Site-Level Construction Information System

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Abstract: This paper defines information requirements to support decision-making needs of site-level personnel constructing a facility. It focuses on information required to drive the process, rather than technical information for design-related problems. The site-level construction information system (SCIS) builds upon basic decision-making theory and a common understanding of the construction process, as represented by the conceptual construction process model. SCIS consists of a four-step process: (1) Establish a matrix of the key project decisions; (2) define the project control system for the given project; (3) establish methods to select the decision-making mechanism, collect information, and implement decision; and (4) propose a method for monitoring the site information system. A case study illustrates key components of this method. A strategy for implementation then follows. The information model presented allows for information gathered from the formal project control system, informal information communication, and unstructured observations on site, to be integrated into a site-level construction information system.

Introduction

Traditionally, the main formal tools used to provide information for project control have been reports comparing expended costs to the budget; and actual progress against scheduled activities. These tools evolved from accounting practices and project planning techniques. In specific cases, these have been complemented with records of the number of quality or inspection defects, safety violations, or accidents on a project. Despite their thoroughness and formality, these reports focus on one aspect of the process, namely the end product. Their primary purpose is to alert the decision maker to any deviation from the project plan. When a problem occurs, this system on its own rarely identifies the causes of the problem (Sanvido 1984). Rather, the decison maker relies on informal data collected by walking the job and talking to people engaged in the work, or direct observation of site activities, to solve the problem. This is manageable on smaller projects, but may prove difficult on large complex projects.

Growth and Decline of Productivity-Improvement Programs

In the 1970s construction organizations saw a phenomenal increase in the size of projects and their staffs. Information required from management systems increased. The formal project control systems and informal techniques fell behind the needs. Therefore, several contractors introduced industrial information gathering techniques on large construction projects. These techniques, instituted in productivity improvement programs (PIPs), gave superintendents and project managers a handle on the lower levels in

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J. Constr. Eng. Manage., 1992, 118(4): 701-715

large project organizations. PIP tools sought to improve resource control and supply, improve planning, and provide relevant feedback for all levels in the organization. These nontraditional tools measured attitudes of people, delays in input resource supply, and the methods used to produce outputs or products (Sanvido 1983).

The subsequent decline in the number of megaprojects resulted in a corresponding decrease in these programs. However, several of these tools remain in use by forward-looking contractors on selected activities and projects (Kratt 1989; Burkhardt 1989). Thus the ability of these tools to provide information about inputs, plans, and outputs illustrates their utility for project control. They support and complement both formal and informal operational control methods used by field people.

Future Needs

The design of projects in the 1990s and beyond will produce more complex building systems. This will result in more specialty design and construction contractors, thus increasing the number of organizations represented in a project. The increasing cost of labor, particularly for specialists, will support more prefabrication of components. The faster delivery needs of owners and the increased coordination requirements of more specialists will demand better site-level construction information systems. Hence the need is apparent for adding tools to complement the current project control environment in order to provide real-time control and coordination of field operations.

Shortcomings of Traditional Project-Control Systems

This section will explain three shortcomings of traditional project control systems on construction projects: excessive reliance on cost and schedule reports; lack of important information not captured by traditional systems; and the need for greater involvement of workers and supervisors in planning and decision making.

Information required in the problem-recognition stage, using the traditional project control systems, primarily consists of cost, schedule and quality reports, and personnel performance reviews. These provide information on progress relative to a standard such as a budget. Budgets reflect the best estimate of probable project costs. While an activity may be under budget or within schedule, the system cannot identify poor resource utilization or poor planning.

Secondly, numerous properties of functions in a management system are not commonly measured or monitored by traditional information and control systems or by PIP tools. Example properties of these functions are: the time a resource requisition takes to complete an approval cycle; the time for resources to get to crafts after a requisition has been approved; the time for a resource to be repaired; the appropriate control level for a particular resource on site; or the method for distributing resources to crafts.

A third problem with some traditional project-management methods was that they drew solely on the experience of site management to develop solutions. It seems logical that the information collected and knowledge utilized to develop solutions should be drawn from sources of data at all relevant levels on the project. This would allow the decision maker(s) the best set of possible alternative solutions. People from all levels that would be affected by the outcome of a decision, insofar as practical, should be involved in developing the solution. This serves two purposes: the outcomes

J. Constr. Eng. Manage., 1992, 118(4): 701-715

at each level will be predicted, allowing solutions to consider all possible scenarios; and the involvement of all levels will build commitment to the task objectives.

Given these shortcomings, we believe that effective project control systems must use forms of information that measure performance with a zero-defects approach; measure the quality and quantity of imputs to the process; and use input from the operating levels of project personnel.

Research Methods

In order to develop a project control system or information system that meets the aforementioned goals, the researchers synthesized information and decision-making theories, and applied them to a known process model. Key steps in the research process were as follows.

1. Review the literature and select process, organizational, information, and decision-making elements relevant to construction site activities.
2. Develop the site-level construction information system (SCIS) by synthesizing the literature, and applying it to the construction process (as defined by the conceptual construction process model) (Sanvido 1988).
3. Observe sites where performance has dramatically improved and determine whether SCIS elements had a role in that improvement.

Theoretical Basis for SCIS

The site-level construction information system (SCIS) builds on a thorough understanding of the process to be controlled; the decision process and its properties; and the decision maker's ability to process information and make decisions. This section will present background concepts and experience upon which SCIS is founded.

Site-Level Construction Process

Sanvido (1988) developed a model representing the functions performed by each level in a hierarchical site organization. This model defines the basic planning and control functions to support effective and efficient construction for each level in the organization. It also defines the feedback and information required to support the control and planning functions. Field studies have demonstrated that jobs where these given functions were performed at the right level in the hierarchy were more profitable, finished sooner and were better constructed than those where the functions were not performed or were performed at the wrong level. Three rules governing the operation of the hierarchy were defined next.

1. Control of resources should be allocated to the controller immediately above the level at which the resource is shared. For example, a tower crane shared by multiple areas and disciplines on a building project should be controlled by the project superintendent, while craft workers control their own tools.
2. The controller must plan and coordinate the work sequence and resources for the control level one step below. For example, a general foreman develops plans to coordinate the various subordinate foremen, while each foreman will plan to coordinate his or her own crew. Good plans involve

J. Constr. Eng. Manage., 1992, 118(4): 701-715

both the upper control level, which is responsible for developing the plan, and the persons one level below, who provide input to the plan.

3. The controller who is planning and controlling resources requires information describing the supply of resources controlled and their control period, e.g., material location, date available, and goals from the aforementioned level, and the plans made to coordinate the resources shared with peers, e.g., crane schedules to support these related decisions. The controller also needs feedback that describes the performance goals for the actual output product at that specific control level, e.g., its quality, cost, and schedule.

Generic Decision-Making Processes

This section outlines three aspects of decision-making related to site-level operations. These are the decision-making process itself, the levels at which decisions should be made, and the distinction between programmed and unprogrammed decisions.

The first requirement for effective control of projects is to understand the decision-making process. Simon (1960) defines and simplifies the decision-making cycle in three steps. The intelligence phase occurs where the decision maker recognizes the problem and gathers data. The design phase focuses on developing alternative solutions. Finally, the choice phase is where the user selects an alternative. In each phase, specific information must be provided by different tools to the decision makers. Current project control tools help managers recognize that a problem exists, while information for the remainder of the decision cycle is obtained informally.

The second requirement for effective project control is to explicitly define the control function and its levels. Anthony (1965) defines three levels of planning and control. These are as follows:

> Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are to govern the acquisition, use, and disposition of these resources. Management control is the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives. . . . Operational control is the process of assuring that specific tasks are carried out effectively and efficiently.

These three levels on a construction project feature the roles of the project manager (strategic); the construction superintendent (management); and the area superintendent/general foreman (operational) on a large project. The project plan, estimate, budget, and schedule represent the strategic plan; typical project control activities, in some cases, focus on management control, while we rely on the experience and field observations of the area superintendent and foreman to provide operational control.

The third important decision-making aspect considers the structure of decisions. Some of the decisions just mentioned are repetitive; others may only be made once in a project's life. Simon (1960) defined decisions to be programmed or unprogrammed. Programmed decisions are repetitive and routine, and can be easily predicted and modeled. Unprogrammed decisions are those that are novel, unstructured, and consequential. Programmed decisions usually are dictated by procedure and can be planned. The objective of an information system is to formally provide information for programmed decisions. It should also provide tools to collect information for unprogrammed decisions.

Decision Maker's Behavior

The final consideration for the SCIS is how decision makers behave. Two important facts to be considered when designing an information system are that humans *satisfice* goals, and too much information overloads decision makers.

According to Simon (1960), humans satisfice in decision making. That is, they strive to achieve a target. Once it is achieved, they seldom go beyond it. This characteristic does not necessarily promote achieving the optimal solution when the unit-cost system defines the goal. If, instead, the target is to reduce unnecessary work and delays to zero, then better performance will result. Productivity improvement tools, some of which are methods studies, delay surveys and craft questionnaires, strive toward this latter goal, and highlight performance problems before or while they occur.

The second key consideration is that excessive information overloads decision makers. Galbraith (1974) stated that decisions are slowed or become ineffective when decision makers are faced with more information than they can process. He presented two strategies and four solutions for decreasing overload that must be considered in this model.

The first strategy is to reduce the number of exceptions or instances requiring a decision. One way is to decentralize authority for "programmed" decisions to the lower levels in the field. The second way is to use longer schedules and fatter budgets, and to overdesign systems (use slack resources). This method normally is too costly to consider as a conscious strategy, but happens by default if other measures do not address information overload.

Galbraith's (1973) second strategy is to increase system capacity to handle exceptions. A shortcoming with some management information systems is that the exceptions are reported a month or so after the problem occurred, normally too late for corrective action. Obviously, an operational information system should highlight these problems as they occur so that decisions could be made to correct the problem.

Normal operating information systems are informal in nature and work mainly by lateral coordination, or discussion of problems between peers on the project. As the project gets larger, lateral coordination between supervision takes more and more time and causes delays by forcing crews to wait for resources. Hence implementation of a formal operating information system or more frequent planning cycles, such as supervision meetings, would increase the capacity of the organization to handle exceptions.

The most desirable method to increase exception handling is to develop a more capable information system. A formal operational information system, as proposed in this paper, would allow monitoring key performance indicators of each process defined in the CCPM. Information must be specific to the resource or process being measured. This solution would best suit programmed decisions, while lateral coordination or increased frequency of meetings to speed up the planning cycles would best apply to unprogrammed decisions.

Site-Level Construction Information System

Given the shortcomings of traditional project control tools, and the theoretical requirements for the system, we propose the following method for establishing site-level decision systems.

1. Establish a matrix defining the major decisions to be made at the strategic, management, and operational levels on the project, their degree of structure, and the responsible party.
2. Develop an information system (project control system) to provide intelligence information to all relevant decision makers for each type of decision. The information system should provide information that measures performance using a "zero defects" approach.
3. Provide a method for developing solutions, i.e., selecting the decision maker(s), collecting additional data, and selecting and implementing the best solution.
4. Monitor the use and effectiveness of the information system and adjust as necessary.

Establish Decision Matrix

The first step on a project is to organize the project and allocate decision-making authority in accordance with the rules prescribed by the conceptual construction process model (CCPM). It formally describes the key decisions to be made by each employee. In this case, Table 1 represents some of the key decisions that are made for a given project with three levels of supervision. The decision makers represent the various levels of control specified by Simon (1960). Where more than three levels of supervision exist, we would expect to find the decisions made at a given decision level split between two or more site decision makers.

The matrix categorizes the decision types into programmed and unprogrammed decisions at the extremes. A third category, semiprogrammed, represents decisions that are made fairly frequently but where the inputs

TABLE 1. Generic Decision Matrix

Decision type (1)	Project manager, strategic decision level (2)	Project superintendent, management decision level (3)	General foreman, operational decision level (4)
Programmed	Submit payment requisition Update schedules	Hire labor Develop budgets Enter time-card data	Order materials Inventory materials
Semiprogrammed	Estimate costs Develop project plan Develop schedule	Develop change orders Request information (RFI) Forecast material needs	Plan/forecast weekly Estimate work-in place
Unprogrammed	Replay key personnel	Replace subcontractor Manage equipment failure	Manage accident recovery

J. Constr. Eng. Manage., 1992, 118(4): 701-715

vary. In order to decrease information overload, we would expect to structure as many decisions as practical and possible.

The control function in the model covers both operational and management control. The higher one goes in the site organization, the greater the swing of responsibility from operational to management decisions. According to Anthony (1965), the information required to support operational (or supervision) control must concentrate on the single subject under decision, be precise and detailed, focus on real time, and measure the desired property. This measure is usually not expressed in cost terms, but rather is based on quantity, quality, time, location, or status. On the other hand, information required for management control often concerns the whole site or area, is typically financial data, includes approximations, is summary in nature, and is historical or projected. The time horizon is much greater than for the operational needs.

All of these decisions, whether programmed, unprogrammed, management or operational in nature, involve the three phases of decision making described by Simon (1960), namely intelligence, design, and choice. For effective decisions, information on each of the three phases must be collected and presented to the relevant decision makers (controller or control group) at each control level.

Define Project Control System

The primary function of the project control system is to provide "intelligence" information. This information is used for monitoring. This control system traditionally comprises formal and informal parts that highlight deviations from acceptable performance levels. Smaller jobs rely heavily on the informal system, while the larger projects use the formal system more extensively. Performance variations beyond acceptable limits trigger warnings. The relevant decision level would then take action. If the problem affects other personnel not under that decision maker, a decision-making group or task force should be set up. Thus the decision maker may consist of one decision maker or a group of decision makers.

Table 2 defines the tools used in the intelligence phase of the decision. These tools provide data on the three basic elements in the construction

TABLE 2. Project Control Tools for Intelligence Phase of Decision

	Decision Maker and Level		
Control type (1)	Project manager, strategic level (2)	Superintendent, management level (3)	General foreman, operational level (4)
Inputs (resource control)	Feedback on project budget and milestones performance evaluation	Feedback on construction budget and schedule	Foreman delay surveys work sampling Questionnaires Interviews
Process (planning)	Project execution plan updates	Methods studies	Time studies
Outputs (products)	Quality assurance Monthly cost/schedule updates	Quality control Monthly/weekly cost/schedule updates	Quality control Questionnaires Interviews

J. Constr. Eng. Manage., 1992, 118(4): 701-715

system to the three basic decision levels shown, i.e., the inputs, the process, and the outputs or products. Traditional project control tools, developed for project management and superintendent levels, provide good intelligence data at those levels of control. The productivity improvement tools are applied to support the general foreman level (operational control). They provide nonfinancial data to support resource control, planning, and output control. This information can be destructive to a project if provided as project management or construction management data, or if used by an untrained superintendent or general foreman.

Foremen delay surveys (Tucker et al. 1982) define the lack of resources or delays incurred by crews waiting for resources such as materials, tools, information, etc.; work sampling (Oglesby et al. 1989) provides an overall projectwide, less detailed account of productive, supportive, and nonproductive work; while the questionnaire and interview (Howel 1980; Oglesby et al. 1989) provide data on the input resources, process, and outputs. Method studies and time studies can provide task-level or project-level analyses of procedures in use and current work methods employed (Oglesby et al. 1989; Burkhardt 1990).

An example of the successful use of operational feedback is described for three buildings (A, B, and C) studied by the authors. Short-interval scheduling was used successfully on the critical items on building A (the core, decks, and chimney walls), on building B (the core cycle), and on building C (the floor and core cycle). The short interval schedule consisted of detailed plans in hourly detail for a typical cycle of one floor. The schedules were then revised and modifications (to correct incorrect estimates and plans) were made as the cycle progressed and feedback was available. This feedback was presented to a quality circle on the core of building B, and to the general foremen and superintendents on the other two buildings for detailed planning. Time-lapse and video filming on building A successfully provided information and feedback to the crews using the short-interval schedules. It increased the slope of the learning curve and sped up the process (Burkhardt 1990).

Another example of the implementation of SCIS principle on a large refinery expansion project follows. A pipefitter foremen and craft workers developed a piping information system with their own personal-computer–based relational database program. This system combined into one report information from seven sources that the crafts had to review. This report was split up for each crew and showed all isometrics (tasks) remaining for that crew, and the status of each material component in each isometric. This allowed foremen to plan their work based on what was available, and freed up time they had wasted looking for material or looking for information in all the other reports. Without this system, a pipe-fitter foreman estimated that he spent up to 6 hours in some cases finding out what material was available. The piping information system decreased this time to 30 min. In addition, weekly work planning made it possible to distribute performance and progress data to these crews.

Define Method to Develop Solutions (Design Phase)

The design phase of decision-making consists of inventing, developing, and analyzing possible courses of action. Three key items explored in detail are selecting the decision-making mechanism (DMM), collecting information to support the decision, and implementing the decision.

Development or design of the solution may be done by a consultant to an organization, a problem-solving team, quality circle, or a task force assembled for that purpose. At this stage, data are collected (usually by experience-based observation or with productivity improvement tools) that pinpoint the cause of the problem. These data are presented to a group or individual, along with a pool of knowledge for developing solutions (e.g., craft experience). These representatives then develop alternative solutions. This information is presented to the controller(s) for evaluation and the selection of the best alternative. The individual or group then develops an implementation schedule for the solution.

Supplemental data normally are collected formally by productivity improvement tools or informally from the work force. Generally, delays in the supply of inputs are compared to a goal of either zero delays, or cost-effective standards for the subject organization. Process data are analyzed using crew balance charts, process flow charts, system modeling techniques at the lower level (Oglesby et al. 1989), while larger, more complex problems will require some form of process modeling or mathematical analysis and simulation (Halpin 1977).

Select Decision-Making Mechanism

Selecting the decision-making mechanism involves allocating the responsibility for a decision to an individual or a group of individuals. Most project decisions are programmed; that is, similar decisions have been made before. These are typically allocated to a single given decision maker in the hierarchy. Alternately, where a decision outcome affects multiple parties and there is no high-level decision maker with all the required knowledge, the decision-making mechanism will be a group. These decisions are frequently unstructured in nature.

The writers propose that an individual is the best choice as a controller when the outcome of the decision only affects his or her process in a significant way. A control group should make the decisions when more than one process will be affected by the outcome. In this case, the decision-making mechanism (group) should consist of those parties that will be affected by the decision, or the controllers of the affected processes. Examples of such groups are found in quality circles (horizontally affected processes) and task forces (vertically affected processes). To be successful, the decision-making mechanism must have the ability (skill, knowledge, and set of values) to make the required decision; and it must be supported by information relevant to the decision being made.

As an example, task forces were formed on a refinery project, and assigned to work on specific problems, such as construction equipment utilization. To support the efficient operation of this function, the contractor trained the discipline superintendents and general foreman on construction methods improvement, goal setting, and work selection and sequencing, all of which are elements of planning. Other site training included orientation to cost, schedule and material-control systems, and weekly work planning and crew-level planning.

An example of quality circles in use on critical items on three sites follows. At the time of this research, three commercial building projects were being constructed under guaranteed-maximum-price contracts, and the ones for cost reduction were on the contractor. We will refer to these as building A, building B, and building C. Building A used informal quality circles on the chimney wall operation, building B had quality circles on the core forming, and building C used them on the core walls, bent and end walls, and project

J. Constr. Eng. Manage., 1992, 118(4): 701-715

cleanup. The only quantitative results available for their effect was on building C, where the core walls were being erected at 56% of the budget unit rate and the bent walls were costing 72% of their unit rate. These quality circles in fact became the decision-making mechanism and accomplished all three of the required functions on the project. Management supplied them with information, facilities, and time to plan, and gave them control of the resources, where practical.

The individual or individuals that constitute the control mechanism each have unique sets of values. These typically are influenced by the organizations to which they are loyal, such as their union, subcontractor, or contractor. Collectively, this mechanism also has a set of values that is influenced by the environment in which it operates. This set of values is communicated to the group by the performance criteria set for the process under decision, formal and informal feedback that top management provides, and the overall performance goals of the project. The set of values of the control mechanism should provide a basis for evaluating the major implications of the decision.

Collect Information

The decision maker(s) must assemble information to determine the nature of the problem. Fig. 1 is a flow chart showing how to collect and analyze information in three phases. In the first phase, the project control system highlights the problem and its cause, and the decision-making mechanism can proceed to develop solutions and evaluate these for implementation.

If the project control system does not identify the cause of the problem, the user proceeds to phase two, comprising problem orientation, data collection, and data analysis. If the problem is identified, the development of solutions is next. If not, the user moves to phase three (the third case), where further data are collected and analyzed prior to solution development.

Once the problem is identified, the decision-making mechanism develops solutions. This mechanism may utilize techniques such as brainstorming, Pareto analysis, process charts, flow charts, etc. Additional data may also be collected at this phase or an individual with specialist knowledge may be brought in.

Phases two and three are both critical. Having an initial grasp on the scope and objectives, the decision maker(s) will seek more detailed information that will improve the understanding of the problem, and provide more quantitative data that can support the selection or design of a solution to best meet the needs. Typical activities in this study include the following:

- Interview all key parties involved in the relevant operation
- Gather examples of printed documents related to the problem (drawings, cost reports, procurement documents, correspondence, etc.)
- Identify and understand current methods and procedures that might be in use
- Establish functional flow of information and decision
- Establish cost and durations of various activities under study

The decision maker(s) may already know many of those involved in the problematic activity, but it is important to return to them for more detailed information. In a small group, such as the crew under a single foreman, interview each person. If it is a large group, exercise care at least to get a

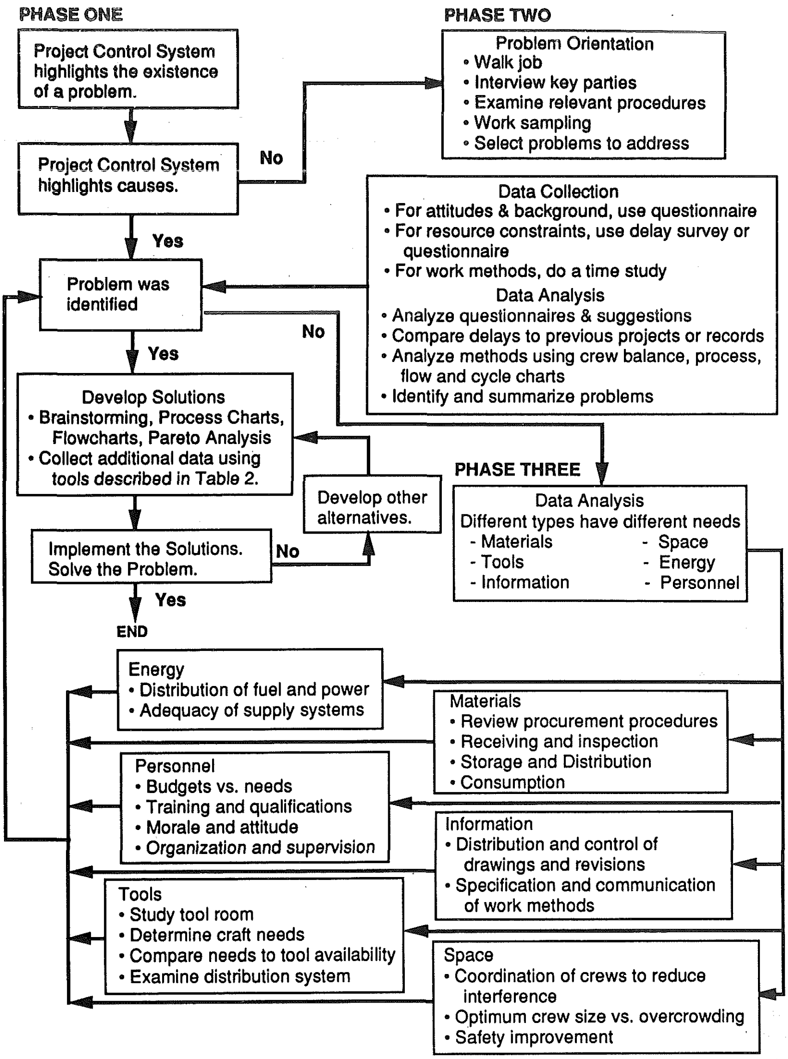

FIG. 1. Information Flow Chart

representative sampling of job functions and opinions. Managers as well as people who provide input to the group (e.g., the procurement and equipment departments supply resources to the crew) and depend on its output (e.g., the crafts of subcontractors who follow the operation) also should be contacted. In a larger study, the decision maker(s) could use a questionnaire or outline to guide the interviews, both to be sure that each interview covers a full range of topics, and for consistency in analyzing and classifying the responses. In conducting the interview, the decision maker(s) will try to assess the skills and knowledge of those who will have to implement the solution to the problem, listen to their complaints about current obstacles

J. Constr. Eng. Manage., 1992, 118(4): 701-715

and frustrations, and get their opinions on steps that would improve the operation. The decision maker(s) should also identify creative and articulate users who might most usefully contribute to the selection or design of the new methods or procedures that will solve the problem.

Finally, the decision maker(s) may reach a point where a resource is isolated as a problem area, and no further progress can be made. Fig. 1 indicates a phase-three follow-up data collection for key resources such as tools, materials, etc. This procedure is essentially the same as that just presented, but it focuses on the crews supplying resources rather than the crews conducting direct work. This stage will typically identify the problems.

Implement Solution

The choice phase consists of evaluating each of the proposed solutions and choosing one of them on the basis of a given set of criteria. This usually is done by a group of people or by an individual with the appropriate authority, i.e., the decision maker(s). Examples of groups are: quality circles, steering committees, employee participation groups, and problem-solving teams. This system proposes that a group of people be required to develop and choose solutions to a problem when the solution will affect many different controllers. Individuals can perform this task if it lies within their own control scope. Decisions generally are most successful when the people making the choice have representation from the group developing the solutions. This is the key phase of the decision process where change is affected.

Monitor Site-Information System

Since a project organization continually grows and shrinks, people's decision levels will change with time. As mentioned in earlier sections, as people progress from the lower levels in a site organization, to higher levels, they use different information, skills, and knowledge to make the new decisions. Thus management must continually monitor the decision-making levels and the appropriate information systems to suit the needs of the project. The proposed SCIS, when used in conjunction with the project data, can provide a workable method for monitoring information needs.

Case Study

This section illustrates the concepts that have been presented with a practical example of a coal-fired power plant that experienced a major turnaround after a change of management. The project had improved its performance by decentralizing authority in accordance with the decision matrix in step one, providing the correct information in the project control system, and making decisions as specified. While the project may not have been through a rigorous organization as specified here, it followed the same principles.

Just over one year prior to the first writer's visit, a contractor for a 6 × 600-MW coal-fired power plant was having serious difficulties in performing the contracted work on the project to the required quality. As a result, progress was falling behind schedule and costs were rising rapidly. Top management in the contractor organization decided to replace the first project manager and to authorize the new manager to reorganize the project. He instituted a number of changes, which resulted in a performance swing from a \$300,000 a month loss to a \$50,000 a month profit. The most significant of these changes were:

Establishing Decision Matrix

The first strategy that the project manager adopted was to cut down on the number of resources not used to their maximum potential (slack resources) and improve the utilization of the others. Before, a number of services had been shared by all the areas in the project. They were controlled by a services manager, but his authority was less than that of the area managers, and the earlier project manager did not give the services manager the support he needed. At the same time, improvements were made to the information system that supported decisions on the utilization of these resources.

The new project manager moved the control of these resources used by all areas in the project to a level just above the level at which they were shared, which is the level prescribed by the SCIS. He took personal responsibility for their control, and made a manager with authority equal to an area manager responsible for them. These services included concrete supply and transport, surveying, excavation, cranes and other equipment, carpenter shop, bulk stores, and material receiving yard. An example of increased utilization was simultaneously to decrease the number of concrete trucks from 11 to eight while, by careful scheduling, improving their output from 30 m^3 per day to 70 m^3 per day. An improved information system that supported better planning accompanied this change: the 5:00 p.m. daily meetings described next.

Another example of reallocating resource control was to centralize certain services that were shared within an area. For example, a specialized concrete crew that only placed concrete was equipped with its own equipment and tools, and a resource supply crew with its own trailer and tractor for each area was allocated to the area manager and his general foreman. They then managed these resources on the activities in that area.

The project manager implemented a number of systems that forced planning at designated levels. He required each section to plan each structure to fit within the milestones given for its area. The project scheduler then planned the structures in detail day by day for each item of work and integrated them for an area.

There were no formal operational plans on the project when the new project manager took over. Site personnel who had worked under both managers confirmed this. The project manager stimulated biweekly planning by requiring each foreman's plan to be posted in his shack and in the general foreman's office. These plans were monitored daily by the foreman and general foreman, and reasons for nonconformance were listed. The project manager spot checked them, but the section managers checked each one every two weeks. To improve scheduling with the subcontractor who installed the reinforcing steel, the general foremen in each section compiled a two-week schedule.

Short-term day-to-day planning was enforced throughout the organization by a meeting every day at 5:00 p.m. This meeting covered surveying, quality-assurance inspections, excavation, concrete, and other needs. Each section manager had to schedule the required services for the next day at that meeting. This forced the section manager to prompt general foremen and foremen to plan ahead for their needs for the next day. A schedule for each of the services was available for each section manager and general foreman the next morning before work started.

Developing the Information System

Each section manager made available the short-term operating information on the project at the daily meeting. There was, however, a lack of feedback to the lower organization levels. This was pointed out to the project manager by the first writer, and changes to improve the system were planned.

The project manager made two improvements to the information flow on the project. The first was to develop a system to get site instructions to the field within three days of their receipt by the contractor. The second was to make the quality-assurance staff responsible for receiving all drawings, distributing them to the field, and retrieving the old versions of the drawing. This prevented crews from working with the wrong drawings. Both systems were functioning as planned and had the desired effect.

The owner on this project emphasized quality, and a comprehensive inspection program was in place. The contractor had quality-assurance and quality-control (QA/QC) programs functioning on the site but this never had much top site-management support. The new project manager changed the responsibility for this function from the home office to himself, and forced each relevant level (reinforcing steel subcontractor, carpenter foreman, and the section engineer) to verify by signature that they had inspected their work, and that their portion of the preparation for the concrete pour was up to specification. The QA/QC inspectors would inspect once this had been signed off. After this approval, the owner's representative inspected the pour. Once the owner's representative signed off, the foreman could order the concrete. The order form was a continuation of the QA slip. To it the foreman added the method of placement, time of placement, crew size, truck entrance and exit routes, duration of the pour, and quantity and quality of concrete. This forced short-term methods planning.

Procedures such as these made people responsible for their own work. There were other rules to force planning. For example, no concrete could be poured within one day after the form was erected. This, with the pour preplanning rules, forced better preparation, which resulted in less rush work, and ultimately less rework. It can be seen that these changes brought specific functions closer to or into conformance with the model.

Summary

In this case study the decision matrix was established in accordance with the method proposed under SCIS, although the project manager was not aware of such a method. Also, the information system provided operating information to the lower levels in the organization about inputs, i.e., concrete; the process, i.e., concrete pour sequencing; and outputs, i.e., QC reports. The solutions to the problem of restructuring were essentially developed by the project manager proceeding through all three phases shown in Fig. 1. He did not use questionnaires or time studies, but substituted direct interviews and site observations to collect data. Other operating decisions were made by groups assembled for daily and weekly meetings. The product of these meetings was essentially the plans for the subsequent periods' activities. After these systems were implemented, the project showed a change from a $300,000 monthly loss to a $50,000 monthly profit.

It is important to note that the authors conducted 11 case studies in this research. The data collected from the cases strongly supported the SCIS.

Strategy for Implementing

In order to implement the SCIS on a site, the company must follow several steps. The collection of tools presented here require that the people using them have training in their use and that they be applied carefully. Contractors must first be familiar with all the tools available and have the ability to determine when to use the right tool. Initially, in-house training and familiarization with the technique is essential. Literature specifying correct procedures for use of these tools abounds. For this system to be successful, the individual responsible for project control in the company must be responsible for the operation of this system. The system must be seen as a single project control "bag of tools," not a system used to parallel current tools. Critical factors in implementing this system, as with any other one, is the requirement for excellent top-management involvement.

Conclusions

This paper proposed a site-level construction information system that is based on a tested theoretical process model of the construction process at the site level, and selected key works in the field of decision making and information systems. It utilizes several practical tools from the productivity-improvement field that are arranged to support the various theoretical decision-making phases. The SCIS is thus a theoretical solution that uses practical tools.

It has been designed to take the best aspects of the different information gathering, reporting and decision-making systems that are available, and integrate them into a system that meets the needs of field-level supervisors. Evidence of the utility of this approach has been cited with examples. While this does not validate the SCIS, it does offer good support for its usefulness.

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