PART 5

MANAGEMENT, FINANCE, QUALITY, LAW, AND RESEARCH

CHAPTER 67

MANAGEMENT CONTROL OF PROJECTS

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Projects are a very common feature of organizational work. They are prominent in aerospace and defense; construction; product development; public sector water, transportation and urban development; strategic thrusts; and in all kinds of team-related activity, including continuous improvement and reengineering activity.

67.1 GENERAL MODELS FOR THE MANAGEMENT CONTROL OF PROJECTS

67.1.1 The Macro Cybernetic Model

Figure 67.1 is a macro framework that places the entire task of the project control system design within a cybernetic framework. The framework can be understood best by viewing it from left to

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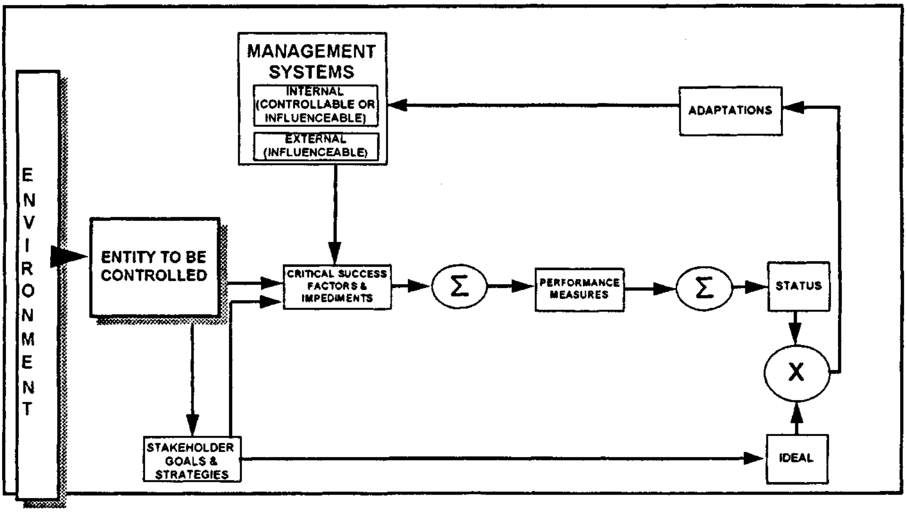

Fig. 67.1 Macro cybernetic control systems framework. (The design framework contained in Maciariello and Kirby, *Management Control Systems: Using Adaptive Systems to Attain Control,* 2nd ed., Prentice-Hall, Englewood Cliffs, NJ, 1994.)

right. The environment facing a project includes the customer, the competition, the technology, and the conditions of the various markets associated with the stakeholders of the project.

The development of effective and efficient project controls begins with the determination of the goals of each of the stakeholders of a project. The project manager should consider *who are the stakeholders* and *what is it that they seek from the project in order to continue to contribute to its success.* Next, strategies should be developed to meet the "inducements" necessary to satisfy the stakeholders, especially the critical stakeholders. Once these strategies are developed for each stakeholder, critical success factors (CSF's) for the attainment of these strategies as well as impediments to the attainment of these strategies should be identified. For each CSF, a performance measure should be developed to allow assessment of how well the project is performing in respect to stakeholder strategies.

Status reports are prepared periodically comparing actual performance against ideal performance. Gaps are a signal that changes must be made and improvements sought. Once performance is assessed and compared to the ideal, changes may be introduced in the management systems of the project in order to make the necessary improvements or adaptations.

The management systems of the project are themselves designed to exert control over the factors that can be controlled, to predict the values of uncontrollable factors and to influence the values of these uncontrollable factors.

67.1.2 Mutually Supportive Management Model for Complex Projects

Figure 67.2 identifies the key elements of the management systems that are required to control complex projects.

More recently, projects and subprojects are being managed by *project teams,* which resemble the matrix organization, although oftentimes the team or project leader has somewhat more formal authority over the functional resources assigned to the project than the project manager has under the matrix structure.

The *management style* of the project manager or team leader has to be predominately *participative,* since the manager often lacks full direct authority over functional personnel. The project leader is deeply involved in the integration of the work of a project. As a result, the project manager must be intimately familiar with the work, the technology, and the people involved on the project. As a result there are situations in which the project manager must be more directive and authoritative in order to accomplish the integration needed.

A project manager should seek to maintain an *open and candid culture.* This is required because there are numerous problems to be solved on a complex project and free and open communications are essential to cope with the dynamics of any complex project. The cross-disciplinary nature of many of the problems on projects require a *team orientation* throughout the duration of the entire

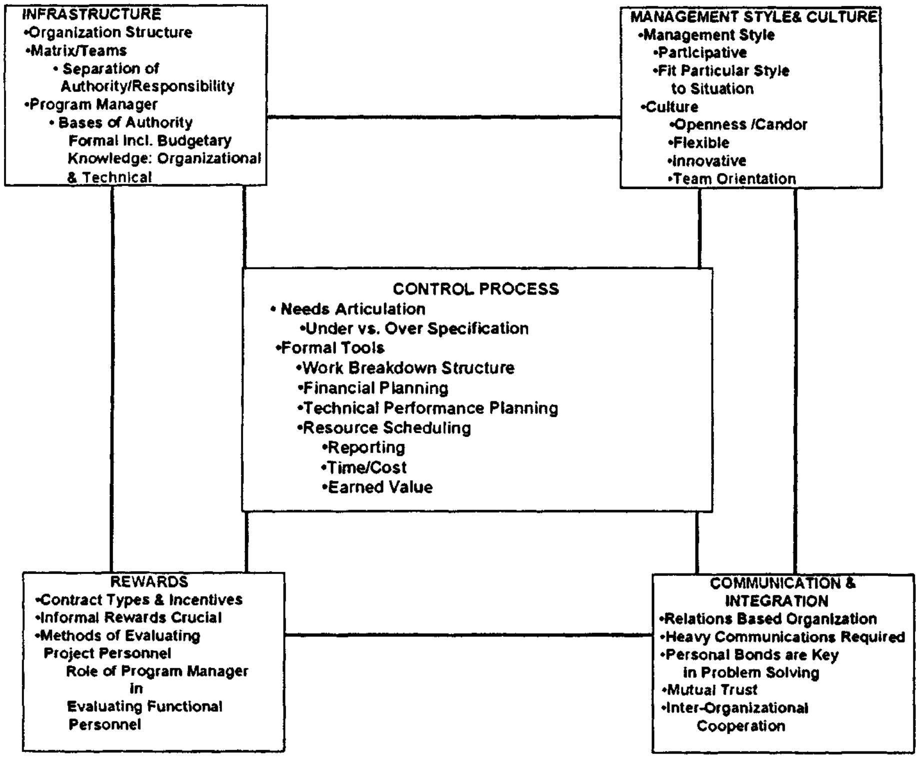

Fig. 67.2 Mutually supportive systems model (MSSM) for complex projects.

project. The high-technology characteristics of complex projects create the need for a culture that is innovative and flexible.

The *communication and integration* subsystem reflects the heavy communications requirement for the successful management of complex projects. *Personal relationships* that are related to flow of work and to problem-solving are key elements in the management of complex projects. The culture of openness should go a long way towards creating *mutual trust* among the various parties who must contribute to a project.

One of the key issues involving *rewards* is a decision about how the project and functional managers interrelate in the task of *evaluating performance of functional personnel* employed in project work. The most effective systems involve contributions from both functional and project managers in performance evaluation, but this has to be worked out in each organization.

Contracting methods on complex projects range from *fixed price* to *cost-plus-profit contracts.* There are various incentive arrangements negotiated between the project organization and the customer. Incentive arrangements are varied but are usually negotiated based upon *performance characteristics* of project deliverables, *schedule or cycle time, functionality,* and *cost performance.*

Informal rewards bestowed among project and functional personnel are especially important in the *relation-based organizations* that work on projects. Informal rewards involve various types of recognition of functional personnel by project managers and by peers.

Many of the new dimensions of control systems that are required in the control of complex projects are found in the control process. A whole new set of tools and concepts is required to more effectively facilitate the added coordination and integration required for project activity.

The *project-control process* is a procedure for the management of a project that operates through the project-control structure (style and culture, infrastructure, rewards, and coordination and integration subsystems) to achieve project goals. The process supports the formal and informal relationships embodied within the matrix or team structures in that it provides information to project and functional personnel upon which their decisions are based. The project-control structure and process must be mutually supportive if project goals are to be achieved.

Differences between processes required for project control and traditional management control occur because of the complexity of project activity and because of the difference in the organization structure employed. Complex projects require tools of *equal complexity.* Moreover, although the traditional functions of management are performed under project management, they are performed in a decentralized manner and are carried out through major changes in responsibility and authority relationships.

Planning and control requirements of complex projects create the need to achieve high levels of coordination without sacrificing efficiency, which in turn leads to the choice of the matrix or team organization, and this structure requires an information system to support it. Throughout this chapter, we shall have occasion to identify the interaction between elements of the process and the project control structure.

67.1.3 The Cybernetic Model and Its Failure Modes

The term *cybernetics* is derived from the Greek word *kybernetes,* which means "steersman." The term refers to a machine that by conglomeration of circuits can correct its own deviations from a planned course.

The study of cybernetics was formalized and extended by the mathematician Norbert Weiner in his book *Cybernetics,* published in 1947.[1] Weiner and his colleagues were originally concerned with the common processes of communication and control in people and machines that were used to attain desirable objectives. From the beginning, cybernetics was concerned with *mapping* the self-regulating principles underlying the human biological system onto systems of machines. Others have attempted to adapt the self-regulating principles found in the human brain to organizations. Most notable, perhaps, in this area is the work of Stafford Beer, which appears in his *The Cybernetics of Management* (1959)[2] and *Decision and Control* (1966).[3]

An essential feature of a cybernetic system is the concept of *feedback.* Feedback is both negative and positive. Negative feedback is a process whereby a system emits a signal that attempts to counteract an unfavorable deviation from a desired result of the system. Positive feedback is a process whereby a system emits a signal that leads to an action that reinforces the current system action and thus results in an ever-widening deviation from a parameter value. A self-regulating (i.e., homeostatic) system requires negative feedback to achieve its objectives. Both positive and negative feedback assist the learning and adaptive processes that are necessary to achieve project control.

The Cybernetic Paradigm and the Control Process

We shall use the cybernetic paradigm in this chapter to represent the control process. The information systems which support the control process are those in the middle box of Fig. 67.2. Figure 67.3

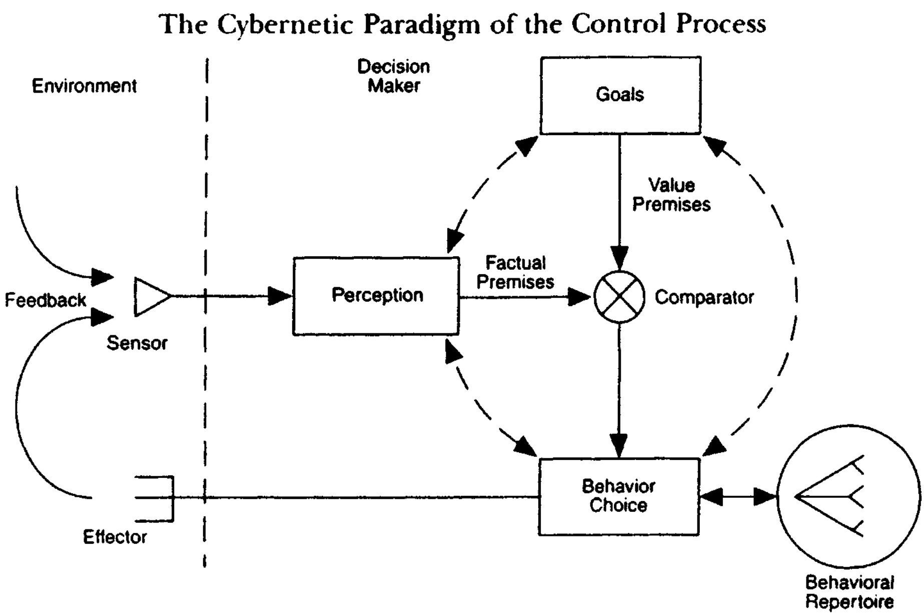

Fig. 67.3 The cybernetic paradigm (from Ref. 4; reproduced by permission of Donald W. Griesinger. A subsequent version of the paradigm appears in Ref. 5).

represents the cybernetic paradigm of the project control process. This particular version of the paradigm has been devised by Griesinger.[4,5]

The cybernetic paradigm represented in Fig. 67.3 allows us to capture the essential elements of the repetitive control process, which may be enumerated as follows:

1. Set goals and performance measures.
2. Measure achievement.
3. Compare achievement with goals.
4. Compute the variances as the result of the preceding comparison.
5. Report the variances.
6. Determine cause(s) of the variances.
7. Take action to eliminate the variances.
8. Follow up to ensure that goals are met.

These eight elements of the control process are captured in the cybernetic paradigm.

The paradigm begins with the assumption that decisions are explained as the result of the interaction between the manager/decision-maker and the environment faced by the decision-maker. Each project manager operates within an environment. The environment includes the "outside world" (i.e., the external environment of customers, suppliers, etc.) as well as other organizational units internal to the firm (i.e., the internal environment). A project manager must be responsive to changes in the external environment of the project as well as to changes within the internal environment.

A project or team manager scans the environment, either formally or informally, so as to absorb information or feedback pertaining to its condition. The manager comes into contact with the environment through the sensors of the project. Sensors are mechanisms used by managers to collect data. The mechanisms include reports that are reproduced as a result of formal attempts to scan the environment as well as "informal reports" that come to the attention of the manager through his or her senses of hearing and sight.

The manager constructs from these data certain beliefs concerning performance and the state of the external environment. These beliefs are referred to as *factual premises.* Factual premises are formed by passing these data through a cognitive process referred to as *perception,* which broadly refers to the psychological processes of extracting information from data and of interpreting the meaning of that information. Cognitive limitations prohibit decision-makers from assimilating all data in the environment, so the decision-maker uses past experiences, organizational goals, and personal and organizational aspirations to arrive at these beliefs about the actual state of the environment.

The manager uses these factual premises in a comparison process with organizational goals and performance measures. *Goals* are themselves a result of past learning concerning performance and accomplishments and represent the desired state for the manager. When a difference is determined to exist between what decision-makers desire (i.e., *value premises*) and their beliefs about the environment (i.e., *factual premises*), they are motivated to seek to close the gap. The *comparator* represents the comparison process that takes place between performance measures and performance information.

When a performance gap exists, decision-makers are motivated to search for courses of action that will move them closer to their goals. This choice, referred to as *behavioral choice,* is made by evoking from experience a limited set of alternatives that have been successful in solving similar problems in the past. The content of the set of alternatives evoked from the decision-maker's *behavioral repertoire* is itself a function of goals, past experience, and the decision-maker's perception as to the state of the environment. Search procedures are also included in the behavioral repertoire.

Alternative solutions are evoked from the behavioral repertoire according to established or learned search procedures. The first alternative found during the search that is believed to solve the problem is normally selected, so long as it meets project requirements. In the event that two or more alternatives are generated by the search procedure as potential solutions to the problem, the feasible alternative with the highest *subjective expected utility* that closes the gap will be chosen.

An alternative will be chosen only if it is expected to meet the goals of the decision-maker. If no alternative is expected to reduce or close the gap, the decision-maker will expand the search process. The search process is motivated by the presence of a gap and will stop when a feasible alternative is found that will close the gap.

Decisions require implementation. The *effector,* a manager, activates the decision, thus serving as a change agent. Control is brought about by action taken by the manager who next seeks to determine the effects of the action. This new information is referred to as *feedback.* If the new behavior leads to a reduction or elimination of the gap, the behavior is likely to be repeated in the future under similar circumstances. If goals are being met routinely, it is likely that the organization will eventually seek higher levels of performance.

In the event that goals are not achieved, the manager will repeat the process. If after repeated attempts the goals are not achieved, the manager will either alter the performance measures that are attended to and thereby distort his or her perceptions of reality, or reduce his or her goals. In either case, the performance gap is ultimately closed.

A certain amount of interaction takes place during the control process among the variables in the cybernetic paradigm. *Goals* direct the part of the environment that is *perceived* by managers. Perceptions about past performance influence current goals. We perceive that part of the environment that pertains to our goals. If decisions cannot be found that meet our goals, we change goals. Additional information may be introduced during the search process that can alter goals and alternatives considered, as well as the part of the environment that is attended to (perceptions).

Potential Failures in Project Steerability*

Potential failures in the task of successfully steering a project towards its objectives include those *external* to the decision-maker and those *internal* to the decision-maker and the organization. Figure 67.4 is the cybernetic model with potential failure modes associated with each external and internal variable of the model.

Steerability may be impeded as a result of four potential *environmental* failures, as defined in Fig. 67.4. *Lack of data* implies that a manager lacks information about the project environment that is necessary to achieve goals. A variant of the lack of data is the *lack of predictability* regarding environmental disturbances that impact performance towards a goal. *Overwhelming events* are environmental disturbances that overwhelm the manager's ability to cope. *Interference* occurs when factors or persons in the environment constrain the behavior of the manager in a way that prevents goal attainment.

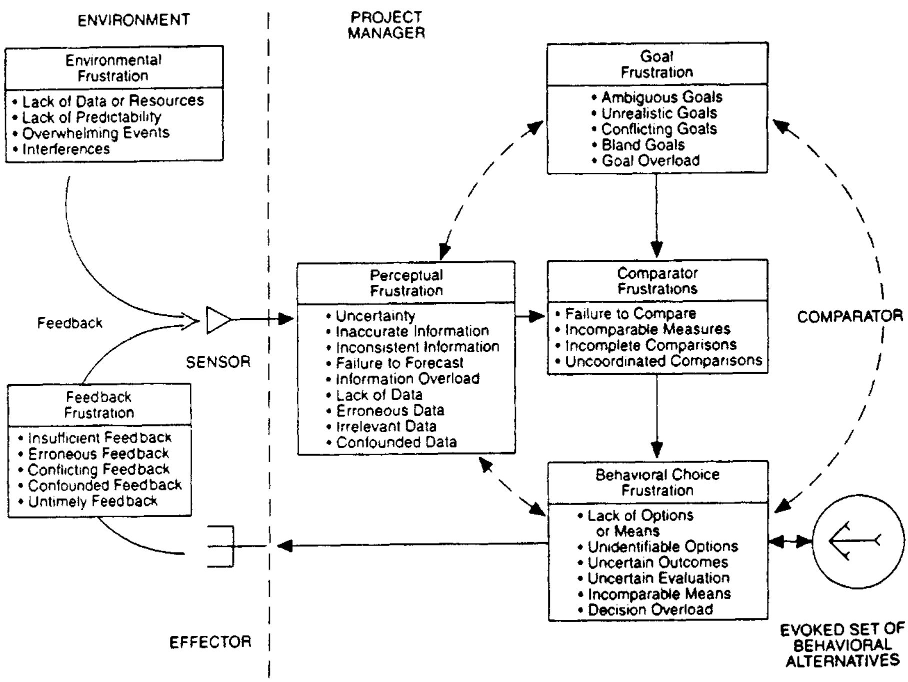

Fig. 67.4 Project management cybernetic failure modes.

*In general, this section is based on the cybernetic failure model as originally formulated by Graham (Ref. 6, pp. 32–47) and by Griesinger.[4,5] The cybernetic failure model was subsequently adapted by Edie Levenison, Joseph Maciariello, and Peter Zalkind for the purpose of analyzing the failure modes of an actual software project. This project and its failure modes are described in Maciariello and Kirby (Ref. 7, pp. 581–588).

Feedback is critical to steering an organization towards its goal. *Feedback frustrations* occur when data for evaluating the effectiveness of past decisions is insufficient. If feedback is insufficient, a manager does not know which actions to repeat and which to delete in the future. That is, there can be no organizational learning. *Erroneous feedback* as to the success of various actions can lead to decision error and goal failure. *Conflicting feedback* leaves the decision-maker confused as o the state of goal achievement. *Confounded feedback* occurs when the results of an action are mixed up with the results of other actions and with environmental changes so the decision-maker is confused as to the ultimate effects of a past decision. Finally, feedback may be *untimely* so far as necessary corrective decisions are concerned.

Perceptual frustration includes many of the same frustrations that are external to the decision-makers, except that these involve perceptual processes. *Uncertainty* occurs when a manager doesn't understand that a goal that is being pursued is in danger of being missed. *Inaccurate perceptions* are concerned with incorrect interpretation of the available data. *Inconsistent information* involves different interpretations of the same event or conflicting interpretations of multiple events. *Failure to forecast* is a failure to forecast the implications of trends that are at least partially visible. *Information overload* is a condition where accurate perception breaks down because of the inability to process environmental information effectively. *Lack of data* is the same frustration as discussed above for environmental variables, except this one pertains to perceptions that data are inadequate for making the necessary inferences. Similarly, *erroneous data* are data perceived to contain errors. *Irrelevant data* are those perceived as being inapplicable for necessary inferences. *Confounded data* may lead to spurious perceptions.

Goal frustrations are among the most serious impediments to steerability. *Ambiguous goals* are those for which criteria for achievement are not clear, thus frustrating the measurement process. *Unrealistic goals* are those that are simply beyond the individual's ability to achieve them. *Conflicting goals* are those individual and organizational goals that are incompatible and cannot be attained simultaneously because of the tradeoffs required for the accomplishment of each goal. *Bland* goals are those that are simply not highly valued, thus providing low motivation for their achievement. *Goal overload* occurs when the complexity of goals overwhelms the decision-maker's ability to sequence or prioritize them. Goal frustrations are so serious that the project manager must take extraordinary steps throughout the project life to ensure that there is continual congruence among crucial stakeholders regarding the goals of the project.

Comparator frustrations include the *failure to compare,* which is a case in which relevant perceptions are not compared to goals to determine if a gap exists. *Incomparable measures* is a case where goals and measurements of progress toward goals are conceptualized differently and incorrect surrogates for goals are measured. *Incomplete measures* is a case where the measure is a valid one for the goal but is incomplete as an assessment of performance towards the goal. *Uncoordinated comparisons* is a failure to compare perceptions and goals at the same point in time. This commonly occurs when there are long processing delays in preparing relevant information.

Behavioral choice frustrations are those involving the decision-making process itself. *Lack of options* is the frustration that occurs when, because of lack of ability, experience or free will, the decision-maker is unable to solve a problem and steer the organization towards its goal. Related, *unidentifiable options* are frustrations produced when appropriate behaviors, although knowable, are simply not accessed by the decision-maker as a result of inappropriate search procedures. *Uncertain evaluations and outcomes* occurs when the decision-maker is uncertain about predictions of the impact of alternatives upon the goal, thus making it difficult to choose effective remedies. *Incomparable means* involve two or more alternatives that are believed to make a contribution toward the goal but whose impacts upon the goal are not strictly comparable, thus frustrating rational choice. Finally, *decisional overload* occurs when too many decisions must be made in a given period of time, thus not allowing enough time for analysis of each decision.

67.2 SYSTEMS DYNAMIC MODELS AND CONTROLLING THE WORK OF PROJECT TEAMS

It is possible to examine the dynamics of the project-control system itself. These dynamics have a significant influence on the ability of the project manager to achieve control. As the project progresses in time, the various aspects of the management control systems interact with one another. These interactions can be described as various patterns of cause-and-effect relationships. When the various subsystems of the project-management-control system are appropriately aligned, they produce mutually supportive interactions that contribute to the efforts to achieve control. In contrast, when they are out of alignment, they frustrate attempts to achieve control.

Patterns of cause and effect in systems often are circular or "linking back" to the first variable. We call these circles of causality *causal loops.* Figure 67.5 is an example of a causal loop. Activity A influences B, which in turn influences C, which then influences A.

Let's assume that a member of the project expresses trust in another member (Action A). The second member, influenced by this action, might take on expanded responsibilities to ensure that an

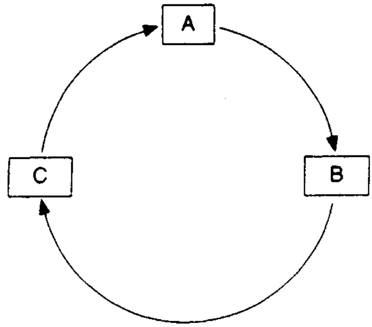

Fig. 67.5 Reinforcing causal diagram.

expected outcome is achieved (Action B). The improved outcome might lead a third member to comment to the first that the second member can be counted on to perform, thus increasing A's trust (Action C). This then is an example of a *reinforcing* causal loop in a positive direction. The opposite can also occur. Reducing trust might cause a member to reduce effort, thus further reducing trust. This, too, is a reinforcing spiral, but in a downward direction.

A reinforcing loop does not occur forever. Limiting forces materialize. Systems thinking recognizes that a change in one variable can cause changes in secondary variables. These secondary changes, not so obvious at first, can begin to feedback influences over time that limit the reinforcement process. For example, if a third party overheard the lack of trust member A has in member B, he or she might begin expressing trust in B, thus *balancing* the downward spiral. The second causal loop thus balances the first.

The second causal loop took some time to take effect. The *delay* is the third building block of systems thinking, along with *reinforcing* and *balancing* loops. Many of the dynamics we observe are due to unforeseen delays. From a management control perspective, the designer can use this kind of dynamic systems thinking to enhance the mutually supportive and adaptive dimensions of the control system.

A general principle to note based on the preceding discussion is:

When a reinforcing process is set into motion in order to achieve a desired result, it also sets into motion secondary effects which usually slow down the primary effect.

Senge[8] and Kirby[9], and Severino (1992) using Kirby's results, have shown that these dynamic control problems can be minimized by creating a *learning (i.e., adaptive) organization.* Drawing from these studies, a learning organization requires the development of a *shared vision* of what the organization wants to accomplish, an environment that is continuously open to new ideas, one that encourages individual learning and mastery, and leadership by example.

We turn now to examine an example of an application of system dynamics to the management of project teams.*

67.2.1 The Dynamics of Controlling a Project Team

The first step a newly formed team must take is to develop a shared vision for its goal or objective. Then they must assess the current situation in terms of the vision. To do this, they must gather information to refine their understanding of the current situation and then determine appropriate action. As a result of the process of implementing the actions and gathering more feedback, members emerge in different roles more suited to the needs of the goal and vision. The team essentially learns to be effective. Each of these steps requires support from the control system.

Using findings from Kirby's study of successful and unsuccessful project teams, Fig. 67.6 shows the reinforcing system of informal activities that allowed the most successful teams to achieve their goals. The key environmental issue found in most successful teams was a culture of *trust and openness.* The leader of these teams had few preconceived assumptions or beliefs about the "best way"

*An expanded version of the models represented in this section may be accessed in "Team Dynamics in Adaptive Control Systems," by R. A. Severino, C. J. Kirby, J. A. Maciariello and N. N. Kelly, The Agility Forum, Bethlehem, PA, (https://www.agilityforum.org:445), 1996.

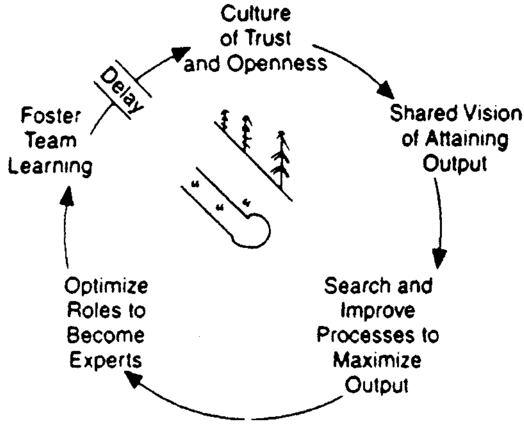

Fig. 67.6 Reinforcing system of informal activities.

to perform any given action. The groups used a free interchange of dialogue in their search procedures to weigh the benefits of any suggested actions. This culture led to the development of a shared vision of the desired objective and a search for the processes that optimize output. These activities represent informal planning activities. Once the process of making improvements was underway, team members assumed roles that better supported the process of further improvement. This led to an environment that fostered team or staff learning. After some time operating in this environment, during which time the teams developed and refined these skills, the process began to provide reinforcing feedback for increasing the level of trust and openness. This further reinforced the other activities, thus accelerating their efficiency.

Unfortunately, neither management staffs nor improvement teams will continue to improve their output endlessly. Figure 67.7 introduces the key limiting or balancing factors to this learning engine. There seem to be five such limiting factors. They should be expected in poorly performing teams and to some extent, eventually, even in successful project teams.

Teams that begin to fail or fail often have a leader or *dominant member* who carries strong preconceived beliefs about how the management team should act. This situation seems to block the discovery and ownership attributes present in the open dialogue of goal-seeking groups and *balances* the culture of openness and trust.

Proceeding clockwise along the reinforcing loop, another limiting factor is a gradual *erosion of the commitment* to the goals of the team that erodes the common vision. There are various degrees of commitment, a minimum being apathy and the maximum being total commitment. As levels of commitment fall, the amount of energy devoted to the goal falls.

Even if a staff remains committed to a goal and retains a culture of openness and trust, it can still be unsuccessful if it lacks an *adequate model of cause and effect.* These models are necessary to understand the meaning of data and in order to facilitate specific actions. The models available include many of the techniques associated with total quality management (TQM).

As team members seek to optimize their roles and become experts, a source of motivating energy propels them to close the gap between current performance and their goal. Senge[8] calls this source *creative tension* and its opposite *emotional tension.* Emotional tension distracts members from pursuit of their goal by forcing them to spend increasingly larger amounts of time in ambiguous roles. The matrix structure is particularly prone to role ambiguity because of the competing and often ambiguous instructions given to project participants by project and functional managers. Emotional tension tends to balance the positive forces that encourage mutually supportive emergent roles. Similarly, when staffs or teams exhibit *defensive routines* in reaction to team conflicts, team learning is curtailed. How teams respond to conflict frequently separates the excellent from the mediocre teams.

In summary, our analysis indicates that team learning is facilitated by the informal subsystems of control. But the formal elements of the control system also interact with the informal elements. Figure 67.8 shows the interaction of the informal with the formal elements of the project-control process.

Figure 67.8 illustrate the cybernetic behavior of both the informal and formal planing activities for a team working on an improvement project. The two activities shown on the left come from the informal systems and involve searching for data, seeking new directions, and formulating plans. These activities are most prevalent during times when teams are searching for solutions to pressing problems. The balancing feedback on the right illustrates the relationships of formal and informal processes. Formal planning and control processes are seen as the formal aspects of attaining output goals through

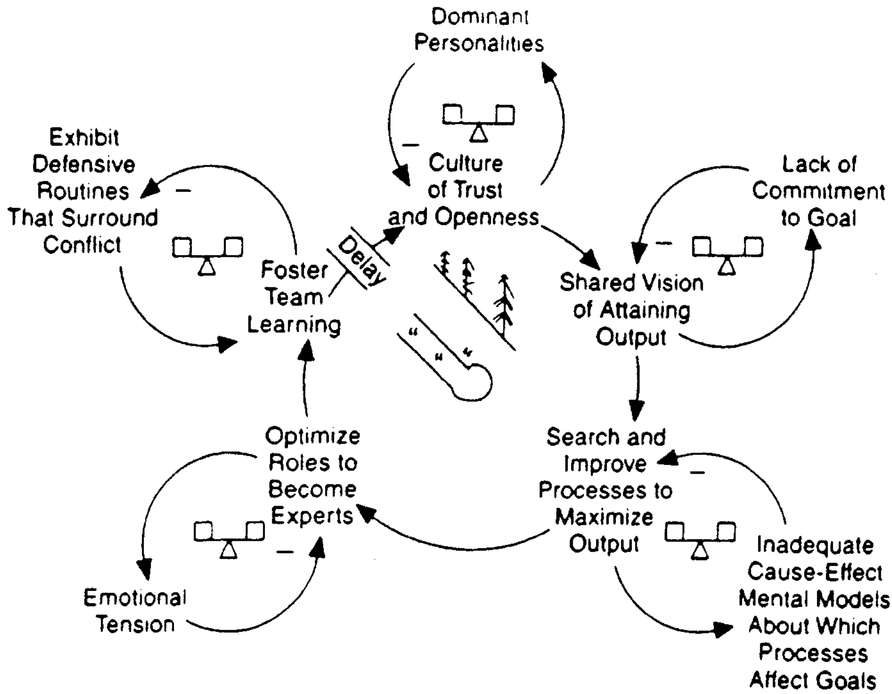

Fig. 67.7 Reinforcing system of informal activities with balancing items.

shared vision, assessing the gap between performance and vision, and taking steps in the planning and budgeting process to close the gap. The formal interacts with the informal to allow the team to achieve its goals. The formal gap measuring activities allows the team to steer its efforts towards goals.

Showing the formal and informal control activities within the context of the entire control system identifies a mutually supportive reinforcing learning system. Figure 67.9 displays a reinforcing loop that we might call the *adaptive control or learning engine*. The reinforcing loop shows the additional influence of formal and informal rewards (as a result of measurement) on team learning, thus linking the structural aspects of the control system to the process aspects.

Finally, we are in a position to view the entire dynamics of the control system as it affects team performance. Figure 67.10 is such a view. Two elements of the control structure not previously discussed are included at the top left. Both set the initial conditions for teams. Prior training or indoctrination for the team is one element and infrastructure or formal chartering of the team is the other.

The reinforcing loop of culture, vision, search, and so on is the upper reinforcing loop along with the five potentially balancing items shown along the outside. The formal control balancing activities support the informal planning processes. The outer loop of measurement and rewards reinforces team learning at the bottom of the structure.

The progress of the project team is determined largely by how close the leadership of the team can come to creating the mutually supporting reinforcing loops by using appropriate elements of the mutually supportive subsystems in a dynamic manner. At any given moment, some loops are rapidly cycling while others are sitting idle.

67.3 SPECIFIC ISSUES IN THE PROJECT-CONTROL STRUCTURE

67.3.1 Organizing for Complex Projects: Matrix Structure and Teams

Complex projects, although requiring close coordination, may not be large enough or of long enough duration to justify a separate project organization form, yet they often require far more coordination than is possible under a functional organization. In other words, neither extreme, a pure functional or a pure project organization, is ideally suited for such complex projects, and the tradeoff implied in the choice between the two is often unacceptable.

As the projects of an organization have become more complex and numerous, the functional organization has been forced to recognize the limitations of its structure. Often this recognition has

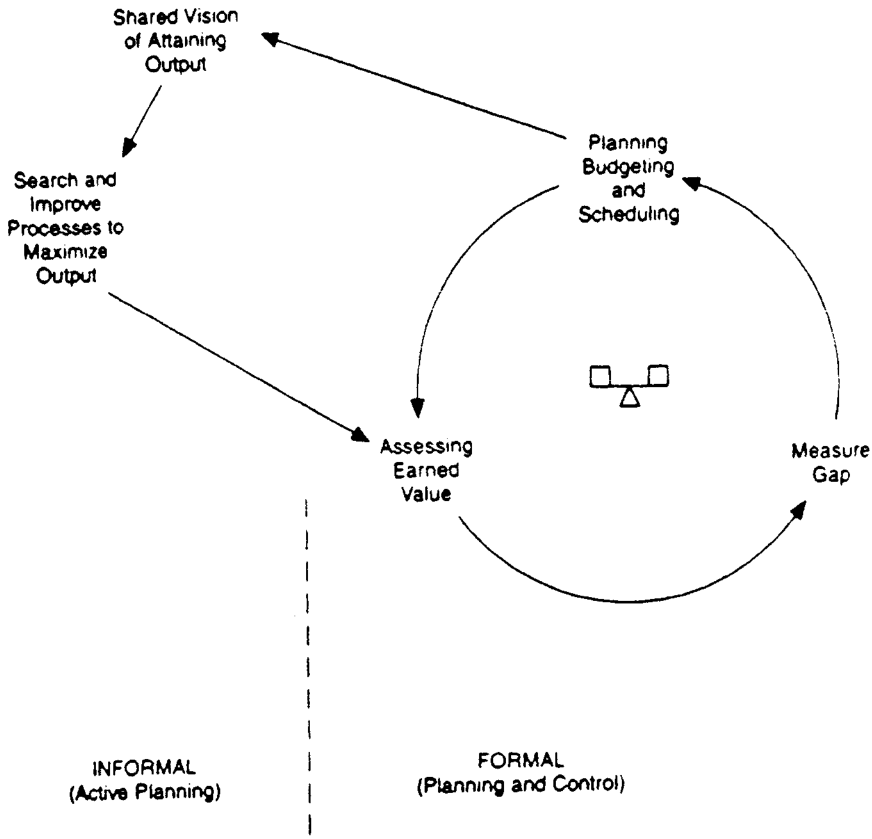

Fig. 67.8 Cybernetic behavior of formal and informal activities.

led to formation of ad hoc teams of functional personnel to handle the "unique" coordination problems created by the high degree of interdependence required among functional disciplines on a given project. As these types of projects are recognized to be the very nature of the organization, team relationships often become less ad hoc and more formal.

Members of teams are selected based on functional expertise from the relevant functional groups. Leadership of a team is often assigned from the functional group that can make the largest contri-

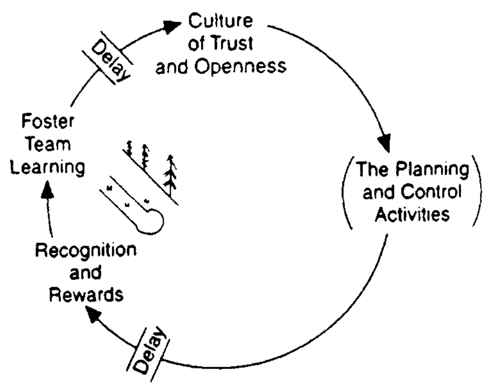

Fig. 67.9 Adaptive control engine.

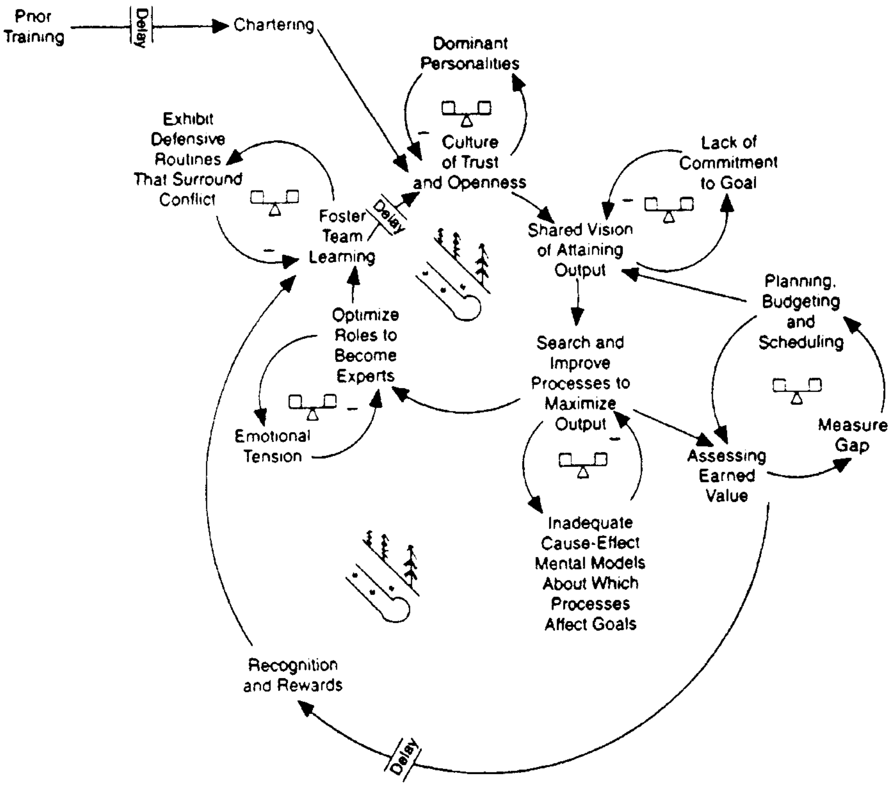

Fig. 67.10 Dynamics of a project control system.

bution toward solving the problem for which the team was formed. Once formed, it provides a device to achieve coordination across specialized functions and is an expedient means of getting complex tasks accomplished.

Although teams are disbanded upon completion of a project, the number of projects requiring such an arrangement should be expected to increase for any organization engaged in complex projects. In these organizations, the need for a more permanent structure that makes relationships among team members more formal soon becomes apparent. The new structure should allow the organization to coordinate these complex activities while retaining functional specialization and resulting scale economies. Neither of the two structures described allows an organization to achieve total coordination of complex activities and full-scale economies of specialization *simultaneously*.

A solution to this organizational dilemma was first provided approximately 40 years ago in the aerospace industry and has since been used in various forms by firms who are in businesses as divergent as food and produce and accounting services. This organization form has become known as the *matrix form* and is used today in many variants of project and product management. Regardless of the type of application, it embodies the assumption that it is not necessary to make an explicit tradeoff in organizational design between advantages of scale economies and coordination. Rather, it attempts to achieve high levels of each simultaneously and thus reach a higher level of effectiveness than either the functional or decentralized form.

With this as background, we now turn to a general description of the matrix structure, followed by illustration of its application to project management.

The Matrix Organization

Regardless of the nature of the firm employing this hybrid organization form, it may be described using a matrix, as shown in Fig. 67.11, with the various products, projects, or services identified in the columns of the matrix and the functions identified in the rows.

The matrix depicts an organization with four projects. These projects represent the primary output of the organization and therefore place demands upon the various functions. The functions, repre-

Projects/ Functions	Project 1	Project 2	Project 3	Project 4	Total Functional Output
Engineering					
Procurement					
Quality assurance					
Logistics support					
Manufacturing					
Project control					
Project management					
Overhead					
Total project requirements					

Fig. 67.11 The structure of matrix organization.

sented in the rows of the matrix, supply resources to various projects within the organization. The total output of a function for any particular period of time is found in the last column of the matrix and consists of the sum of all the contributions of a particular function to various projects. Each row of the last column represents the demand placed upon one function by multiple projects. This demand may be measured in physical units of input, such as resource hours, or in monetary units.

Functional contributions that are indirect, such as research and development, contract administration, personnel, business planning, public relations, and finance are included in the overhead row of the matrix.

The matrix itself, however does not uniquely define the distinguishing characteristics of the organization form used in project control, although the term is widely used to describe the organization form. Any organization may be described as a matrix; it need not be a hybrid form. All organizations produce outputs that may be identified in the columns of a matrix and use inputs that may be identified in the rows of the matrix. That is, all organizations have a purpose and use inputs or processes to fulfill the purpose. The truly distinguishing characteristics of the matrix organization structure, in all its variations, lie in the dual dimensions of management embodied within it and the allocation of responsibility and authority resulting from the dual management dimensions.

The matrix organization uses two overlapping dimensions of management, each of which may be identified with the matrix. The dual dimensions of management may be identified by referring to Fig. 67.11. Under the matrix organization structure, full responsibility for the goals of a project is given to project managers, and this responsibility is identified by the column dimension of Fig. 67.11. However, functional personnel who perform the work on the projects of an organization receive direction from functional management under the matrix structure, thus providing the second and overlapping dimension of management for the projects of the organization. The functional dimension of management is identified by the rows of the matrix.

Therefore, although the project manager assumes full responsibility for delivery of a product that meets performance specifications on a timely basis and in accordance with a contractual resource limits, he or she does not have full direct authority over the functional organizations that actually perform the work. If he or she did have such authority, the organization would not be a hybrid at all; it would be simply a decentralized project form. The distinguishing feature, therefore, of the matrix organization is the separation of the responsibility for the goals of a project from the authority to direct the work necessary to achieve those goals.

Furthermore, although there is a separation of responsibility and authority under the matrix structure, functional personnel actually do operate subject to dual sources of authority: the *knowledge-based authority* within the functional organization and the *resource-based authority* of the project manager. Unity of command is thus broken. This is rectified, to some degree, in organizations that use teams within the matrix to manage projects.

Even though the hallmark of the matrix is the separation of responsibility and authority, in practice we find that rather than a clear separation of responsibility and authority, we have formal and informal relationships among project and functional personnel that lead to a distribution of responsibility and authority.

Project-Matrix Organization. Project organizations are concerned with planning, coordination, and control of complex projects of an organization; projects require many activities proceeding both serially and simultaneously toward an *ultimate goal,* and continuous and intricate interaction among many different functional personnel of an organization. The goals for each project ordinarily include profit, either short term (i.e., the project only) or long term (i.e., future business). The goals are met by achieving agreed upon performance with respect to cost, quality, functionality, and time variables. Therefore, cost, quality, functionality, and schedule are ordinarily among the key success variables for a project. Upon completion of all activities the life of the project ceases and the organization is *dissolved.*

Figure 67.12 provides an example of a typical organization for the management of complex projects with the matrix structure superimposed. The formal organization chart, however, does not illustrate the dual dimensions of management embodied within the matrix. These dual dimensions were illustrated in Fig. 67.11.

The role of the project manager and his or her staff is to carry out the planning and control process of a project *without* getting involved in the actual direction of functional work. Under the matrix structure, the project manager plays the role of a planner, coordinator, and controller whose chief concern and responsibility is to produce a project on time, within cost constraints, and in accordance with quality and performance specifications. The project manager of a medium- to large-scale project generally has a small staff assigned directly to him or her. The staff is charged with responsibility for the planning, coordination, and control of subdivisions of the project.

Authority for directing functional work and accomplishing the technical tasks of a project lies with the managers and individual contributors of the various functions. The individual contributors to a project do not ordinarily report to the project manager, but rather to their respective functional managers. Often, in the matrix organization structure, a connection is made between the project office and functional groups by the appointment of assistant project managers, project engineers, or project leaders for each of the major functions, and these assistants report either directly or indirectly to the project manager.

67.3.2 Project Teams: A Case Study

Improving productivity and quality can follow many courses of action, but all improvement methods are forms of continuous adaptation. The focus of management in this example is upon the acceleration of significant quality and productivity improvements through the use of informal, ad hoc teams within a complex project.

The Project

The AN/BSY-1 Combat and Control System is produced for the Los Angeles class nuclear submarines used by the U.S. Navy. As a major subcontractor, Hughes Aircraft was responsible for a number of complex subsystems produced by other major contractors and integrated at their facilities.

As a major subcontractor to the AN/BSY-1 Project, Division 1E of the Ground Systems Group of Hughes Aircraft Company supplied a large suite of command and control electronics. The system, when installed on the Navy vessel, provided a complex stream of data to the operators in charge. The electronic systems consist of multiple electronic control units, modules, appropriate interfaces, and housings. The control units are built from an array of electronic modules that are contained in drawers. Without timely completion of the appropriate mix and quantity of modules, the system could not be assembled and the total project would have suffered a delay.

The Project-Control System. The project was organized in a formal matrix structure. A project manager, along with manufacturing, quality, engineering, and material managers, all reported to the division manager. Formal project reviews were held with each functional area, reporting on its specific activities. Formal cost information, material requisitions, and quality systems were used to control operational status. Project plans, including cost, schedule, and quality, had been developed early in the project and were tracked at project reviews.

The project struggled to meet objectives over a period of months. During this time, each manager had a good rationale for his particular problems. In general, the individual managers felt they were performing their specific functions adequately. A growing amount of internal pressure was being placed upon each functional group at project reviews to meet current goals. Interpersonal communications were sporadic, but largely directed at identifying causes for schedule slippage.

The essential formal control system was in place, but informal "teamwork" was not being utilized by management to support the project purpose or to adapt to current needs. Productivity and quality did not meet management expectations.

After a lengthy and complicated design phase, production was initiated in early 1986; product flow progressed slowly. In July 1987, module production stopped due to yield and productivity issues. Multiple internal inspections were implemented and 7700 complex module assemblies were being reviewed at various stages of assembly. The project was in danger of falling behind schedule. These problems were all internal issues. Management was determined to ship excellent hardware on time and on schedule to the customer.

The challenge facing management was to improve quality, increase productivity, and regain schedule integrity concurrently and quickly. The situation was not unlike many that are found in U.S. industry today. The customer desired strict compliance to contract specification as well as improved timeliness of delivery and increased productivity. The challenge was to dramatically improve all three parameters.

The Project-Improvement Effort. During the following 18-month period, no major capital investments were made, management personnel remained basically stable, customer pressure was intense but steady, and no major changes in the functional scope of the product were initiated. The

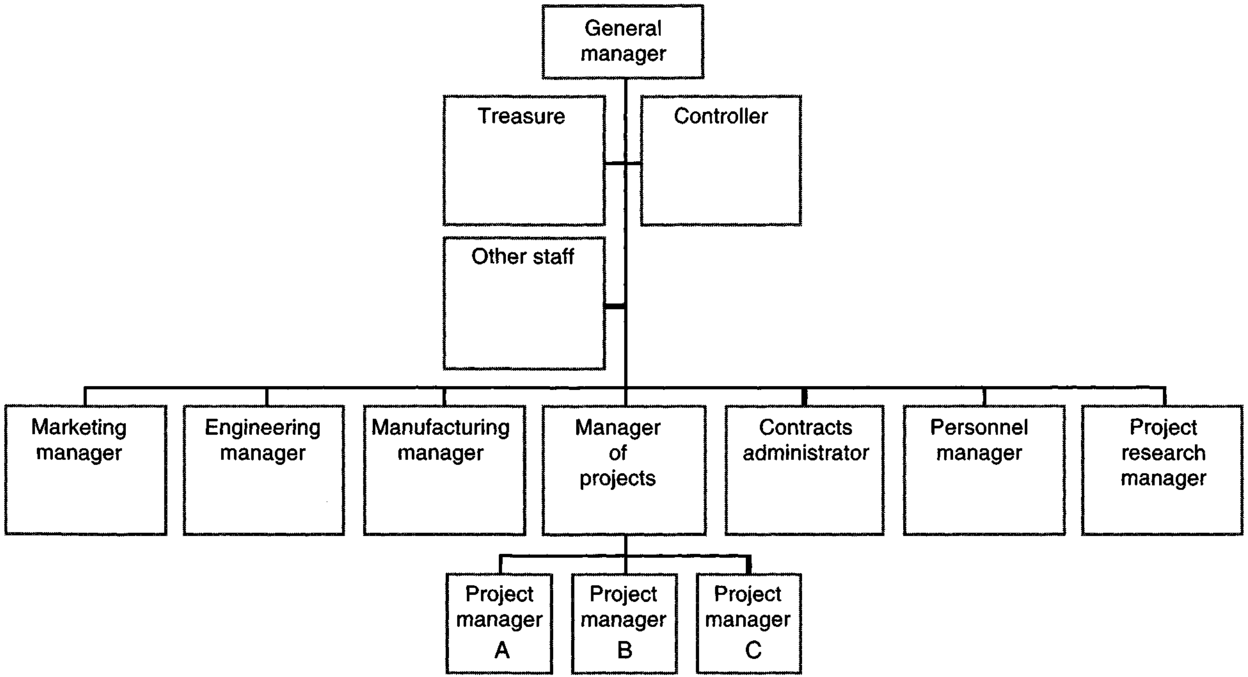

Fig. 67.12 Project matrix organization structure.

major change was an extensive effort to improve productivity and quality, which led to the development of appropriate informal management systems.

The improvement effort really began on July 10, 1987. A multidisciplinary ad hoc team chaired by the division manager was formed. Membership consisted of various individuals from all levels of both organizations. The team concept was supported both by the customer and by Hughes management, which had agreed to "work together" to meet the challenge that faced both organizations. As a result, both Hughes and customer were called upon, as needed, to resolve issues immediately. At first, the *purpose* of the improvement team and the project was clearly established. Specifically, the project purpose was restated as "to *produce high quality products at low cost, on time to meet the customer's complete satisfaction.*" The team was to assist in achieving the purpose. The following operative *values* were explicitly established in direct support of the purpose:

1. Each individual will respond to meet his or her customer's needs.
2. Each individual will be responsible for the quality of his or her output.
3. Each individual will support other members.
4. Each individual will continue to improve his or her performance.
5. Ad hoc *project improvement teams* will be utilized.
6. If problems arise, individuals will seek expert advice.

Over the next few months, the multidisciplinary team met daily. Individuals began surfacing needs, quality reports were clarified, process plans were clarified, and "skills" training was instituted. A great demand began to be placed upon the "experts" from both companies who were actually able to solve problems regardless of reporting level or subunit assignment.

Management demonstrated support for the establishment of appropriate *interpersonal relationships* by actually establishing more ad hoc management teams. Management utilized appropriate personnel regardless of organizational structure. By *communicating* the new dominant values, the functioning of *networks at all levels* was encouraged. Additionally, past values and norms that were perceived as barriers were changed. For example, previously, if an individual raised a concern, it was considered "complaining" about problems. The new values encouraged everyone to not only "complain" but to "suggest changes."

At the same time, informal adaptive management systems were being strengthened by implementing appropriate *informal rewards.* Management presented certificates and team awards and held informal cake-and-coffee celebrations to reinforce the new culture that supported adaptive controls.

In December 1987, the original division level ad hoc team was disbanded and local management teams began to track progress. Informal networks were reasonably well established, and changes had been made in the formal quality and production systems.

In September 1988, work cells (clans) were introduced. Workers were cross-training each other as they informally managed the product through their respective areas. Members began searching for new improvement efforts. As an example, "just-in-time" (JIT) production was introduced into the work flow.

By July 1989, over 1000 improvement suggestions had been received and implemented. The informal control processes were being utilized. The project was able to adapt quickly to schedule changes and to new quality requirements.

Additionally, the *management style* had changed to be more participative in support of the team concept. Consensus decision-making was used, as management more often assumed a *facilitative role.*

Results

Within the period from July 1987 to November 1989, quality defects were reduced from 23 defects/module to .04 defects/module or only *two thousandth* the previous defect total. The project schedule went from six months behind schedule to completely on schedule. The module cycle time decreased from approximately 39 weeks to 5 weeks. Costs were reduced significantly. The local customer representatives stated that the assemblers were extremely enthusiastic and conscientious and that the modules were the best quality that they had *ever* seen.

The improvements were the result of management cooperation, *increased teamwork,* a clear sense of purpose, and "hard work." Management did not just implement improvement teams or new techniques, such as JIT or statistical quality control, nor did they implement a set of improvement projects. Instead, management established the appropriate informal subsystems addressing issues in all five subsystems represented in Fig. 67.2 plus defining a clear purpose, complete with supporting values and beliefs. The result was tremendous improvements in both quality and productivity. Virtually no changes were made in the formal management systems, including the matrix organization structure.

Figure 67.13 displays the changes made in the informal control system of the division to foster the project improvement effort represented in this case.

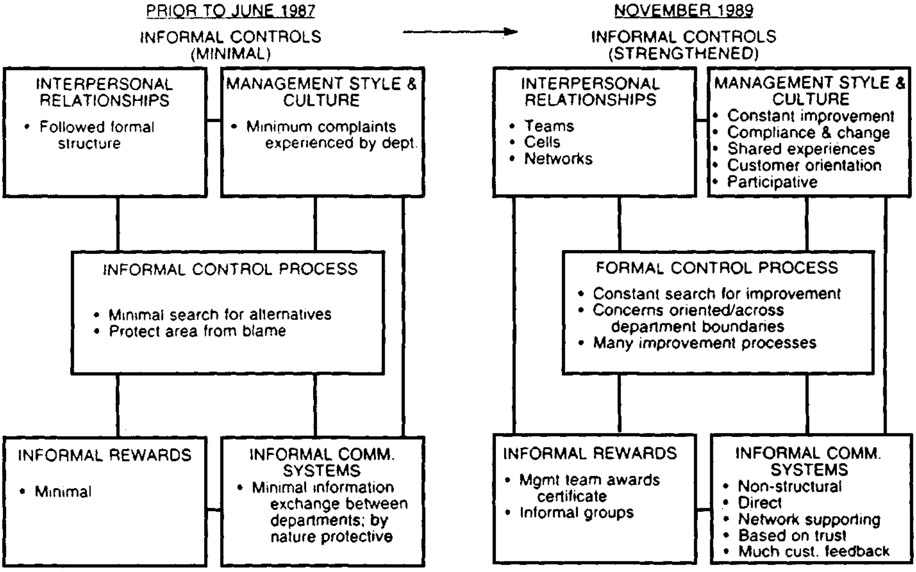

Fig. 67.13 BSY-1 Informal systems: before and during improvement effort.

67.4 SPECIFIC ISSUES IN THE PROJECT-CONTROL PROCESS

67.4.1 Project-Planning and Control Process: Overview

Figure 67.14 summarizes the project-planning and control process. The process provides for planning according to goals and requirements and control by exception. The process is initiated by establishing detailed project requirements, and in meeting them, we simultaneously achieve the goals of a project.

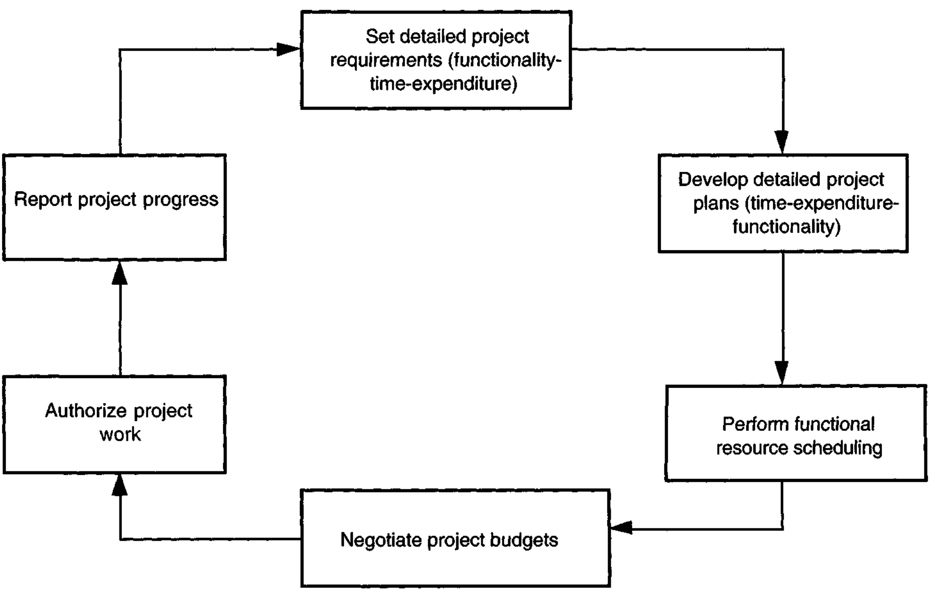

Fig. 67.14 Summary of project-control process.