CONCEPTUAL CONSTRUCTION PROCESS MODEL

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ABSTRACT: Managers have tried several project-specific methods to improve declining construction productivity with mixed results. Most solutions have focused on supporting craftsmen in the field. This paper presents a conceptual model of the construction process, defining goals for management and control systems to support the craftsman's needs in the field. This model comprises four generic flow charts with rules that govern them. The first defines the needs of the craftsman. The second specifies the support functions required from a site organization, while the third defines all of the other major site-related functions. Finally, the limits of site management control are specified. Craft support is the acid test of a functioning system; thus validation of the model focused on the first two flow charts. Analysis of five groups of similar projects showed that the closer a site organization is to the conceptual model, the better its performance. Site evaluation tools are presented.

INTRODUCTION

The problem of poor productivity in the construction industry has been widely recognized and documented. (Business Roundtable 1982; Bennett 1980; Gregerman 1981; Judson 1982; Sanvido 1983). The principal cause of poor productivity, as documented by many authors (Howell 1983; Judson 1982; Parker and Oglesby 1972; Proc. Conference on Productivity Improvement 1980, 1981, 1982; Revay 1978; Sanvido 1983), is management ineffectiveness, not unmotivated or unskilled workers. The goal of this paper is to provide a conceptual model for designing effective management systems that support the craftsmen in the field. This will improve construction productivity.

Productivity Definition

Productivity is defined as the ratio of product output to input resources. The term productivity can be used as a measure of total labor productivity, crew productivity, craft discipline productivity, project productivity, or even the productivity of selected resources, e.g., cash or construction equipment. Similarly, inputs or outputs can be measured in various quantities, e.g., tons, cubic yards, hours, or dollars. Thus, the model must allow for input and output to be expressed in a variety of units.

Productivity Improvement Efforts

Prior to 1970, the main method construction companies had to improve site productivity was to redesign management systems and organizations on poor projects and/or replace management personnel. In the early 1970s,

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Note. Discussion open until November 1, 1988. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on July 15, 1987. This paper is part of the *Journal of Construction Engineering and Management*, Vol. 114, No. 2, June, 1988. ©ASCE, ISSN 0733-9364/88/0002-0294/$1.00 + $.15 per page. Paper No. 22540.

the modern Productivity Improvement Program (PIP) evolved as another method to improve productivity. A PIP is defined as a formalized program for improving the productivity of a project by enhancing the information flow and feedback systems and the resource supply systems and improving the construction methods and the planning function. These PIPs were typically implemented on projects 50–80% complete that were behind schedule and over budget. These programs were developed to enhance management systems that had failed in certain aspects. More recently, PIPs have been implemented at the beginning of projects to augment weak project management systems (Sanvido 1983).

Need for Model

What all these efforts had in common was to supply resources, to conduct planning, and to give feedback to the crews, i.e., the organization was set up to support the craftsman. The successes and lessons learned were typically carried forward informally to subsequent projects by the staff. Few formal procedures or methods for improving productivity are found in such companies (Howell 1983). The need for a model to design organizations has been set forth by Tatum (1983). He showed that there was no well-used method for designing project organizations in construction. Thus, to improve productivity, there is a need for a conceptual model to support the design and development of management systems.

Objectives of Model

The objective of this paper is to describe a conceptual model of the management functions that are required to improve the productivity and performance of site construction operations. The basic features of the model are: (1) Definition of the basic tasks of the craftsmen and the input resources required; (2) identification of interrelationships between different functions involved in supporting the field construction process and specification of rules to govern their performance; (3) definition of the scope and boundaries of the on-site construction process; and (4) categorization of external influences on the construction process that are beyond the control of the site personnel.

Method Used to Model Construction Process

From an extensive review of the literature, Alexander's (1974) dynamic system model shown in Fig. 1 is selected as the model that best represents the construction process. Examples quoted by Alexander illustrate the model's application to manufacturing and the process industry. Construction activities are not as repetitious as those in manufacturing, and typically the key decisions are made by craftsmen or immediate supervisors. In Alexander's model, the control function was performed by an automatic controller. In the construction model presented in this paper, the control function is performed by the craftsmen and supervisors.

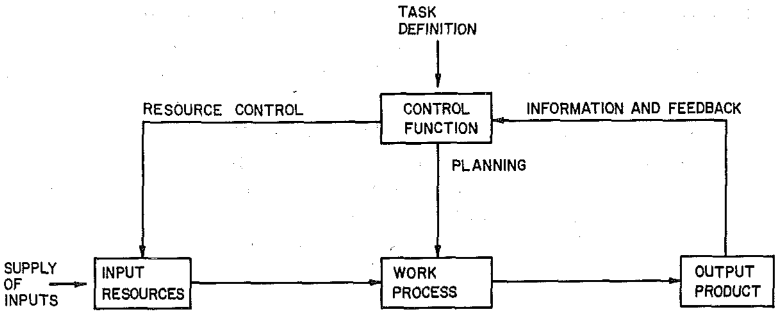

FIG. 1. Dynamic System Model for Each Level in Organization [Based on Alexander (1973)]

Examples of each of the components of the dynamic system model for the construction situation follows.

Model of Craftsman's Function

This model of a site management system was developed with the goal of supporting the craftsman in the field. Fig. 2 shows the functions that a craftsman must perform and the support needed to perform the work. The craftsman controls the process of taking the inputs and converting them to outputs. The conversion method used by the craftsman is constrained by the type and supply of resources, the limitations on work methods set by the influences on the project, and the constraints imposed on the process through the control function.

The craftsman has to plan the work within these constraints. The quality of the plans depends on the craftsman's skill, motivation, physical strength, and experience. The plans are altered by feedback received on the outputs of the process. This feedback is primarily informal observations by the craftsman. The craftsman can regulate the flow of inputs under

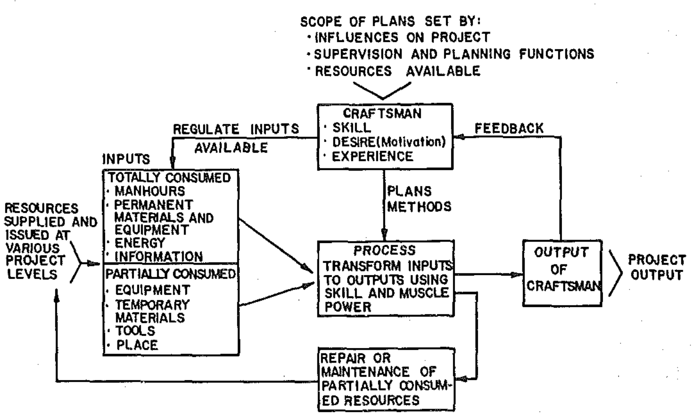

FIG. 2. Construction Process at Craftsman Level

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his control. Those inputs not under his control can be obtained through requisition from an immediate supervisor.

There is one other function on the dynamic system model (Fig. 2) not covered by the generic model (Fig. 1). It is the repair and maintenance of partially consumed resources. Alexander's model only deals with totally consumed resources. In Fig. 2, resources that are partially consumed in the process, such as temporary materials, tools, or equipment, are returned to the on-site supply source for reuse. Before they can be reissued, certain maintenance or repairs must be completed. These activities will restore the resource to a usable condition. Another type of repair and maintenance is that done at the available work space, namely clean-up of the site and safety improvements. A detailed explanation of the components of the model follow.

Inputs—Resources Consumed in Construction Process

Resources are divided into two categories called "totally consumed resources" and "partially consumed resources."

Totally Consumed Resources

Totally consumed resources are those that are wholly consumed or whose value as an individual resource decreases to zero during the construction process. These resources are replenished by bringing more onto the site. Totally consumed resources comprise the following:

- Manhours are the amount of the employee's time that is consumed in the work process. Typically it is the time for which a worker is paid.
- Permanent materials are materials or components from which the final product is made. These are normally wholly consumed and produce a quantity of waste. Such materials typically can be subgrouped into: (1) Bulk materials, e.g., pipe, lumber, sand, or rock; (2) manufacturers' standard materials requiring little fabrication, e.g., switchboards or standard fixtures; and (3) engineered materials, e.g., special forms, pipe, or spools (Johnston 1981). Permanent equipment is any piece of machinery that is a part of the final structure, e.g., pumps or turbines.
- Energy consists of fuel for machinery, electricity, and other sources of power.
- Information refers to engineering drawings and specifications. It does not refer to plans developed by the contractor, which are considered as constraints on the planning function.

Partially Consumed Resources

Partially consumed resources have a residual value that is less than their original value. The value can be replenished by activities such as maintenance and repair. Typical resources of this type are the construction equipment, temporary materials, tools, and a place to work. Partially consumed resources comprise the following:

- Equipment refers to construction machinery on a job-site that is used to assist in construction.
- Temporary materials are those that support personnel, e.g., a scaffold or rain cover, and work, e.g., concrete forms.
- Tools are mechanical aids other than equipment used by the craftsmen to help transform inputs to outputs.

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- Places to work include providing a clean, safe environment in which the craftsmen can work.

Work Process—Conversion of Inputs to Outputs

The process of work is the physical action that uses a process to convert input resources into the desired outputs. It is governed by the control function. Examples are the implementation of coordination skills, muscular power, and intellect to convert materials, manhours, and energy, by use of information, tools, space and equipment, into units of output.

Outputs—Synthesis of Outputs into Project

This process ensures that outputs of individuals support the desired output of the higher control level, namely the foreman, and, similarly, outputs of disciplines, areas, and finally the completed project. This process is dictated largely by the function that sets the characteristics of the work process—the control function.

Control Function—Control Work Process and Its Inputs

Control encompasses planning and resource control. The two activities are performed concurrently by the respective controller. The controller of the smallest dynamic process is the craftsman, while the project manager is the controller of the largest, the project. These two functions are expanded.

Planning defines a work process to change inputs to outputs. This process consists of planning the methods used to construct the desired product within the necessary constraints. These may be set by external bodies, owners and owner representatives, contractor home office, and resource suppliers. Typical constraints are defined by the available quality, capability, and quantity of the inputs and the specified quality, cost, and timeliness of the outputs. The planning function is performed at various levels by appropriate project personnel. Work at a given control level should be planned within the constraints set by the next highest level. Plans should also coordinate resources and schedules of control levels below the controller.

Resource control serves to regulate flow of inputs to achieve desired results. The basic function described here is to make certain that the resources needed to accomplish the work are available. The plans dictate this process. Feedback that the controller obtains about the outputs of the process is used to modify the resource control.

It is possible that the plans may be altered if certain resources are not available. This is accomplished by requisitioning substitute resources. These are often controlled at a higher level. Part of the controller's job is to approve requisitions for resources he is authorized to control and to release resources into the distribution system to the crew members so that they can perform their work.

Obviously, the craftsman cannot secure all inputs or make all plans. The purpose of the site organization in this conceptual model is to coordinate the craftsmen and supply their input requirements. The next section describes the required organizational functions.

Supporting the Craftsman

Construction is a combination of many interconnected dynamic processes categorized by different types of trades, e.g., pipefitters, ironworkers, carpenters, cement masons, and electricians. Construction is coordinated through ever-increasing levels of control up to the project manager. The construction process can thus be represented by a structure composed of multiple dynamic models (Fig. 1) arranged in a hierarchy. Fig. 3 shows each function for a given organization, with a distinct control function, a set of inputs available, a specific work process, and outputs. The work process of a controller includes all the functions of each controller one level below. This hierarchy will collectively supervise and plan the sequence of project tasks in order to coordinate the craftsmen's efforts. This hierarchy also ensures that resources are distributed and allocated to the correct activities and that information and feedback is provided in a timely manner.

Unlike a typical organizational chart, Fig. 3 easily shows the divisible units of input, process, output, and controller. This hierarchical model has its primary focus on the craft level. This is in sharp contrast to an organizational chart where the main focal point is on the project manager. Herein lies one of the main strengths of the model.

Operation of Hierarchy

A set of rules define how the hierarchy (Fig. 3) functions. These rules are as follows.

Resource Control

Ideally, control of resources is allocated to the controller immediately above the level where the resource is shared. For example, a tower crane shared by multiple areas and disciplines on a building project will be controlled by the project superintendent, while a craftsman controls his own tools. Input includes both totally and partially consumed resources.

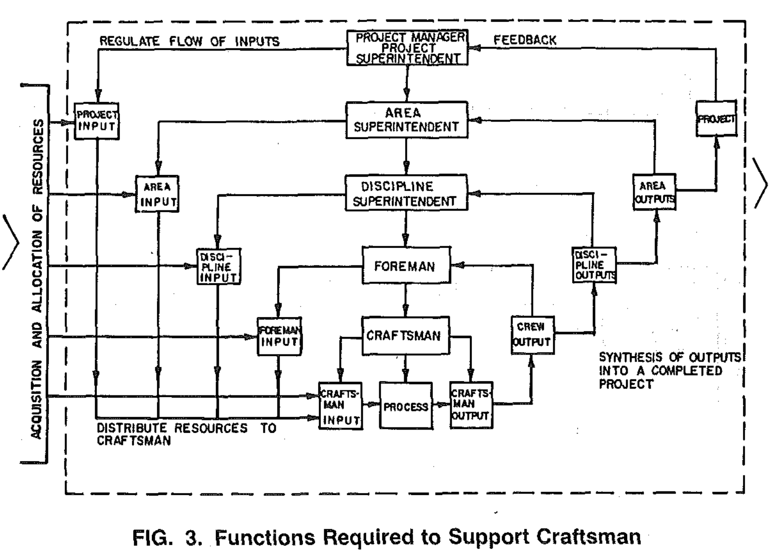

FIG. 3. Functions Required to Support Craftsman

Planning

The controller must plan the process with all planning and resource constraints in mind, and for a time frame commensurate with his responsibility. Typical constraints are input resources available to that level, priorities, milestones for activity completion, limited authority and responsibility of the controller for an operation, and the methods prescribed by upper control levels or quality assurance programs.

These constraints normally are beyond the daily influence of the controller and are the responsibility of his supervisors. However, within these constraints, the controller can have substantial influence on the work process. The controller will plan the method to be used in the process and regulate the flow of inputs to support the planned method.

Information and Feedback

The controller requires information to support decisions. He also needs feedback that describes the attributes of the actual output product in terms of its goals. The feedback must accurately describe performance of the controller's task (process) and not that of his superiors or peers. The information must accurately describe resource availability and allocations, and the plans/goals that the controller is expected to meet. The accuracy, timeliness, and relevance of the information determines the quality of the decisions made.

Consolidated Overview of Construction Process

For the sake of completing the model, typical site management functions required to support the hierarchy are added. This forms a consolidated overview of the construction process shown in Fig. 4. Each of these management functions are explained. The hierarchy of support functions (Fig. 3) is also grouped into basic functions. The following explanation refers to Fig. 4.

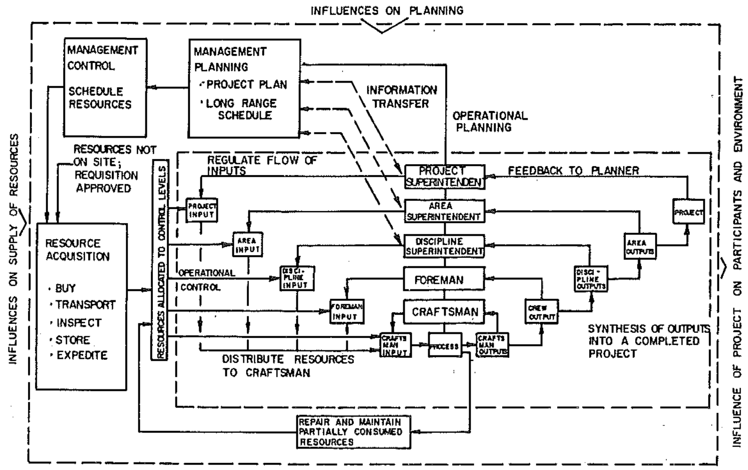

FIG. 4. Consolidated Overview of Construction Process

Management Planning

This activity consists of determining the strategy for executing the project, developing the long-term plans to achieve the goals, and periodic monitoring of programs against the plans. CPM and other decision-making tools aid in this analysis. There are considerable demands for communication and feedback between management and site supervision. Management plans are eventually converted into plans with a shorter time span. These are operational plans to be used by the foreman.

Management Control

The primary activity is to allocate resources to the project to support the plans and accomplish the scheduled work. It includes authorizing major purchases or acquiring key resources. This activity usually occurs long before work is assigned to crews.

Resource Acquisition

This function consists of acquiring services and resources for the project based on management plans. It is also driven by changed requirements or site deficiencies. The process begins with: (1) Executing labor agreements, purchase orders, subcontracts, rental agreements, etc; (2) checking and tracking until a resource is delivered to the site, normally called expediting; (3) on-site inspecting to check that the contracts and agreements described have been completed on time, on budget, and to the specified quality and quantity; and (4) storing resources in a temporary location.

Resource Allocation

Once resources are delivered and stored at the site, they must be allocated to a control level through a redistribution system. This control level should be the level immediately above the control levels that share the resource. Obviously it is impractical for a project manager to control the tools on a project, but in some instances this is done. The other impractical extreme is to let the crews control a critical item, such as a 300-ton specialized crane.

Operational Control

The mechanism for distributing resources to the craftsmen is operational control. This is either a formal or informal decision mechanism for deciding what resources should be distributed in what manner and by which level of control. This is in response to the input/output needs determined by the control function. This process can vary from a requisition system to a first-come, first-served system.

Operational Planning

These are the short-term plans required to meet the goals specified by the management plan. It can vary in scope from three months to a daily plan. A large factor that influences the conversion of management plans into operational plans and their correlation is the availability of resources. The lack of resources requires the adjustment of operational plans to focus on a lower priority activity. The success of management control is when operational plans, which are driven by resource availability, correspond to management plans, which dictate resource acquisition.

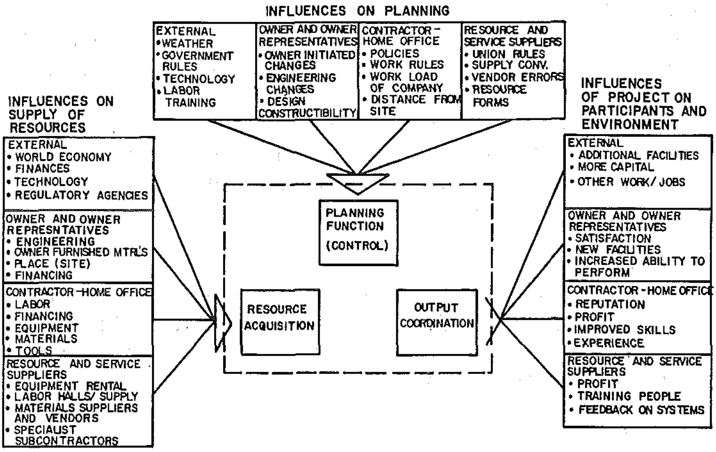

FIG. 5. Influences on Construction Process

Synthesis of Outputs into Completed Project

This activity is the end result of proper planning and resource allocation. Here, various crew outputs, e.g., concrete, rebar, etc., are combined to form the project structure.

Influences on Construction Process

To complete the model, the influences beyond the control of the site organization are shown in Fig. 5. These dictate the scope of project activities. They are grouped into influences on the supply of resources, planning, and the project participants and environment. In each of these categories, there are four parties that affect or are affected by the construction process. These are: (1) Parties external to the construction project; (2) owners and owner representatives; (3) the contractor home office; and (4) resource and service suppliers.

This concludes the explanation of the conceptual construction process model (CCPM). In essence, the CCPM includes the models described in Figs. 2–5. The remainder of the paper focuses on validating and applying the model to actual situations.

Validation of Model

In order to validate the CCPM presented, the key feature must be identified. The final link in the planning and resource control function with the craftsman is the supporting site organization. If the craftsman are not coordinated closely and resources are not supplied, then the site organization is not functioning. Thus, examination of the resource control, planning, and feedback functions on the site will provide the acid test of a functioning management system. This method is also the most practical, since all actors are located on-site, and answers to interview questions can easily be validated.

The validity of the model was tested by evaluating the following hypothesis: "Performance on a construction project is closely related to

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the project's resemblance to the conceptual construction process model." The definition of key terms in the hypothesis follow.

The key feature of the conceptual construction process model is shown in Fig. 3. It is the hierarchical arrangement of resource control, planning, and information and feedback functions as performed by the respective control levels on the site. The rules governing operation of the hierarchy define the scope of the functions for each control level.

Performance is ultimately measured by progress compared to schedule and budget for given design and quality standards. The schedule and budget were reviewed and checked to be reasonable for that project. Other cross-checks and indicators of performance were quality reports, safety reports, absenteeism and turnover records, visual inspection of the job site, and discussion with site managers.

In evaluating the hypothesis, project performance was determined by the cost and schedule performance of the general contractor. These both vary with the type of work, owner, contractors, labor force, market conditions, and design criteria. Thus, in order to accurately compare cost and schedule of projects, the writer selected groups of projects with similar external influences and characteristics to those described. This allowed comparison of cost and schedule for similar projects in the same market conditions.

Evaluation of Hypothesis

The hypothesis was evaluated by grouping similar projects, and then ranking and comparing two factors for each group. Projects were grouped with others that had similar external influences, as shown in Fig. 5. Similar influences included the same owner, the same labor pool, and/or the same contractor. The closeness of fit of the site organization with the modeled organization was determined by an index, CONIND, which is defined later. The hypothesis was evaluated by ranking CONIND values and the relative performance of the projects for each group. The correlation between the two determined support for the hypothesis.

Project Selection

It is obviously impractical to evaluate the hypotheses presented for each and every condition that may occur on any construction site. For this reason, the study focused on the contractor site organization where the contractor had a legal obligation to provide to a client a service or structure that had time, cost, and quality specifications. These site organizations had at least four levels of supervision arranged in a simple hierarchy and more than one crew working on the site. The contractors typically had control over the major portion of the site operations. Eleven projects ranging in size from $4.5 billion to $100 million were chosen. Two large projects were divided into eight areas for analysis. This provided manageable organizations. These projects and areas were sorted into six groups for analysis (see Table 1).

Data Collection

The data defining the closeness of fit to the model was collected by interview with craftsmen, foreman, general foreman, supervision, and management. A set of questions, not included due to length, provided a

TABLE 1. Analysis of Groups to Evaluate Hypothesis

Group (1)	Project (2)	Relative performance rank (3)	Good/bad (4)	CONIND value (5)	CONIND rank (6)	Rho (7)
1	SA1—CANAL	4	B	15.28	4	
	SA1—VAULT	2	G	1.94	2	
	SA1—BRIDGE	1	G	0.97	1	
	SA1—OFFICE	2	G	2.89	3	0.9
2	SA2—INTCHG					
	Area 1	1	G	4.00	1	
	Area 2	3	B	11.31	3	
	Area 3	2	B	5.53	2	1.0
3	SA2—COAL					
	Area 1	1[a]	G	2.24	3	
	Area 2	2[a]	G	2.21	2	
	Area 3	3[a]	G	2.05	1	
	Area 4	4[b]	B	6.35	5	
	Area 5	5[b]	B	4.91	4	0.5
4	SA2—INTCHG	2	B	6.95	2	
	SA2—COAL	1	G	3.56	1	1.0
5	US5—COMM1	2	B	6.52	2	
	US5—COMM2	1	G	1.95	1	1.0
6	US4—HOTEL	—	G	1.38	—	
	US3—REFINE	—	G	1.28	—	
	US3—NUKE	—	B/G[c]	4.7	—	N/A

[a]Performance was very close together, hard to separate, all good.
[b]Performance was very close together, both worse than the first three areas.
[c]Project was in a state of flux from poor performance in some areas to good in others.

guideline to the interview. Questions were designed to be nonleading, e.g., to ascertain the planning function, craftsman were asked "What are you going to do tomorrow?" and the foreman, ". . . next week?" Responses indicated whether planning was done or not. A schedule (when available) was used to verify whether daily activity was per schedule and sequence or not.

The tool, equipment, and material-supply systems were selected as the resources that had similar significance on most projects. They were almost always under the complete control of the project manager and were indicative of the three major cost categories on a job. Tools are the method in which labor is leveraged; thus poor tool control and supply will indicate poor labor control and usage. The data on these three resources formed the nucleus of the resource systems analysis. Typical questions to determine control of resources were: "Can anyone take control and direct equipment?," "Can anyone help themselves to material?," "Where are tools stored?," "How often do people not get their requests filled?"

These data were collected before any performance data, thus preventing biased results. The interviewer also provided visual independent checks on responses, collected data from the source, e.g., craftsman, and did not reveal the purpose of the interview to the site personnel. The procedure used for data analysis follows.

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Data Analysis Procedure

1. Divide the three primary functions, resource control and information and feedback supply into components, e.g., resource supply into equipment, permanent materials, tools, etc.; and each of these into subcategories, e.g., equipment into front line, utility, and small.

2. Determine which level in the site organization performs these functions by questioning site personnel and observing site procedures.

3. Develop the controller-function chart (Fig. 6) for the project by plotting functions on the horizontal axis and control level on the vertical axis.

4. Plot the ideal situation using the following rules:

   (a) Resources are controlled at the organizational level immediately above the level at which they are shared.

   (b) A controller should plan to coordinate work sequence and resources for the controllers directly below him and no lower.

   (c) For the controller to make efficient decisions, he must have information on the supply of the resources he controls, the plans made to coordinate his work, and feedback describing his output.

5. Plot the actual project situation on the controller-function chart with *x*s.

6. Determine the closeness-of-fit of the actual situation to the ideal, and calculate CONIND (see the following page). Two example calculations are shown in Fig. 7.

7. Group similar projects for comparison. This was done by selecting those with similar external influences (see Table 1), e.g., cases US5-COMM1 and US5-COMM2. On larger projects, e.g., SA2-INTCHG and SA2-COAL, it was possible to collect enough data on these areas to compare their management properties with their relative performance on the same project. Each group contained projects done by the same contractor for similar owners in the same geographical area and market conditions. Thus, comparison of budgets and schedules becomes a valid method of evaluating relative performance.

8. For each group selected in step 7, rank their CONIND value.

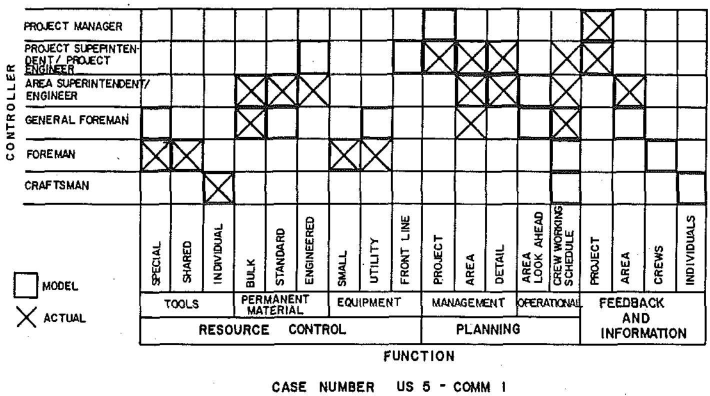

FIG. 6. Controller-Function Chart

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CASE # VARIABLE		US5-COMM1 SCORE	US5-COMM1 FUNCT	US5-COMM2 SCORE	US5-COMM2 FUNCT
RESOURCES					
TOOLS:	SPECIAL	2	2	2	2
	SHARED	0	1	0	1
	INDIVIDUAL	0	1	0	1
PERMANENT MATERIALS:	BULK	0	2	1	2
	STANDARD	.5	2	1	2
	ENGINEERED	2	2	0	2
EQUIPMENT:	SMALL	0	1	.5	1
	UTILITY	2	2	.5	2
	FRONT LINE	4	2	0	2
MOD		15		15	
FSC		21		9.5	
MFSC		1.4		0.63	
PLANNING					
MANAGEMENT:	PROJECT	.5	2	0	2
	AREA	0	2	0	2
	DETAIL	0	2	.5	2
OPERATIONAL:	LOOK AHEAD	4	2	0	2
	WORKING SCH.	1	1	1	1
MOD		9		9	
FSC		10		2	
MFSC		1.11		0.22	
INFORMATION AND FEEDBACK					
	PROJECT	0	2	0	2
	AREA	.5	2	.5	2
	CREW	4	1	.5	1
	INDIVIDUAL	4	1	0	1
MOD		6		6	
FSC		9		1.5	
MFSC		1.5		0.25	
CONIND					
1:1:1 WEIGHTING		4.01		1.10	
2:2:1 WEIGHTING		6.52		1.95	

FIG. 7. Analysis of Cases US5-COMM1 and US5-COMM2

9. For each group in step 7, rank their relative performance.
10. Compute Spearman's rho between rankings in steps 8 and 9:

$$\text{rho} = 1 - \frac{6\Sigma d^2}{[n(n^2-1)]} \quad \text{(1)}$$

where d = the difference between the CONIND and performance rank for each of the cases in the group being ranked; and n = the number of cases in the group being ranked.

The following section explains step 6 in detail.

Calculating CONIND

1. Determine SCORE i for each of resource control, planning, and information and feedback as follows:

- Function not performed: SCORE i = 4.
- Function performed at lower level; suboptimized decisions requiring extra resources: SCORE i = 2.
- Function performed at higher level; overcontrol, increased time for decisions to be made: SCORE i = 1.
- Function performed at correct level: SCORE i = 0.
- Function performed by two levels where one specified, or performed by one level when two specified: SCORE i = 0.5.

2. Determine FUNCT i. If the function being evaluated has a major effect on the project, i.e., something controlled by the general foreman or higher (as modeled), then FUNCT $i = 2$; otherwise FUNCT $i = 1$.

3. Compute FSC for each function group: FSC = (SCORE i) * (FUNCT i).

4. Calculate MFSC. The value of FSC for a function depends on the number of tasks in that function. To compare function groups on the same basis, an absolute score called MFSC (modified function score) is calculated on MFSC = FSC/MOD, where MOD = the sum of all the FUNCT i-values for a function group.

5. Calculate CONIND. The CONsistency INDex, CONIND was used to evaluate closeness-of-fit to the model: CONIND = 2(MFSC control) + 2(MFSC planning) + MFSC (info/fb). The three MFSC values were added with a weight of 2:2:1 to form CONIND, because the information and feedback function is covered by control and planning and is a requirement for them to function. Thus a part of it is accounted for by them.

This concludes the procedure for evaluating the hypothesis. The results follow.

Analysis of Results

Results presented in Table 1 indicate excellent support for the model. Group 3 represents the weakest correlation between performance and closeness-of-fit to the model. Further examination of group 3 shows that areas 1, 2, and 3 had respective CONIND values of 2.24, 2.21, and 2.05.

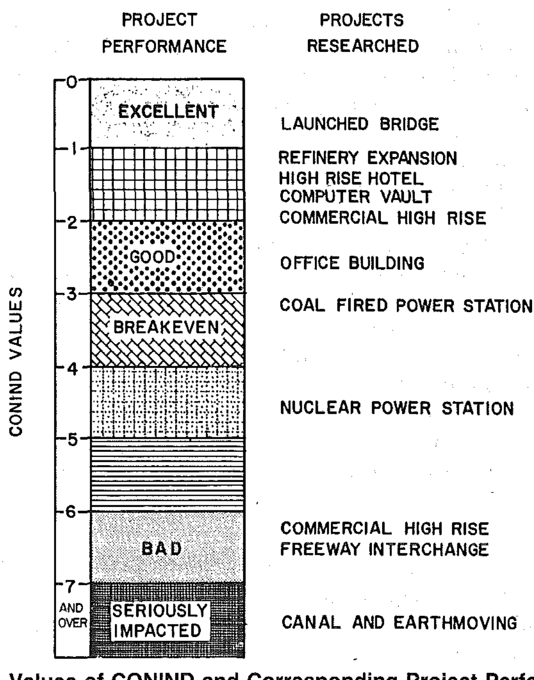

FIG. 8. Values of CONIND and Corresponding Project Performance

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These are all within 10% of each other. Bearing in mind that this test is approximate, we can rank all three as equal performers. Then the rho for group 3 becomes rho = 0.9. This indicates excellent support for the model.

The writer tried using different weighting factors of 1:1:1, 2:2:1, etc., in calculating CONIND. In all cases, the ranking of each of the three MFSC scores was the same. This supports the claim that the three functions are interrelated. Thus the weighting factors did not influence the results in any significant way. The 2:2:1 weighting seems logical for reasons explained earlier.

There is preliminary evidence to suggest that CONIND is in fact an appropriate absolute scale for evaluating performance of a project as reflected in terms of cost, schedule, and quality (see Fig. 8). A CONIND value less than 3 indicates good performance, 3–4 is break-even, and above 4 is a poorly performing project.

Practical Applications

The model CCPM describes a generic interrelationship of key functions, arranged in a hierarchy, that are required to support a construction field operation. The number and magnitude of these functions depends on the number of craftsmen that must be supported in the field at a point in time and their mix. This is dictated by the nature of the work. Thus these functions and therefore the tasks of supervision will change over the life of the project.

While a project may be run well at a stage early in its life, this does not imply that by performing the same functions it will perform well later on. Thus, active changing of the organization and information systems at critical stages in its life and retraining of personnel are paramount to its success. This is borne out in the cases mentioned in the literature where projects went out of control when the type of crafts were increased or changed without a corresponding change in organization, support systems, and information system (Howell 1983).

The writer has used this model to audit construction projects and systems in a major petrochemical construction program of $240,000,000 annually. The philosophy was extended and applied to engineering organizations in this program. In 1985, improvements were implemented in the engineering and construction organization that effected $10,800,000 in savings. These improvements were implemented in the following areas: materials management, document control, handover documentation, project engineering, project funding and control, contracting, constructibility, quality control, site operations, and safety. Many of these improvements were simply readjusting management and control systems to support the craft's needs and the engineer's needs. Clearly, the CCPM has the potential to effect a 5% budget savings if applied correctly.

Conclusion

The model presented in the paper represents a structure of functions to be performed on a project. It has been shown that projects that function closer to the ideal case specified by the model perform better in terms of schedule, cost, and quality than those who are further from the ideal situation. There is considerable support in the literature for improved productivity resulting from improving one of the components of this model. The references include 30 articles supporting this claim. The reader should review the entire appendix for details, but a few select articles cited as follows support improved productivity through: (1) Planning (Ballard 1982; Borcherding 1977; Casten 1980; Parker and Oglesby 1972); (2) resource supply and control: (Howell 1983; Judson 1982; Sanvido 1983); (3) supplying information and feedback: (Galbraith 1974; Gorry and Scott-Morton 1971; Levitt 1981); and (4) having people control defined functions: (Borcherding 1972; Gregerman 1981; Walton 1972).

This tool will serve as a useful guide for those analyzing or designing site management and control systems, when given a particular company culture, characteristics of people available, and the scheduled work to be done. Finally, the controller function chart has been found to be a useful tool for identifying project problems. This approach of designing a site organization to support the needs of the craftsmen is a tool that when properly applied with the right people can improve poor project productivity and reduce project cost by up to 5% of the budget.

Acknowledgments

The writer wishes to acknowledge the assistance of Boyd C. Paulson, Jr. for guidance as research advisor and mentor during the project and its field application, the companies that made sites available for the data collection, and over 300 craftsmen, foremen, and supervisors who allowed me to collect data.

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