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PLANNING AND MANAGING FUTURE SPACE FACILITY PROJECTS

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SUMMARY

Human productivity and well-being in space are dependent on the effectiveness with which space projects are planned and managed. To learn how ground-based personnel of a space project plan and organize their work and how such planning and organizing relate to work outcomes, an extensive longitudinal study of the management and execution of the Space Lab Mission Development Test III (SMD III) was performed at NASA Ames Research Center (ARC) in 1976. The purpose of this paper is to provide members of future projects with a view of the problems likely to arise in their organizations and to provide some methods of coping with these problems. After summarizing the conclusions and recommendations that pertain strictly to SMD III management, we focus on the broader context of future space facility projects and indicate additional problems that may be anticipated. Finally, we provide a model of management that may be used to facilitate problem solving and communication — Management by Objectives (MBO). Since MBO has its limitations, particularly when applied to federally funded scientific projects, we also consider some problems of communication and emotion management that MBO does not address directly. We present models for promoting mature, constructive and satisfying emotional relationships among group members. These models are discussed in relation to specific problems that were concountered in SMD III and are likely to arise in future space facility projects.

INTRODUCTION

Human productivity and well-being in space are dependent on the effectiveness with which projects are planned and managed. Effective and satisfying patterns of communication and organization among planning and support personnel, crucial to the effective completion of projects, also influence the morale, confidence, satisfaction, and performance of those who work within the space facility. Ground-based planners and managers must perform creatively and with great technical precision within demanding time constraints. Any failure on the part of ground-based personnel to discern quickly any organizational or technical errors can result in a mission that is fraught with ill-will, low morale, distrust, poor communication, emotional stress and physical illness; in turn, these factors may threaten the safety of the mission. Thus, among the things that must be learned before long-duration manned space facilities become operational is how to plan and manage the ground-based portion of

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such projects so that its members have the ability to develop efficacious communication and effective, satisfying work relationships.

In order to learn how ground-based personnel of a space project plan and organize their work, and how such planning and organizing relate to work outcomes, an extensive longitudinal study of the management and execution of the Spacelab Mission Development Test III (SMD III) was performed at Ames Research Center in 1976. This study, which we will call the SMD III Management Study, summarizes and documents the conditions surrounding the successful completion of the project. Based on findings of the SMD III Management Study, an analysis was performed of the organizational problems that inevitably need to be solved in the planning and managing of a space facility project, and recommendations pertaining to future mission management were developed.

For detailed information on the planning and management of SMD III, the reader is referred to the full report of the SMD III Management Study by Robert Helmreich et al. (ref. 1). That report summarizes and documents the conditions surrounding the successful completion of the project as well as the conclusions and recommendations derived from the study.

This report summarizes the findings of the SMD III Management Study and the analysis and recommendations that were developed as a result of that study. The purpose of this report is to provide members of future projects with a view of the problems likely to arise in their organizations and to suggest some methods of coping with those problems. After summarizing the conclusions and recommendations that pertain strictly to SMD III management, we will focus on what has been learned in the broader context of future space facility projects and indicate additional problems that may be anticipated. Finally, we provide a model of management that may be used to facilitate problem solving and communication — management by objectives (MBO). Since MBO has its limitations, particularly when applied to federally funded scientific projects, we also consider very briefly some of the problems of communication and emotion management that MBO does not address directly. As an example of theory in this area we present Bowen's model for promoting mature, constructive, and satisfying emotional relationships among group members. These models are discussed in relation to specific problems that were encountered in SMD III and are likely to arise in future space facility projects.

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BACKGROUND

A management study was initiated by Ames Research Center to document SMD III (Spacelab Mission Development Test III) activities and problems. The detailed findings and recommendations of this study, which are presented in the formal report of the SMD III Management Study, are relevant to life sciences as well as other scientific participation in future space missions.

SMD III was the third in a series of ground-based simulation experiments designed to test logistics and management procedures for life sciences space experiments. SMD III differed from earlier simulations in that it was a dedicated life sciences mission; that is, most of the experiments on board dealt with humans or animals. All three simulations were conducted at Johnson Spacecraft Center, Houston, Texas. Most of the life science support is at Ames Research Center, however, so it was decided to make SMD III a collaborative effort of Johnson Spacecraft Center and Ames Research Center. Ames responsibilities were: to propose human and animal experiments for inclusion in the test; to develop the hardware for the experiment and integrate it into the experimental racks; to deliver the payload of equipment to Johnson Spacecraft Center; to develop documentation procedures for life sciences experiments; to conduct crew training for the Ames experiments; and to provide crew and management personnel as necessary for the successful completion of the project.

Ames Research Center Experiment Proposals were solicited April 9, 1976, and final selections were made after an initial review of each proposal by a joint Johnson Spacecraft Center-Ames Research Center committee. The crew was selected and began training at Ames Research Center, first in the individual laboratories of the principal investigators, then in a partial Spacelab configuration. The integrated equipment was shipped to Johnson Spacecraft Center on February 14 where it was re-assembled and double-checked in the simulator. The crew then trained on all experiments individually in the final Spacelab configuration. Final training was a preliminary run of 2 days of the actual 7-day simulation. The 7-day simulation began May 17, only 2 days later than originally scheduled. The test was successful: it did not fall seriously behind schedule, and all experiments but one produced usable data. Ames Research Center fulfilled its responsibilities for staff, experiments, and hardware, and the two Centers collaborated successfully in bringing about the simulation.[1]

Another goal of SMD III was to set up and test the operational problems which would be associated with a Science Operations Remote Center (SORC). Since most principal investigators were at Ames Research Center, and the simulation was conducted at Johnson Spacecraft Center, a SORC was set up at Ames which received data from the simulator in Houston for review by individual principal investigators. The SORC concept operated well once the data link was established; there were few data handling problems during the simulation (ref. 1, pp. 3-4).

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[1]The reader is referred to the following sources for more detailed description of the project and recommendations for future spacelab missions: (1) the SMD III Science Management Report, coordinated by John A. Rummel and Paul X. Callahan. October, 1977; (2) Spacelab Mission Development III Test Operations Report, Glen H. Cress III, August 29, 1977 (this report was originated from the Johnson Spacecraft Center side of the project and refers the readers to other Johnson Spacecraft Center reports on SMD III); and (3) two SMD III articles in *Aviation Week and Space Technology* issues of May 9 and June 27, 1977.

WHAT WAS LEARNED BY THE SMD III STAFF AND BY THE MANAGEMENT STUDY TEAM

Project members developed expectations, attitudes, and skills that enabled them to solve the problems that arose and thus to make SMD III a success. This learning would be beneficial if transferred to subsequent projects. In general, effective teams should have continuity of personnel.

Individuals also learned expectations and strategies for coping with organizational problems that can now be avoided, given the insights gained through study of the project itself. Such expectations often persist even when the problems that produced them are no longer present, and can be counter-productive by creating self-fulfilling prophecies and by causing antagonism. This discussion is intended to create a new perspective on the problems that were experienced. It is hoped that this perspective will enable managers to suspend old expectations and eliminate or restructure old problems so that they are easier to resolve.

The SMD III Management Study team examined the communication and organization that existed within the project. By interviewing each project member many times and comparing individuals' expectations of themselves and of one another, it was possible to see the overall configuration of problems in addition to (and by abstracting from) the isolated symptions of problems. We observed that some project members inappropriately transferred habits suited to individual scientific activities to the SMD III team project. We also noted that a short-term team project, such as SMD III, requires new modes of management that reconcile the needs of individual employees with the new overall goals of the team and the organization. Such effective new modes of management were not always established or effectively reinforced in SMD III. Consequently, the project team sometimes labored under emotional stresses that could have been reduced by changes in the managerial process.

We did not observe a lack of ability on the part of the individuals within the organization; rather, we observed a lack of optimal adaptation to the *project mode* of research organization. There developed some less-than-optimal patterns of communication, organization, planning, and clarification of roles between organizational units and within the hierarchical structure of Ames Research Center. This lack of optimal adaptation to the project mode of research and the partial use of old, inappropriate management patterns were virtually unavoidable under the circumstances. That is, the lack of training for project management, the time limitations, and the inadequate staffing and resources inhibited optimal planning and managing of SMD III.

We noted that the Life Sciences Directorate is only beginning to develop the capability to manage space missions. It is only through considerable experience that project management teams *learn* project management. SMD III was the first major effort to create such a learning process for manned missions. The learning process is made difficult by two circumstances:

First, the special problems of managing manned *life science* space missions with on-board experiments are not yet understood. The process that NASA has successfully employed in physical science space projects (e.g., of building a telescope on Earth and shipping it into space where it will probably work) is not entirely appropriate to life science space projects (where the capacity of a living organism, be it a mouse or a payload specialist, to function in space is as yet poorly understood). In its pioneering attempts to do life science research in space, Ames Research Center must define the special needs of this research and find management mechanisms for meeting them. Ames must not allow itself to be forced into management modes and time constraints that are found to be incompatible with the successful conduct of life science research in space.

Second, since its beginning in late 1961, the Life Sciences Directorate at Ames has operated largely as an academic-type research organization. The autonomy of scientists has been recognized as an important condition for the stimulation of individual scientific accomplishment. Now, however, the availability of the Space Shuttle and Spacelab has created the opportunity for dedicated life science missions, and such missions will require a *project mode* of operation. The skills of managing individual scientific programs are not necessarily the same skills needed for managing team projects. The Directorate lacks a highly experienced team of project managers and an overall management scheme that supports the project mode.

The success of SMD III is attributable to the extraordinary commitment, ability, and creativity of its project team. It is hoped that this discussion will pinpoint some of the problems encountered so that future project teams can confront those problems more directly and create a more workable context for carrying projects to satisfactory completion.

HOW TO USE THIS DISCUSSION

Remember that the problems and proposals presented here pertain to plans for future spacelab projects, projects that will be more complex than SMD III.

Use the ideas presented in this discussion to identify possible problems in future projects. The points raised here are suggestions of where to begin problem solving in project planning and management, rather than firm recommendations or conclusions that might guide any or all management activity. This analysis expands on the recommendations contained in the SMD III Management Study by suggesting a broader view of the problems and recommendations that pertain to space mission management. No attempt is made to list all potential problems or solutions.

Consider using the models of rational and emotional management processes that are presented here as complementary ways of enabling members of a project to take responsibility for creating and coordinating a team effort. Neither model can be implemented exactly, but one model can be used to complement the other.

The first model, management by objectives, provides a rational plan for development of broad-based decisionmaking, planning, evaluation and control in organizations (refs. 2, 3). Ideally, management by objectives (MBO) begins with top management, which sets forth a basic goal. Subsequently, at each successive level, members of the organization set forth the objectives, roles, and tasks required of them if the basic objective is to be achieved.

The second model, Bowen Family Theory, describes emotional dynamics of enduring groups and organizations and provides guidelines for creating communication (social and emotional patterns) compatible with the broadbased decisionmaking system established through MBO (ref. 4). If MBO were to work perfectly, that is, from the top down and with the full support and participation of top management, there would be relatively little need for understanding and managing the emotional dynamics of the project group. In most organizations, however, MBO must be instituted in imperfect ways at lower levels of management. The resulting communication "cut-off" with top management creates problems and insecurities that must be remedied if the project team is to function optimally. Bowen Family Theory explains dynamics of the emotional ties that develop in enduring groups. It indicates how mature and constructive emotional processes can be established and reinforced in groups, and how to open communication with "cut-off" persons higher in the hierarchy.

PROBLEMS THAT MUST BE CONFRONTED IN FUTURE PROJECTS

Below are outlined two major kinds of management problems that require extensive managerial experience and autonomy if they are to be solved efficiently: problems of project planning and problems of role clarification. These problems are likely to arise in any real (as opposed to simulated) space facility project.

Problems of Project Planning

Four major problem areas in project planning that require further attention are: price estimation, documentation, career development, and time lines for work to be performed in space.

1. *Realistic price estimation* must be done when the initial project budget is being prepared. Congress is requiring stricter accountability and budget overruns cannot easily be made up from other funds. Incorrect budgeting will badly weaken projects. Realistic price estimation calls for total team commitment to the project; that is, close, deeply committed working relationships among principal investigators, engineers, and managers — relationships that did not emerge in the early stages of SMD III. A related problem that has plagued other NASA projects is that cuts or redistribution of funds, subsequent to project planning, force a project to operate on a lower budget than originally planned. Contingency plans are needed for setting priorities and reducing the scale of projects if necessary. By planning these contingencies ahead of time, political in-fighting and poorly considered compromises become less likely should budget cutting occur.

2. The role of *documentation* should be carefully thought out at the beginning of project planning. Documentation is the memory, recall, and selective attention system of the project, and should be developed so that it performs these functions with maximum efficiency. (In contrast, in SMD III the formal control documentation procedure inundated project members with all tentative plans, and with all changes in plans.) Informal planning and integration of payloads by the project engineers or managers need to be carried out in consultation with the documentation specialist. Informal documentation, as well as control documentation, should be flagged to get the attention of those whose attention is required. There must be a cooperative relationship between project managers and the control documentation officer so that experiment-requirements documents are completed by the time they are needed by others (such as those who monitor contracts for hardware development), and so that nonessential preliminary information does not get included in the control documentation.

3. *Career development* planning needs to be made explicit in future projects. In SMD III, some project members perceived that their position in their regular organizational unit would be jeopardized by participation in the project, and their performance was impaired as a consequence; however, there was no avenue for exploring or resolving these matters. Although projects are temporary, they are potentially important to career development; therefore, the special employment problems connected with project participation must be made explicit. The risks, rewards, concerns, goals, and uncertainties of the project should be discussed by management and project personnel at the outset of the project and periodically thereafter. Contingency plans must be developed jointly that enable management and staff to reduce risks to self and to NASA, to increase the rewards to all, to clarify concerns, and to deal with the uncertainties as wisely as possible. For example, as the project progresses, personnel should be assisted in preparing for professional alternatives beyond the project. There should be clear-cut priorities so that project staff reductions resulting from budget cuts could be anticipated.

4. *Time lines* based on Earth-ideal estimates create unrealistic expectations of personnel who perform work within the space facility. Appropriate time lines must be established for on-board work, allowing for space conditions and the crew's inexperience in working in such conditions.

a. In this regard, appropriate goals, lead times, staff, and budget, must be established so that man-machine engineering can be done properly and so that life science procedures can be adapted to Space Shuttle conditions. Before the project is budgeted, ideal zero g working conditions for the payload specialists must be defined. Man-machine problems and problems of adapting scientific procedures to space must be considered during all stages of payload development.

b. Realistic contingency time lines must be established so that unexpected scientific findings can be responded to. The purpose of manned scientific missions is to provide a system component — a person — who is able to respond to the unexpected scientific event. Yet time lines typically do not take such contingencies into account.

c. Overall time lines need to be established by making broad-based decisions that take into account the entire sequence of tasks that must be performed at each level of the project. To ensure that overall time lines and specific subsets of time lines are reasonable, experts from prior projects should be identified and queried early in project planning.

Problems of Providing and Reinforcing Clear Roles

Five major problem areas of role clarification that require further attention are: creating general role clarity for all project personnel, clarifying the long- and short-term roles of persons whose work crosses organizational boundaries, clarifying to principal investigators the nature and degree of commitment that the project will require of them, clarifying and supporting the role of project engineers, and clarifying and monitoring roles of non-NASA project personnel located at non-NASA locations.

1. In general, project managers need to develop highly sensitive ways of clarifying roles and enabling persons to fulfill needed roles. There are three main ways of doing this: through selection and placement procedures, through communication and leadership training, and through job redesign.

a. Selection and placement. The manager needs to reassess from time to time whether given individuals are best suited to the roles that have been assigned to them and make reassignments accordingly. Because of an individual's personal characteristics or the character of his permanent position in the organization, it may be difficult to accomplish a given role, whereas another role might be fulfilled with ease.

b. Communication and leadership training. Most individuals find it difficult to communicate across organizational boundaries or with individuals with whom role relationships are not clearly established. This is particularly true for projects in which communication lines and project objectives have not been made clear throughout the organizational hierarchy. There are many types of training in communication and leadership that enable individuals to overcome normal inhibitions about communicating under difficult and disagreeable conditions to create channels of effective communication and to get the job done effectively. Ideally, managers should have knowledge and experience with such programs so that they can recommend them to others as needed.

c. Job redesign. As a project develops, the magnitudes of individual's roles expand and contract. Managers need to be aware of these changes, and should be prepared to redesign roles and re-delegate responsibilities when appropriate.

2. Major projects inevitably cross organizational lines. Thus, the various individuals working within a project have different kinds of nonproject responsibilities (e.g., commitments to ongoing programs, permanent job descriptions, possibilities for promotion or transfer, and so on). Project managers need to be sensitive to these differences among persons.

3. Principal investigators need to know what kind and how much of a commitment they are expected to make to the project. They need a clear understanding of the risks and rewards involved. This information should be communicated at the time project research proposals are solicited and again when preliminary proposals are accepted. The character of the required commitment should be made clear in a formal written document, and should be restated and discussed by the individuals who administer or supervise the proposed work. Supervisors should make it a point to learn what other responsibilities the principal investigator is likely to have at the time of involvement with the project. A two-state peer review process such as the following should be instituted.

Initial proposals should be solicited that outline the theoretical importance and general procedures and hardware required. These proposals would be evaluated both by a peer review committee, for scientific merit, and by a technical committee, for feasibility and problems of integration with other candidate projects. If the solicitation shows that there is an extremely high level of peer review, peer collaboration, and intensive peer cooperation and problem solving throughout the project, people will be discouraged from submitting poorly thought out or dishonest proposals. They will see that any lack of integrity will be found out and cause them professional embarrassment with both government administrators and their academic peers. Proposals could be ranked within four broad categories: (1) not scientifically worthwhile, (2) not technically feasible, (3) worthwhile with technical or other modifications, and (4) worthwhile and feasible as proposed. It should then be possible to group proposals by theoretical or methodological similarity and to ascertain overlap between studies. At this point, communication could take place with principal investigators whose proposals were ranked as category 3 or 4. In particular, recommendations could be made that investigators sharing theoretical or methodological approaches, consider an integrated proposal and that further integration with a NASA principal investigator be explored. It would be appropriate and highly desirable to provide limited funds to principal investigator candidates for such activities.

This recommendation for encouraging collaboration is made in the realization that collaboration may be counter to the research style of many scientists and that collaborative work may tend to seek the lowest common denominator of scientific excellence. It is felt, however, that the nature of research in Spacelab requires a high degree of teamwork and that the development of a team approach may be more effective if the principal investigators play an active role in the process rather than having such a structure imposed after the selection of an experiment for a mission. It is felt that the scientific integrity of joint proposals can be maintained by having this preliminary integration and modification take place before final peer review for acceptance.

After principal investigators with proposals in categories 3 and 4 have responded to initial feedback and submitted revised and more detailed proposals, final scientific and technical review and acceptance or rejection could take place.

It is also recommended that additional scientific review by peer committee take place after acceptance and before flight simulation to evaluate the effect of integration and later modifications on the scientific worth of the study.

The essence of these recommendations is that scientific review and integration of the battery of experiments proceed hand-in-hand and that principal investigators be included in the process during the review and early modification stages. The fostering of communication between potential principal investigators and program management early in planning should also aid in the creation of an effective research-management team (ref. 1, pp. 67-68).

4. Special planning and sensitivity are needed to enable project engineers to secure the full cooperation from principal investigators and equipment contractors. Engineers need to be given the administrative and fiscal authority necessary to accomplish tasks prescribed by the principal investigators. Failure to give engineers sufficient authority will result in failure of the project to meet its time lines.

5. Special effort is needed to clarify and monitor roles in NASA-non-NASA collaborative groups. The authorities and responsibilities of each role must be clearly defined so that roles can be understood by all and filled by others if existing personnel leave the project.

There are many situations within a project that require highly organized planning and extensive role clarification. The following three situations are presented to illustrate this need.

Example 1: Directors of subprojects (i.e., scientists, engineers, and others in charge of individual components of the project) lack the authority and often the ability to integrate their projects with the rest of the payload. It is essential to have a senior project manager who can direct this work and clarify the planning and role relationships required to facilitate integration of subprojects. Senior managers are needed who can accurately budget the work, create realistic time lines and develop the experiment-requirements document describing exactly how the project will be carried out. The scientist who is inexperienced at project management serves primarily as a consultant; the project manager takes responsibility for making the scientific project operational in space. The project manager essentially trains the scientist in management of his own program. If the scientist is involved in a series of missions, he may not have to rely as much on the project manager in later flights. In any case, however, there is a need for project managers who are experienced in price estimation, creation of contingency budgets to handle budget cuts, documentation of the experiment, communication of exact commitments to all involved in the project, reviewing and monitoring at all stages, and creation of appropriate time lines for all phases of the project.

Example 2: Matters internal to NASA may arise that cause project members to withdraw some of their time and energy from the project. Such matters might include reorganization and reduction in force, possible relocation of NASA employees to other Centers, and the start of new projects. In such cases, project management must know how to revise plans quickly and direct others to fill the roles that are vacated.

Example 3: When personnel take on increasingly complex roles that gradually change in the course of the project, they need a means to create new role agreements with the other personnel. Conflicts must be resolved between taking the initiative (and perhaps taking on roles that ultimately do not serve the project) and continuing with old role agreements (which may become dysfunctional as role requirements change). The project team must have rescurces for planning and role clarification that are adequate to these tasks. Management by objectives offers such a resource.

MANAGEMENT BY OBJECTIVES

Management by objectives (MBO) is an effective way to communicate and coordinate activities within a project or organization. If carried out as prescribed, MBO would be a significant help in resolving the problems identified in the previous section. Unfortunately, MBO is difficult to implement in government agencies that conduct and direct scientific and engineering programs. MBO, as operationally defined, is results-oriented. MBO works well when the output is fairly tangible, the method of production well defined, top management is clearly committed to the product, and the commitment is appropriate to the budget. However, there are two major reasons why these conditions do not hold for large scientific projects that are budgeted by Congress and managed by a government agency.

First, objectives are rarely clear. Government agencies challenge managers to discover the main objectives of their programs. Congress often changes its views, hence managers cannot be sure where programs are heading, how they will get there, and how performance will be judged. Top management within agencies is often more concerned with influencing Congress than with formulating, communicating, and supporting the agency's objectives.

Second, MBO requires that communication and planning flow downward in the hierarchy in a systematic way, but in scientific projects, in which creativity and discovery are vested in the individual scientists, the flow is predominately lateral and upward, rather than downward. The literal application of MBO ground rules to a space science project might result in inappropriate planning and gauging of progress. Top management might set goals that would prove unworkable. Inappropriate yet easily quantifiable measures of progress might be used rather than measures that are appropriate yet difficult to quantify.

Thus, the value of MBO in space projects lies not in its literal application but in the conceptual tools it offers for understanding what needs to be communicated (upward, laterally, and downward).

The purpose of this section is to show how the basic planning of SMD III might have occurred under a system of managing by objectives. MBO is now widely known to NASA managers and is described in various publications (refs. 2, 3, 5).

Managing by objectives involves top managers devising long-range goals and having subordinate managers establish the corresponding objectives for their departments or units. After top management approves the objectives developed by its subordinate units, the process is passed on to the next lower unit and ultimately down to individual employees. Since all employees participate in defining roles and standards for themselves, it is clear who is responsible for enacting each role that is defined. Finally, each role is integrated into the career and manpower planning of the organization. All individuals are clearly rewarded for their commitment to the objectives and to their own development in roles they helped define.

Managing by objectives is not rigid. It is a *context* within which people plan in an organized way and get feedback on their progress. There are frequent reviews. Objectives and roles are changed as required by the emerging problems that are identified. The system's advantage does *not* lie in creating task structure or roles. Rather, a system is established for continually restructuring and reevaluating so that dysfunctional or ambiguous working relationships are quickly identified and remedied. A second important function is creating a clear understanding throughout the organization of each individual's responsibility, so that the source rather than the symptoms of problems can be addressed. A third and perhaps most important function is to provide a system of broad-based decisionmaking whereby individuals contribute by defining their roles in carrying out organizational decisions. This process is shown in figures 1-3 and is discussed below (figs. 1-3 are reproduced through the courtesy of Scott, Foresman Company, publisher of ref. 3). This is a well-known way to improve the quality of information and thus to improve the decision processes of an organization. It also increases the level of motivation and commitment of individual employees. We turn now to the application of MBO to space facility management.

The Value of MBO

As mentioned earlier, managing by objectives requires a total commitment (limited only by resources) to a clearly defined goal by managers at all levels of the hierarchy. This kind of commitment at higher levels of management rarely exists anywhere and, as suggested previously, certainly not in scientific projects within government agencies. However, it is useful to understand the planning and communication that maximally facilitate goal fulfillment, even if such planning and communication are incomplete.

Project personnel need a conceptual framework for understanding the *ideal* pattern of communication, so that they can predict how the pattern will be disrupted when the information flow has failed at some level in the organization. The daily demands of running a project are so great that managers often do not have the time to discern disruptions in the overall flow of communication unless they know just what to look for. With a conceptual framework of how information *should* flow, one can recognize when "upstream" problems are developing, how they will affect one's own work, and how to resolve them before they become crises.

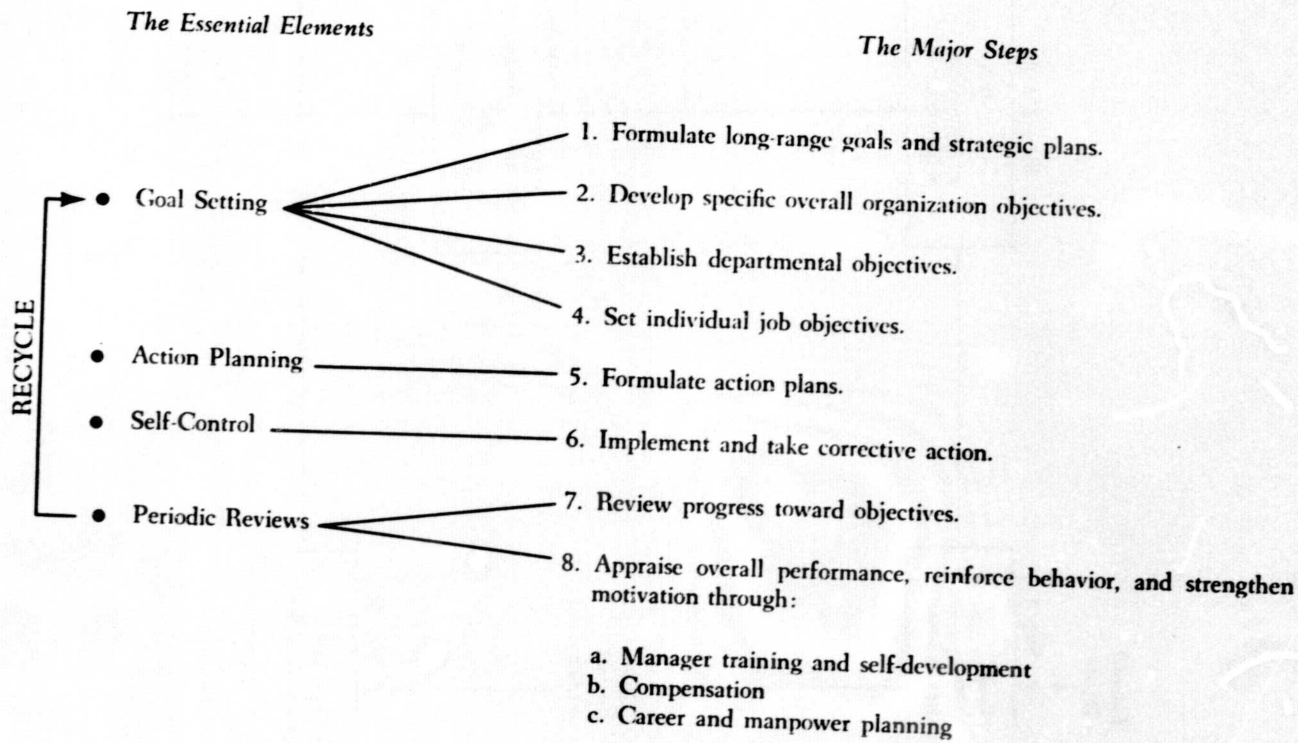

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Figure 1. - The MBO process.

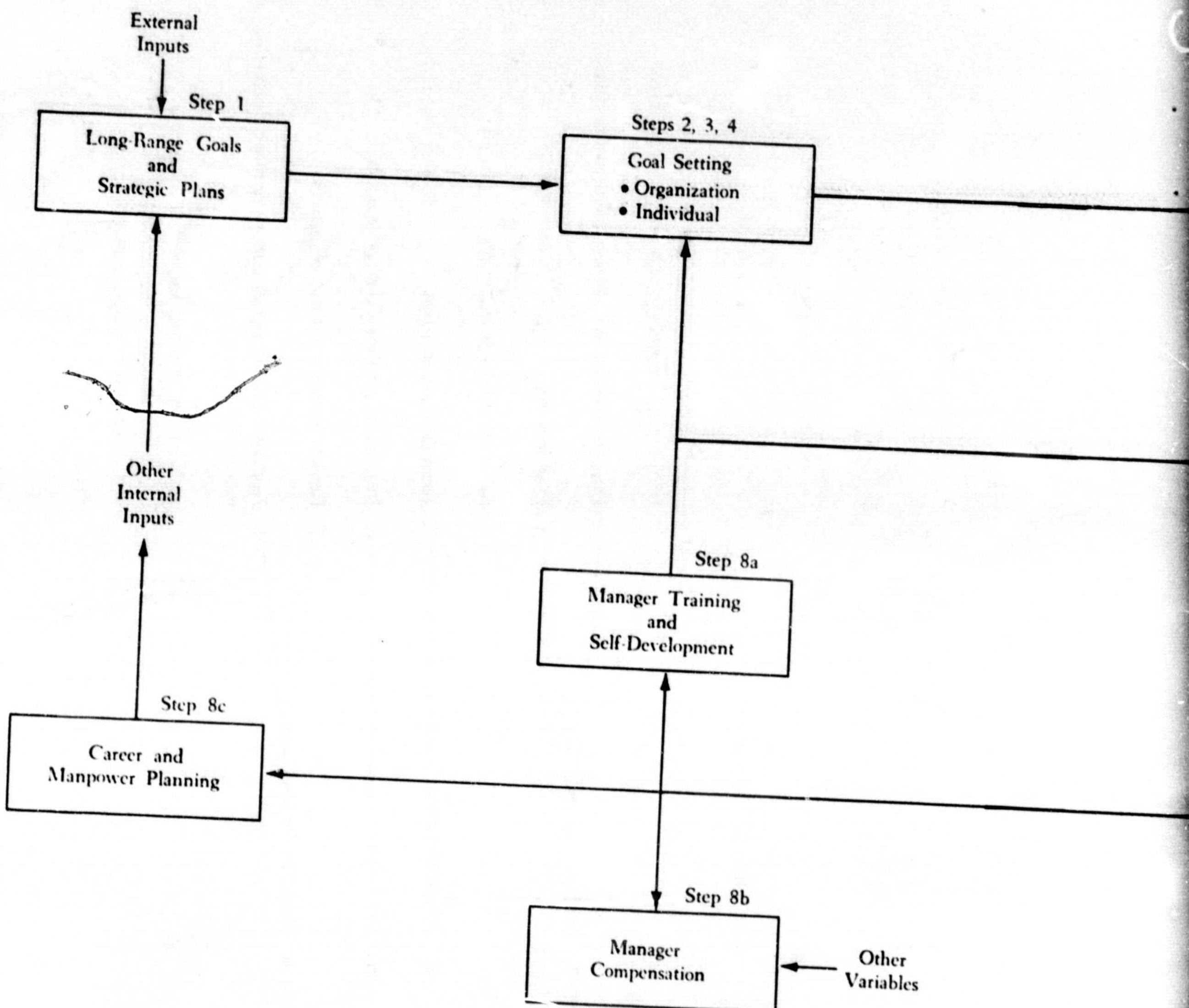

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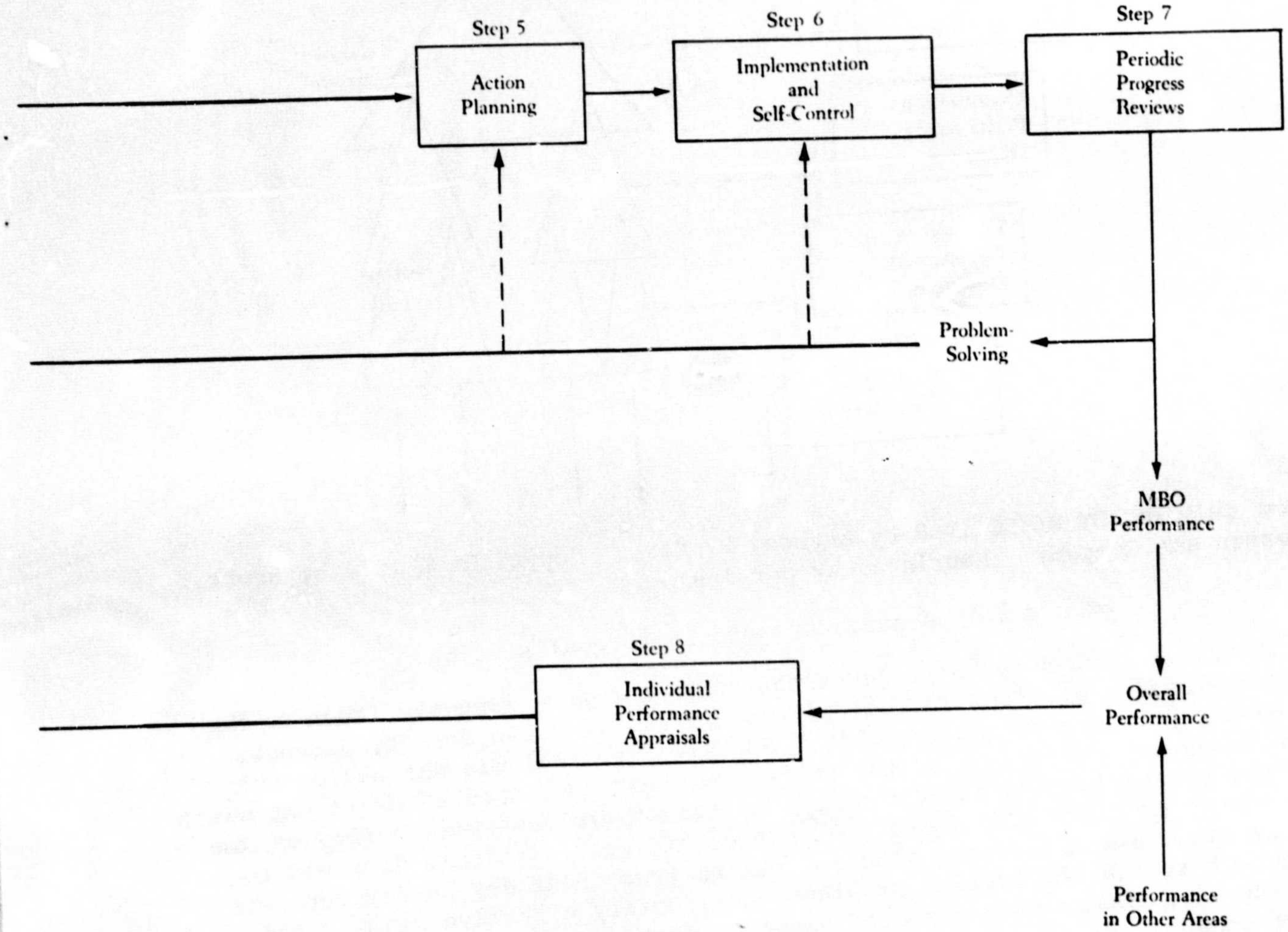
Figure 2. - MBO as a system.


Step 5
Action Planning
Step 6
Implementation and Self-Control
Step 7
Periodic Progress Reviews
Problem-Solving
MBO Performance
Step 8
Individual Performance Appraisals
Overall Performance
Performance in Other Areas

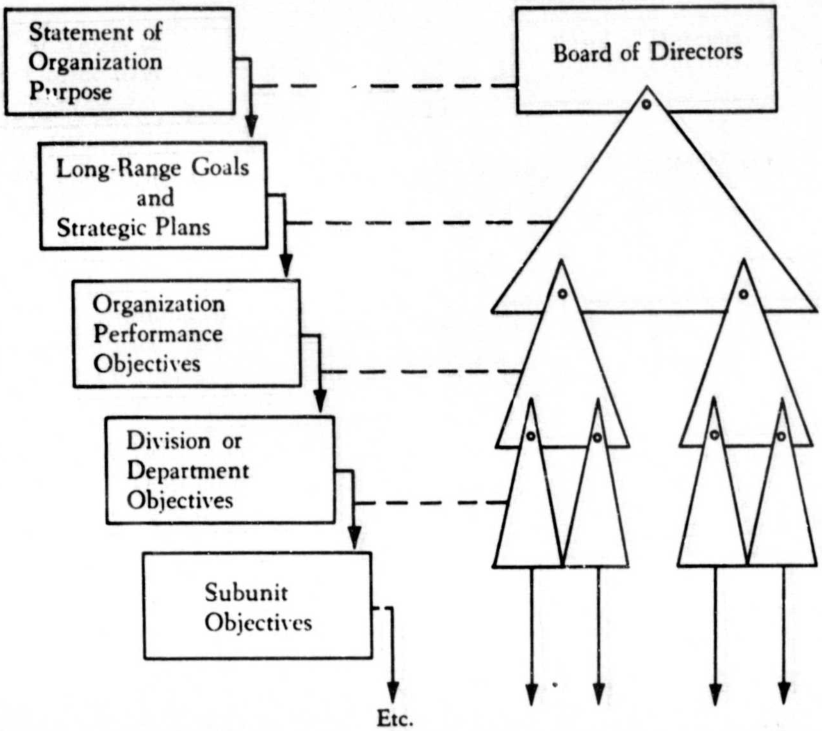


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Figure 3. - A cascade approach to goal setting.

If all participants in projects can share a common language (such as MBO) for understanding problems in communication flow, they can detect, discuss, and resolve problems far more easily. SMD III personnel did not share such a common language. For example, the project manager developed an excellent sixth sense for perceiving and understanding "upstream" problems before they became serious or disruptive. He found that one of his most difficult jobs was to persuade other members of the team to look up from their day-to-day concerns long enough to see the broader problems and identify effective ways of handling them. A common understanding among project personnel of the desired flow of communication would have facilitated problem solving and decision-making.

The Organization of this Discussion

In chapters 1 through 3, of reference 3, pp. 1-45, there is a detailed conceptual overview of MBO. The concepts discussed in those first three chapters will be used extensively in this discussion. The four essential elements of MBO are: (1) goal setting, (2) action planning, (3) self control, and (4) periodic reviews. There are eight major steps in carrying out these elements. The four elements and eight steps are illustrated in figure 1. In figure 2, these components of management are integrated into a system of management activities. Using this framework, we will now examine the management activities of SMD III to see what planning and communication actually occurred and what would have been constructive but did not occur.

The Flow of Goals and Responsibilities in SMD III:
Steps 1-4, Figure 3

1. *A long-range objective* (e.g., over five to ten years) of NASA and of the Life Sciences Directorate at Ames Research Center is to become an operational facility for originating life science research that will be performed on Space Shuttle missions. Top management at Ames and at Headquarters, however, has neither made this objective explicit, nor discussed any of the uncertainties about this objective. Clearly, long-range objectives, uncertainties about reaching objectives, and contingency plans for the agency and its employees can be discussed meaningfully only if Headquarters and Ames are aligned in their general goals and are actively engaged in a cooperative, open working relationship.

This failure to establish common goals and an open working relationship clearly influenced the team effectiveness of SMD III. For example, some principal investigators did not organize their work to meet NASA's long-range objective. From the interviews with individual principal investigators, it appears that some came up with various possible interpretations of the ambiguity: (1) some did not believe that Ames Research Center actually would devote itself to the long-range objective and hence believed that SMD III was an exercise in futility; (2) some believed that Ames would not reward those who devoted themselves to this long-range objective as opposed to the traditional objective of doing individual scientific research, and hence believed they would be risking their careers by devoting their energies to SMD III rather than to their own individual research; (3) some believed that the project mode of research simply was not much different from individual research, which would lead them to hold an unrealistic view of what was required of them to create a successful SMD III "mission."

These interpretations were not unreasonable. Indeed, SMD III was not given a clearly defined budget, and there were no dedicated life-science missions slated for the immediate future. Some principal investigators who dedicated themselves to working on SMD III as requested found themselves in trouble when they returned to their own individual research projects — many were held accountable for failing to keep to original schedules for their individual research and their future research budgets were jeopardized. Finally, the differences between a project mode and business-as-usual were not explicitly discussed.

By failing to be clear about its long-range goal, top management created a setting for confusion. Individuals did not know where to place their commitment; lack of clarity placed unnecessary work and stress on everyone concerned.

How could top management have been clearer? Of course, no one can be certain what kinds of budgets Congress will give to NASA for future space missions. How, then, should top management communicate its basic goals? The problem is actually little different from that of most businesses where market factors are unknown. What is required is that top management continually explore and communicate with NASA employees the indicators by which one can estimate the probability that the Agency's goals are reachable. Indicators in the *external environment* that predict whether Congress and society will support or fail to support Ames Research Center's goal may be assessed. These indicators include national goals of science and government, availability of budgetary support and current public evaluation of NASA's programs. When these indicators reveal ambivalence toward NASA's program of science in space, top management should communicate this clearly. Middle management could then create flexible career ladders so that principal investigators would allocate some time to both individual and project research. In short, management should acknowledge uncertainty when it exists.

Top management needs to assess its resources and weaknesses in relation to the task of meeting its goals. Are its facilities adequate? Is its research activity configured appropriately? Do its scientists know what is expected of them? Is goal setting systematically coordinated with performance appraisal and reward?

The answers to questions about whether the external and the internal environment can support a major new goal are often ambiguous. But the questions should be asked, and the answers — however ambiguous — should be communicated explicitly to the rest of the organization. Unclear indicators of the probable success of the organization in meeting its goals should not be ignored. Unclear indicators call for explicit communication and contingency planning, that is, planning of alternative uses of resources and alternative career ladders.

In the absence of explicit communication and contingency planning, as was the case with SMD III, individuals are left to second guess top management and do their own covert contingency planning. The result is harmful to the individual and to the organization, in terms of lack of coordination, lack of commitment, and low morale.

2. *The specific objectives of the organization* — (Step 2 of MBO as shown in fig. 1) are objectives decided upon by upper management that promote the long-range goal of the organization. In the case of SMD III, no specific overall objectives were set forth. It can, of course, be argued that the objectives of SMD III were to evaluate the feasibility of Ames Research Center project administration, to collaborate with Johnson Spacecraft Center, to establish a remote operations center, and to initiate on-board animal experiments. For purposes of MBO, however, this statement of objectives is incomplete. Although it may have been adequate for top management, it failed to guide project management or the individual principal investigators. Their objective had to be the successful conduct of these activities.

Whatever the objectives — to evaluate or to succeed — the statement gives no indication of how to judge the degree to which the objective was met. What specific, verifiable things were to be done? How would one determine whether they were done satisfactorily? Not all objectives can be fully developed before a project begins. Nevertheless, all objectives should be stated clearly and revised or elaborated as deemed necessary in the course of periodic reviews.

The specific objectives of SMD III were somewhat different from the business objectives discussed by Raia (ref. 3). The objectives of SMD III were not to develop and market a product. The product involved the simulation of life science space mission research involving large numbers of on-board animals. To manage by objectives, upper management would have needed to state explicitly the expected products and processes. The criteria for successful completion of experiments should have been stated. These might have included: payload specialist research procedures deemed satisfactory according to pre-stated criteria worked out by the principal investigators, principal investigator experiment development that met the pre-stated criteria set by the original review committee and by the project engineer, and so on. Likewise, major criteria for judging the effectiveness of the remote operations center and the effectiveness of the collaboration with Johnson Spacecraft Center should have been developed.

The final objective — development of an effectively managed project — is the development of a process and of new skills within project personnel. How can this be stated in terms of specific objectives? Since processes are less tangible than products, the specification of objectives is somewhat more subtle than that described by Raia. What must be specified are the information that is to be developed and communicated, and the pattern in which it is to be developed and communicated.

In the discussion that follows, suggested sets of objectives for developing an effective management process are set forth, in the cascading form suggested by Raia and illustrated in figure 3. To be acceptable and motivating to the members of an organization, objectives must, of course, be developed by the organization's managers at each level, not by the authors of this discussion. What is offered here is merely an example of what might be developed.

It is suggested that the following specific goals be set forth by upper management. These, in turn, would be developed into performance objectives by each appropriate subunit, and further broken down into specific tasks and roles for individuals.

3. *Specific project objectives* (Step 2 in figure 1 or Step 3 in figure 3).

   a. Define and communicate explicitly to all potential participants the commitments required of personnel in the project mode. Include explicit communication about the collaboration required among people from different parts of the project (e.g., between engineers, managers, principal investigators, trainers, payload specialists, control documentation personnel, shop workers, procurement personnel). Include recognition of the organizational boundaries that must be crossed to accomplish this collaboration and the difficulties of doing so. Include analysis of the autonomy and cooperation, time commitment, and new skills that are required for optimal performance, as well as analysis of new environments and problems that individuals will have to face.

b. Define and communicate explicity to all potential participants the risks and rewards of involvement in the project mode. Include the risks of having the mission or one's part in the mission cancelled, the risks inherent in sharing research facilities with others on board the shuttle, the risks of having to learn new skills, and so on. Include the rewards that management has planned in terms of new career ladders, performance evaluation opportunities, new training, and new status. The ways in which one may view risks as potentials for rewards should be communicated as fully as possible. Periodic employee-management meetings should be held to ensure that perceptions of project risks, rewards, and uncertainties are shared and are as accurate as possible.

c. Define and communicate explicitly to all potential participants the possible conflicting institutional demands that may be placed on them and the steps that can be taken to resolve these conflicts. Define conflicts between overall NASA organization and project organization, between organizational management and project management, between individual principal investigators' resources (equipment and budget) and project resources, and so on.

d. Define, organize, and participate in broad-based decisionmaking using the system of managing by objectives. Define the lines of authority and the role definitions, indicating who occupies each role at each level of the organizational hierarchy. Define the sources and flow of information so that individuals can obtain the information needed for decisionmaking. Designate the needs for travel, phone, video, etc., to handle communication and dissemination. This means defining a system of managing by objectives as illustrated in figure 2 and described by Raia (ref. 3). Steps 7 and 8 in figure 2 are crucial: specifying the steps and schedules needed to create regular and objective feedback to each project member, flexible problem solving, and regular opportunities for career development and reward. The flexibility with which the system can respond by identifying and solving problems and rewarding individuals should be assessed formally on a weekly basis.

e. Develop criteria for deciding what roles call for NASA employees and what roles call for outside personnel.

4. *Group objectives* — (Step 3 in figure 1 or Step 4 in figure 3). Each of the specific overall organization objectives previously described is to be translated further, by each group, into objectives of the activities of that group. We will not continue here to list possible overall objectives or to break these down into organizational objectives and individual objectives. The managers and staff of future projects are best qualified to select their own objectives.

THE USE OF MBO WITHIN NASA PROJECTS

What we have done so far is to give examples of ideal patterns of communication within the MBO model. Managers who understand the MBO model and who have a sense of the pattern of ideal communication that enable people to agree on goals and activities and keep one another apprised of progress can manage by objectives. They do so by using the MBO model to discover what kinds of objectives, planning, and review are needed and by *initiating the communication at their level*, directing it upward, downward, and laterally as appropriate. This, of course, does not result in the orderly flow suggested by Raia, but it does result in communication and problem solving.

To initiate management by objectives from the level at which the need for communication is perceived, various problems must be overcome. The two main problems are (1) learning to perceive what objectives need to be set and how they should be communicated, set, and reviewed, and (2) learning how to communicate when channels have not already been established and communication is not expected. These problems become easier to solve when workers understand how MBO functions ideally and why *ideal* MBO procedures are impossible to establish with NASA scientific projects.

As mentioned above, the basic MBO concepts are clearly set forth by Raia and a sense of some of the modifications needed in projects in the public sector can be gleaned from Morrissey (ref. 2). Managers who wish to take the initiative to implement MBO at their level need to take steps to sharpen their perception of the problems that may arise. Managing a scientific project involves far more than production of things. It also means developing practical systems of activity and of anticipating services and safeguards that are ancillary to the ultimate product or activity (e.g., systems of safety, fireproofing, and so on).

How can one anticipate what activities will be needed? The following are suggested ways to brainstorm:

1. Refer to documentations of previous scientific projects, such as SMD III, to gain familiarity with the kinds of activities that have been involved. By analogy, determine whether similar activities will be required to complete the forthcoming project.

2. Discuss and explore percentions of the problems that are likely to arise in the forthcoming project with persons who have worked on other space facility projects.

3. Note the kinds of management problems and solutions that are discussed in books on scientific management such as those by Morrissey (ref. 2), and Sales and Chandler (ref. 5); note also the management problems that are implied in the discussions of space facility projects, politics, and activities in popular biographical books about space facilities such as reference 6.

4. Share and discuss the objectives developed with coworkers and invite them to develop and communicate their sense of necessary project objectives.

5. Encourage the project director to invite brainstorming of this kind at project meetings throughout the duration of the project.

To communicate effectively with project personnel and with persons in other parts of the organization who interface with the project is another matter, to which we now turn.

COMMUNICATION PROBLEMS IN IMPLEMENTING MBO

Communication problems in the implementation of MBO or other management schemes arise in various ways: (1) MBO is usually not implemented at higher levels of management, so that there is a rift in the communication between middle and upper management and between project members and liaison persons located elsewhere in the organization. This rift is brought about by a difference in values, beliefs, and language connected with planning and management; (2) even persons who have agreed to use MBO may, at times, lapse into other ways of planning and managing; (3) individuals within a project are likely to differ in the style in which they communicate and it is difficult to establish rapport and to communicate effectively with persons whose style is radically different from one's own; (4) some individuals are preoccupied with personal worries about other matters or with private, uncommunicated feelings about the person to whom they are speaking, and this interferes with clear communication about work-related matters; (5) individuals may differ in their evaluation of the importance of various project activities. Any of these five situations are likely to lead to poor communication and planning which, in turn, may lead to errors, coverups, distrust, blaming others, low morale, illness, and so on.

There are various models of communication that offer insight into the causes and consequences of poor communication, and into ways in which communication can be improved. Unfortunately, none of the existing models have been tailored specifically to problems of management. Hence, a set of definitive solutions cannot be given to the communication problems likely to arise in the planning and management of space facility projects. However, Bowen's model of communication is sufficiently general in scope and relevant to project settings that it comes as close as any to offering a useful general blueprint for improving communication in projects.

Murray Bowen, a psychiatrist, regards conflict, breakdown of old forms of social organization, struggle to attain new objectives, and changes in goals as prerequisites to the development of good communication and mature, satisfying relationships. Apparently, those beginning a new project within an existing organization are potentially off to a good start, for these are precisely the conditions under which a new project begins to function in an existing organization. The basic concepts contained in Bowen's model and their application to various kinds of groups and organizations are described by Hall (ref. 4); relevant ideas for program management are summarized briefly here. Bowen's basic premises are:

1. The mental and physical health of a group are revealed in and affected by the way it copes with the conflict between need for deep emotional, social, and organizational attachments versus need for growth and autonomy. For example, a new project within a larger organization needs to function in new ways, yet this interferes with established patterns of relating with members of the organization, and threatens to disrupt previously satisfying relationships and to jeopardize feelings of security. The health of members of the project is affected by and revealed in the way in which they cope with this conflict.

2. The effective response to this conflict is to create appropriate new roles (through MBO), to communicate one's roles and plans openly, to experience and accept the tensions that occur when changing the status quo, and to allow others to resist one's new role, responding to any resistance simply by continuing to communicate the new role. One should not acquiesce to expectations that one will return to the old role, nor should one respond in some dramatic or lasting way to any lack of support received. The difficulty with implementing MBO is that members of the organization tend to resist the formation and enactment of the new goals and roles since these are a threat to the status quo. The effective response to this resistance is to continue to communicate the new roles and expectations, to accept the new role as the legitimate role, to tactfully ignore old role expectations, and to continue communicating the new, legitimate role expectations until they are fully accepted and acted upon.

In contrast, two ineffective ways of responding are (1) to cut off communication with those who threaten one's autonomy (i.e., the enactment of one's new role) and disagree with one's objectives; and (2) to remain in the setting, projecting anxiety on others, scapegoating, labeling others as inadequate or the cause of problems, and making oneself or others weak, dependent, ill, or unable to function.

A major informal role of managers and of individual staff members is to clarify ways in which conflicts or lack of communication are opportunities for growth. Facilitation of communication can be initiated from any or all locations, informally, by any individual who understands how to do so. This includes communication within and between Centers, and between a Center and Headquarters. Communication is facilitated by identifying the inadequacies of the existing communication (e.g., by identifying communication cut-offs within the organization, or identifying those who are "stuck" within the old structure, making themselves or others unhealthy or inadequate) and by helping the persons involved to re-establish communication with coworkers in an effective way. We refer to these as *informal* roles, in contrast to the formal use of MBO. MBO is a powerful formal tool for establishing new roles and objectives and communicating them. It is the "official" way for managers and staff to respond constructively to conflict. MBO makes it easy to grow into appropriate new roles that one creates largely for oneself in consultation with one's manager, coworkers and subordinates. The MBO model makes it legitimate to set up appropriate new roles that alter the status quo. However, more than MBO is needed to enable project personnel to communicate openly. Managers will be more effective if they are aware of the following repeated patterns of behavior in their staff:

1. Resistance to change in the roles of others who wish to change roles; for example, failure to acknowledge new job titles or reporting channels.

2. Unwillingness to accommodate to role changes brought about by the loss of a member of the group.

3. Resistance by another to the role changes of individuals who must play multiple roles.

4. Unwillingness to communicate with persons who resist one's own efforts to take on new roles, a failure to resist old role expectations, or expressed conflict over roles.

5. Resistance to mutual planning or discussion by persons anywhere in the hierarchy, especially by persons at higher levels who do not wish to encourage those below them to initiate requests, plans, or discussion.

6. Resistance to some specific roles because of incompatibility between individual goals and project or organizational goals.

Effective leaders identify resistance and bring it into the open. They shape, guide, and reinforce the new roles as required and make it clear that it is everyone's responsibility to shape, guide, carry out, and reinforce the new role relationships that are agreed upon. They also make it clear that these role relationships may be changed, but only by discussion and explicit agreement. Personal decisions to cut off communication, to take on roles that were not agreed upon, or to complain or grow weak within the organization are recognized as disruptive symptoms. All conflict is brought out into the open and resolved through creation of new objectives and roles and through review procedures that ensure that the new objectives are being met satisfactorily. It needs to be acknowledged at the outset and throughout the project that bringing conflicts into the open and agreeing on new objectives and roles causes stress; however, such stress leads to group growth and effective functioning, provided that its members continue to communicate openly and honestly.

Effective managers remember that they must operate by the rules they establish for others. When changes occur in policies, goals, personnel, and roles, managers need to look within themselves as well as within others to see what emotional resistances there are to the changes. They should provide explicit acknowledgement of new roles, goals, personnel, communication channels, and problems. They should find creative ways to acknowledge and reinforce new systems, for example, through new signs, written agendas, changes in location of offices, titles, schedules, distribution lists, group meetings, appointments, access to information resources.

Effective managers recognize that groups grow and change in the course of a project and that this affects the quality of group communication and emotional tone. If the project is planned in a satisfying way in the beginning, group members will thrive on a high level of agreement and esprit de corps. Eventually, however, group members will want to grow in their own roles in ways that call for autonomous decisionmaking, and that will inevitably threaten someone else's cherished status quo. Effective managers are ready for this shift from close cooperation and interdependency to dissatisfaction, striving for new roles and threatening of status quo. They encourage project members to express their perception of need for role change. They encourage the group to be flexible, to remain in good communication about their perceptions of objectives, and to plan and enact new activities without resistance. The group must be reminded that as the project develops, the mark of its success is the group's ability to reflect on its changing roles and goals, to make appropriate choices, and to continue to examine the adequacy of the chosen roles until the new goals are achieved. The group must be reminded again and again that change in one part of the project necessarily produces changes in other parts of the project and that this needs to be accommodated willingly and discussed as appropriate.

The group will never cease to experience conflicts between its need for stability and interdependency versus its need for growth and autonomy. Effective managers convey that this is so, and that the conflict should be cherished and responded to with reflection, communication, planning, and reinforcement of new agreements. It should not be responded to with thoughtless reaction, submission, cut-off of communication, resistance, or rebellion.

Change always results in some stress. The effective manager needs to recognize undesirable patterns of stress management (e.g., submission or cutoff) and to help project staff members to seek more autonomous, planned, and communicated moves through use of the MBO model. Usually, stress is experienced as coming down from above. Norms and demands tend to get transmitted downward. New members of a group and individuals who do not communicate effectively tend to experience much anxiety because they are unsure how to respond to new demands and conflicts. MBO gives members at lower levels ways to define new demands clearly in the form of objectives and to shape their own roles so that they are compatible with overall management goals. Effective managers facilitate this process and reinforce the new agreements thus developed.

Undoubtedly, the most difficult and stress-producing communication in groups where MBO is only partially implemented is communication upward to a supervisor who does not want to share or take responsibility. The manager who wishes to facilitate good communication with such a supervisor needs to make it a point to understand that person and to communicate on a regular basis, even if the communication is not reciprocated. The subordinate must firmly communicate the fact that, for the superior's own benefit, he or she must have the superior's support and there must be a free flow of relevant information in both directions.

Processes of initiating communication under conditions of no agreement and no cooperation are often facilitated by training. Workshops on communication are offered throughout the country and are well worth the time and cost. The manager seeking to improve group effectiveness should explore one or more of these and encourage other members of the project to do likewise.

In summary, we have tried to address some of the problems of management we have encountered in the course of a simulated space mission. It can be anticipated that even more problems will arise in complex missions with heterogeneous crews and diverse goals. The success of space projects to date should not result in the sanguine belief that problems in space or in Earth/space coordination will be minimal in the future. (For a discussion of psychological adjustment in maturing, high stress projects, see refs. 7, 8.)

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