacceptable performance.

Step Two

The process of analysis, therefore, begins by determining the presence of organizationally imposed constraints, i.e., whether management has provided the required resources and organized the work in such a manner that the workers are free from constraints imposed by management's failure to effectively perform its job and are, therefore, able to fully utilize their capbilities. Management performance is multidimensional in nature. Worker performance is drastically reduced when management fails to provide the workers with the necessary resources. These include not only equipment, materials, and tools, but also information about the work, such as material and tool location, and direction as to what is to be done and how it is to be done. If workers are not provided with these resources, they will be unable to perform as expected and, depending upon other factors, will search for what is needed to do the job or wait until it is provided to them. In either case, performance is reduced.

Management must also plan, schedule, and control the work to prevent the development of constraints. Work sequencing is extremely important. The carpenter must have completed scaffold erection before a fitter crew can begin work on an elevated piping system; the fitter must finish his work before the insulator may begin his. This chain continues until the laborer cleans up the site. Failure to have prerequisite work completed greatly reduces worker performance because time is lost while the constrained crew is relocated to another task. Work must be scheduled to minimize congestion because crew or worker interferences reduce worker performance. Crews must be sized appropriately for the tasks to be performed. If crews are too large, significant periods of idle time will occur. Crews that are too small require crew members to perform additional duties that constrain output. Similarly, management must act to mitigate the effects of weather on workers if it wants to eliminate potential constraints on worker performance. Unit rates for the fabrication of structural steel elements in the rain will be significantly higher than rates for the same process in good weather unless temporary shelters are erected over the fabrication area. However, the erection of the shelters, in and of itself, results in higher unit rates because hours are expended to erect the shelters while no structural steel is being fabricated. Thus, ineffective management serves to increase unit rates above what they would have been without the constraints.

The data typically used to identify organizational constraints are obtained through two different but related types of studies: work or activity sampling and delay surveys. Activity or work sampling may be defined as follows:

> Work sampling is a statistical sampling procedure that involves collecting a large number of random samples or observations of the activities of people or equipment. When an observation is made, the state of being or condition of the subject being studied is noted, and this state is classified into predetermined categories of activities that have been selected because of their pertinence to the work activity. From the proportion of observations in each category, inferences are made regarding the total work activity (Thomas 1981).

The process of work sampling involves a person walking through a construction project at random times on random routes observing workers and categorizing what he sees each worker doing into a predetermined set of categories. For a detailed discussion of work sampling, see Thomas (1981). Work sampling uses the statistical principles of drawing inferences about a given population by analyzing samples drawn from the population. Inference allows one to say that the percentage of observations recorded in a given category reflect to a known degree of accuracy the percentage of time actually spent in the state or condition. The activities of a craftsman may be divided into eight categories.

1. Direct work: Applying tools or physical effort productively to perform or help perform a job assignment, e.g., positioning of equipment or materials, pulling on a wrench, welding a bead, stringing a wire, digging a ditch, pounding a nail, etc. Any momentary break in this activity would be observed as some category other than direct work.
2. Transporting: Transporting tools and/or materials within 50 ft of the work

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area not otherwise classified as direct work. This includes storing, sorting, cleaning, adjusting, etc.

3. Obtaining tools and materials: Moving, traveling with tools, equipment, or materials outside of the immediate work area. Obtaining tools from a tool trailer or material from a remote storage area are examples.

4. Planning and instructions: Giving or receiving instructions, e.g., foremen giving instructions to craftsmen, craftsmen giving instructions to fellow craftsmen, etc. Any conversation or review of documents (drawings, specifications, sketches, etc.) that is directly related to the job.

5. Traveling empty: Moving or traveling empty-handed, whether walking or riding in a vehicle.

6. Waiting and idle: Waiting for one to perform work set forth in item one for safety reasons, or for normal waiting required, such as when a helper has to wait while the welder does the welding or when the welder has to wait while the helper cleans the weld. This also includes waiting for other crafts, contractors, crew members, supervision, quality control, transportation, material, tools, equipment, or any unexplained idleness.

7. Personal and breaks: Any activity that obviously serves personal needs of the worker, e.g., using the rest room, smoking, eating, drinking, changing or adjusting clothing, or sitting/standing in a group which is not classified as idle waiting.

8. Late starts and early quits: Beginning late in the morning or after lunch and/or quitting work early before lunch or the end of the work day.

The direct work category represents productive activity. The worker is expending effort and using equipment and tools to transform materials into a desired output. Identifying activities that divert time from this category is the primary objective of work sampling. If a worker must search the job site to find the necessary resources, he is spending time in something other than direct work, which results in a decrease in productivity. Work sampling may be viewed as a process of identifying impediments to maximizing direct work.

Workers cannot be engaged in direct work 100% of the time. There are activities that must be performed so that direct work can take place. A second category listed is transporting, which involves transporting tools and/or materials within a specified distance of the work area. Tools are kept in tool storage trailers or gang boxes, and materials are delivered to the work area and stockpiled until needed. Workers must transport them as they are needed. Ideally, the resources will be available within the specified distance at the work site. However, this may not always be true because of storage limitations, poor planning, or a variety of other reasons. When this occurs, workers are required to leave the work area to obtain the resources. This activity is categorized as obtaining tools and materials. It is similar to transporting except that it involves leaving the immediate work area. Effective planning and scheduling should minimize the time spent in obtaining tools and materials by ensuring that the necessary resources are delivered to the work area shortly before they are needed. Significant percentages of time engaged in obtaining tools and materials indicate a constraint arising from poor planning and/or execution.

Workers cannot immediately pick up the tools and use the equipment to transform the materials into outputs. They must have direction. A fourth category involves time spent in planning and instructions. This category in-

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cludes time spent by workers receiving and/or giving instructions to foremen and fellow workers. Without the appropriate direction, the transformation process is extremely inefficient because the workers do not know or are unclear as to what they are to do.

Traveling empty represents time spent moving about the job site empty-handed. It is important to understand that this category is related to transporting and obtaining tools and materials. If a worker is installing light fixtures in the ceiling of an office and gets down off the scaffold and walks across the room to obtain fluorescent tubes, he is considered to be traveling as he walks across the room and transporting on his way back as he carries the tubes. The same rationale applies if the worker has to leave the immediate work area to obtain a conduit fitting. To obtain a more accurate indicator of time spent traveling without an apparent reason, it is necessary to subtract the percentages for transporting and obtaining tools and materials from that of traveling. Large percentages of time in this category are indicators of probable constraints.

The category waiting and idle must be explained because it includes some activities that may be considered productive by many people. If a worker is working on a rolling scaffold and is installing heating and ventilating duct, he may have a partner whose job it is to hand him sections of the duct to install. While the worker on the scaffold is installing a section, the worker on the floor may be waiting to hand the installer another section. If this worker is observed waiting to pass up another section but does not have the section in his hands, the observer conducting the study will classify the worker as waiting and idle. If he has the section in his hand, he will be categorized as transporting. It may be possible to reduce waiting and idle time by having the worker place several sections of duct on the scaffold and perform another task while the installer installs those sections. This category also includes time spent waiting for equipment, materials, etc., which are periods of forced or involuntary idleness. The waiting and idle category is a prime indicator of constraints. If pipefitters cannot erect pipe in an elevated pipe rack because they are waiting for a crane, their performance has been constrained by management.

Personal and breaks is relatively self-explanatory. It includes all time spent in what is considered personal time. Going to the rest room, coffee breaks, and blowing one's nose are examples of activities that would be classified as personal and breaks. However, lunch breaks are not included because lunch time is not part of the scheduled work day.

The final category is that of late starts and early quits. If an observation tour is conducted 10 minutes after the start of the work day and seven of the eight members of the work crew are engaged in one of the activities listed above and the eighth member is not yet at work, he will be classified as a late start, if he does report for work that day. If he fails to report, he will not be included in the study for that day.

Delay surveys reveal time lost solely as a result of delays. In a delay survey, foremen are asked to report delays greater than a specified time that were experienced during the day (Tucker et al. 1982). For example, foremen might be asked to report any delays greater than 15 minutes that occurred due to equipment breakdowns, material availability, tool and equipment availability, waiting for information, waiting for other crews, waiting for inspection, etc. The objective in a delay survey is to identify the reasons for

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and extent of delays. Total delay time will correlate very highly with the waiting and idle percentage in a work sampling study. If the survey reveals that there is a significant amount of delay as a result of workers waiting for a crane, it would be possible to reduce these delays by adding more crane capacity to the project. A delay survey may be done periodically on a project to track progress in eliminating delays.

Data from work sampling and delay surveys, as well as from other sources, are used to answer the question: "Is the work environment free from organizationally imposed constraints?" If the answer is "No," improved job management is necessary. This may include better planning and scheduling, deployment of more equipment and tools, better direction of the work force by the foreman, etc. If the answer is "Yes," the analysis moves to the next stage.

Step Three

Once it has been determined that the work environment is free from managerially imposed constraints, the analysis proceeds to the question of the worker's possessing the knowledge and skills necessary to perform at the expected level. This question is concerned with three personnel actions taken by management, either consciously or by default: selection, training, and job assignment. The knowledge and skills in question are those that are specific to the task to be performed and can be the carpentry skills necessary for formwork construction or the welding skills necessary to weld alloy pipe. They can be acquired through formal training programs, either on the job or off-site, or informally on the job by trial and error. The model of worker performance presented by Maloney and McFillen (1983) contains a feedback loop, which allows for learning to take place as a worker attempts to perform a task. If learning does take place, a worker, in the absence of a formalized training program, will eventually acquire the skills necessary to perform the task. During this learning period, performance will be lower than when the worker is fully trained. To complete a task, management must select workers possessing the skills necessary to complete the task, train workers who lack the requisite skills, and assign workers possessing the skills to perform the task. If management fails in any of these actions, worker performance will be less than expected. In the specific instance of productivity, unit rates will be higher for several reasons. First, the worker will take longer to perform the task because he does not know more efficient ways of performing it. There is a high likelihood of the use of trial-and-error approaches to the task. Consequently, there will be work that must be rejected or reworked. The quality of the work performed is poor. As shown in the flowchart, data that indicate a lack of knowledge and skills are productivity rates, actual versus budgeted costs, schedule performance, safety performance in terms of accident rates, and quality performance. In addition, work sampling and delay survey data may reveal significant waiting and idle time and delays for waiting for instructions, which together indicate workers not knowing what to do or not being sure of themselves. These data may indicate a constraint or a lack of knowledge and skills. It is necessary to determine whether the workers have the necessary knowledge and skills before proceeding to an assessment of the presence of the requisite abilities. This is true because knowledge and skills can be acquired through training programs.

After determining that the worker has the necessary skills to perform the task, management must answer the question of whether the worker has the physical and mental abilities necessary for expected performance. These abilities are innate. There is no training program that can provide them. Through its selection procedures, management strives to eliminate those individuals lacking the requisite abilities. For the most part, management is successful in this. Mental abilities diminish only slightly during the normal working life of a construction worker. Physical abilities, however, diminish more rapidly. This is not to say that most older construction workers cannot perform their jobs. It is to say that many suffer from job-related diminution of performance. For example, many tile setters suffer from lower back problems as a resulting of working on their knees. Other crafts are plagued by similar job-related physical problems. If management does a good job in selecting workers, the lack of physical and mental abilities will have a low probability of being a factor contributing to poor worker performance. However, management must be aware of the presence of workers whose physical abilities have diminished. The performance of workers who do not possess the requisite abilities is significantly worse than that of workers with the necessary abilities. They simply cannot perform the task.

With these data, the question "do the workers possess the necessary knowledge, skills, and ability?" can be answered. A negative answer indicates the need for improved selection, training, and assignment. The training may not be solely for the craftsman. It may be necessary to train foremen to better recognize skill differences in workers and to take these differences into account in making job assignments.

Step Four

If there are no constraints on performance and the workers have the necessary knowledge, skills, and abilities, the analysis turns to whether the workers have the motivation necessary to perform as expected. Motivation is a critical determinant of worker performance in construction because, as contrasted with much work in manufacturing in which the pace of work is machine-determined, the pace of construction work is determined by the worker and his crew. This pace will fail within a broad range. If, for illustration purposes, it is assumed that a worker's maximum performance is defined as 100 on a scale of 0–100, the worker's actual performance will fall somewhere between the two extremes. The location on the scale will be determined by the worker's motivation once any organizational constraints have been removed and the worker possesses the requisite knowledge, skills, and abilities. Effort is the evidence of motivation. Therefore, if a worker is motivated, the intensity of his effort will be high and the duration of that effort will be long (Maloney 1983b). A lack of motivation, on the other hand, will be evidenced by low-intensity effort for short time periods and long periods of inactivity, including extended coffee breaks, late starts, early quits, etc. What motivates a worker is an empirical question and is specific to the worker and his situation.

There is a wide range of data that can be used to determine whether performance problems are a result of lack of motivation. As shown in Fig. 2, these data can range from objective data such as productivity rates and costs to more subjective data such as those obtained from surveys of and interviews with workers. Most project personnel are familiar with the traditional measures of project performance such as productivity, budgets, schedules, and quality. Data on absenteeism, tardiness, and turnover may indicate the lack of motivation to come to work, be productive, and remain on the project. High grievance rates indicate that workers' needs are not being met. Interviews and surveys of the work force provide additional information on the motivation or lack of motivation present in the work force. Work sampling and delay survey data may also indicate motivation problems. Significant percentages of time spent in waiting and idle without corresponding delays indicate that the idle time is voluntary and, therefore, most likely due to a lack of motivation. Similarly, large amounts of time categorized as personal and breaks and/or late starts and early quits will indicate a motivation problem.

The question "do the workers possess the necessary motivation?" may be answered with the suggested data. If the answer is "no," management must address the job context, which covers everything to do with a job except the actual work to be performed, and the job content, which is the actual job activities or tasks. Job content can be changed by modifying reward practices, improving supervision, changing working conditions, developing a team identity, or numerous other actions. Job content can be modified by changing the core job characteristics of the job, such as the variety, identity, significance, autonomy, and feedback associated with the job. All of these changes have the objective of providing the worker with the appropriate incentive. If the answer is "yes," the analysis moves to evaluating the performance objective.

Step Five

Once it has been determined that a worker is sufficiently motivated, the last question to be asked is whether the performance goal or estimate is realistic. Estimates are typically developed from historical data. Unless conditions for the work to be performed approximate those for which the data were obtained, there is a possibility that the estimate may be inappropriate for the current job. If the estimate was made without benefit of historical data, the possibility of error is increased. An estimatae is only as good as the assumptions used to make it. Therefore, an estimate must be evaluated in the context of the technology and methods employed in performing the work. Thus, an estimate may be realistic given the technology and methods the estimator believed would be employed in performing a task, but at the same time, may be unattainable given the technology and methods utilized in the field. If the estimate is unrealistic, it should be revised. If it was realistic, it will be necessary to change the technology and/or methods to improve the performance.

Summary

The performance analysis framework presented provides construction managers with a guide with which they can logically analyze construction performance. Use of the framework allows the manager to follow a targeted approach to performance improvement, which facilitates more efficient analysis. The real cause of poor performance can be identified more quickly and actions to eliminate the problem can be devised that will be more effective in problem elimination. The result will be improved performance on construction projects.

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