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EVALUATION OF THE GODDARD RESEARCH AND ENGINEERING MANAGEMENT EXERCISE SIMULATION

by A. J. Rowe, P. Gruendeman, and D. McConaughy

Prepared by
UNIVERSITY OF SOUTHERN CALIFORNIA
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for

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GREMEX FINAL REPORT OUTLINE

I. INTRODUCTION

In August 1967, GREMEX was demonstrated to industry participants in order to explore and evaluate the program. GREMEX (Goddard Research and Engineering Management Exercise) is an R&D management simulation exercise designed to provide a simulated project management environment for the instruction of R&D project management techniques to R&D executives.

This was a joint presentation by Goddard Space Flight Center, the University of Southern California, and Management Technology personnel. Industry attendees included personnel from Hughes Aircraft, Jet Propulsion Laboratory, Douglas Aircraft, TRW Systems, Lockheed, Northrop, North American Aviation, and System Development Corporation.

The potential value of such a program is significant in view of the rapid growth of large technical projects, the myriad of alternatives involved, the vast manpower and dollar budgets, and the need for scientific management approaches in the technical administration of these projects.

This demonstration revealed that there was considerable interest on the part of industry in the utilization of the GREMEX program for university and management courses. However, there are a number of ways in which the exercise can be improved in terms of its effectiveness and usefulness to industrial participants. These can be summarized as follows:

1. Modification of the GREMEX program to provide more explicit knowledge and understanding of the model so as to enhance its value as a training medium.

2. Emphasis on the broad aspects of R&D management, utilizing simulation as a powerful training tool.

3. The referee's role should be changed to that of an instructor working more closely with the participants.

4. Efforts should be made to reduce the cost of using the GREMEX exercise so as to permit wider dissemination and utilization by industry.

The GREMEX program conducted at SDC demonstrated the basic value and worth of the GREMEX simulation as a portion of a project management course. It is evident that a number of steps should be taken which would enhance its efficiency and effectiveness to NASA and industry.

The key value of the GREMEX program for industry is that it can be the training vehicle to assist a project team in learning how to work effectively under a simulated pressure environment and how to manage resources to meet program objectives. In fact, one of the participants indicated that he would recommend the use of this simulation exercise jointly by all members of the Project team prior to the actual start-up of a program. This is because of the education and experience gained by being subjected to the challenge and dilemmas of a project manager meeting the activities encountered at GSFC. Not only does the exercise provide familiarization with NASA form 533, PERT Cost/Time, etc., but it simulates two years of effort in the one week. Decisions include selection of spacecraft contractor, contract type, experiments to be conducted, start dates for activities, requests for reports, etc. As in real life, the simulated actions of the project manager influence technical performance and schedule completion within budgeted costs.

As one might expect, any program can be improved, especially when considering its use for another purpose than it was initially designed. Even so, GREMEX proved remarkably flexible in terms of coming close to satisfying industry requirements. The environmental simulation proved to be a very close approximation of the real world of the program manager. On the other hand, there were numberous details which could be modified to improve the ease of play and the educational transfer value. This was particularly apparent from participants comments, as well as problems encountered in running the computer program. The details of these findings are presented in the body of the report along with recommendations for ways of modifying the exercise to improve its effectiveness.

Undoubtedly, the overall value of the exercise is well recognized; while ways of modifying it are reasonable and should be given serious consideration. Probably, the two major changes which would enhance the value of GREMEX to industry are to simplify the program and refereeing so that more companies and universities would be capable of using it, and secondly to broaden the scope so that it includes a larger number of functions normally associated with R&D program management.

I. A. WHAT IS GREMEX

GREMEX (Goddard Research and Engineering Management Exercise) is a computerized program used to simulate the environment of a project manager involved in the research and development activities of spacecraft management. It serves as a vehicle for training and appreciation of the inherent problems of project management relative to NASA space contracts. One of its prime purposes is to provide personnel an opportunity to develop management concepts, become involved in a wide range of decision-making activities, and to gain meaningful experience in these management techniques and processes.

Specifically, the GREMEX program involves a hypothetical spacecraft project S-101 entitled "Orbiting Optical Observatory" which is extensively described in a series of technical and administrative orientation documents. The player-participant in the exercise assumes the role of a GSFC project manger. He can influence hardware reliability, schedules, and costs by the decisions he is allowed to make. The participant begins the exercise by reviewing the Project Development Plan which is provided and which clearly establishes the technical objectives, testing activities, and estimated costs. The participant must evaluate several spacecraft contractors, and must make decisions regarding the initial selection of a contractor as well as the type of contract. He must also consider contract awards to universities and governmental agencies for the spacecraft experiments. In his evaluation, he considers individual contract cost, time constraints, and state of the art alternatives that may or may not be known in establishing his overall management plan. He also is allowed to select and specify the type and frequency of management reporting he feels necessary. Reports are available weekly, monthly, and quarterly and they include PERT, PERT/COST, NASA 533, and others that are based on actual NASA reporting formats. Throughout the development and construction of the spacecraft and experiments, the project manager must constantly deal with problems involving activity start and completion dates, budget allocation and control, reliability features of the components, and a series of perturbations which come up unexpectedly and require specific management decisions. The participant makes decisions once each simulated month and he continues for approximately 2 ½ simulated years until the spacecraft and experiments are fully integrated and the spacecraft is launched.

The participant has three general sources of information for making decisions: (1) extensive orientation materials handed out before and during the exercise, (2) the management reports he has specified which are processed by the computer each month, and (3) a referee who can play the roll of NASA headquarters or a contractor where a personal exchange (or phone call) by the project manager is requested. (The referee also acts as a buffer between player and computer to verify the legality of the player actions and serves to evaluate exercise results at the finish of the program.) Also involved in the exercise is a formal presentation and progress reports to all members of the exercise.

In general, GREMEX is a sophisticated management exercise which extensively models the many detailed characteristics of program management. It requires a rather large computer (IBM 7094 or 360/65) and a staff of 4 - 8 persons to administer the exercise. The participant should have some prior knowledge of PERT, contracting, and the aerospace environment to obtain maximum benefit from the exercise.

The GREMEX program was developed to provide experience in R&D project decision-making from a management rather than a technological perspective. In recent years, the growth of scientific and technological programs connected with the space program has created the requirements for engineers and scientists to effectively lead projects involving large resources of manpower and dollars. Engineers and scientists have been given management positions almost entirely on the basis of their technical accomplishments, with little regard to their capability, experience, or desire to become managers. It is with this problem in mind, that the GREMEX project was conceived and developed by GSFC.

B. STUDY OBJECTIVES

The GREMEX original concepts and mathematical model had been developed in 1964 by Management Technology Inc. in conjunction with Dr. Vaccaro and other GSFC personnel. A computer program was written and two implementation plays were successfully held in late 1966. Although the participants were primarily from NASA, personnel from both MTI and USC attended a demonstration conducted by the GSFC staff. Since that time, there has been considerable interest on the part of industry to evaluate and possibly utilize the model and its concepts in industry. Many companies had expressed interest in participating in the exercise to better understand and evaluate its utility in improving their managerial processes and in aiding in developing improved communications with NASA.

The task of demonstrating the exercise was a joint effort by GSFC, USC, and MTI. USC and MTI provided the facilities, industry, participants and evaluation, while GSFC provided the computer program and technical staff to conduct the exercise during the period of August 21 through 25. The objectives of the USC/MTI efforts were as follows:

1. To demonstrate to industry the NASA technology relative to GREMEX in R&D project management, by having industry members participate actively in the exercise.

2. To enhance communications of space-derived management technology present in the GREMEX exercise to industry R&D project management and to evaluate the information transfer process.

3. To study the simulated learning environment to determine how best GREMEX could provide improved management development for both industry and NASA.

4. To document and evaluate the contribution of the GREMEX program as a training vehicle and its potential for future applications.

5. Provide recommendations to NASA relative to improvements and modifications of GREMEX.

6. Develop and provide a magnetic display board for the time-scaled project networks.

7. Provide technical simulation and model building support.

8. Provide project coordination and facilities for the demonstration.

9. Conduct behavioral research by university staff to evaluate interactive dimensions and methods of presenting GREMEX in a training situation.

C. OPERATING MODE OF THE EXERCISE

The physical operation of the GREMEX demonstration was conducted at the System Development Corporation facilities in Santa Monica, California. The two major facility requirements which had to be considered were physical separation of the participants and the turn-around time between submission of decisions to the computer and return of the results. SDC had the requisite combination for conducting the GREMEX exercise.

The computer program was set-up on the dual 360/67 time-sharing hardware system in order to allow maximum availability of a computer when the player decisions were ready for processing. Since it is difficult to schedule the arrival of player input to the computer this computer configuration was a very important consideration. Another important requirement was the time for the processing of decision input to the computer system. The SDC system provided minimum manual handling (mounting of special tapes and operator interface) and also allowed on-line print-out of the results. This set-up resulted in a 15 - 20 minute turn-around for the computer system to process the participants decisions. This time covered all five teams which were involved in the exercise. Although accurate records of hardware times were not kept, it has been estimated that two minutes were required for CPU processing and ten minutes for print-out of all five teams. The SDC hardware system used is shown in Appendix II.

The keypunch room and participant classrooms were conveniently located near the computer room which provided approximately a one-half hour total turn-around time given that no special problems or re-runs were necessary.

The industry participants were organized into four teams of three members each and a fifth team was composed of MTI and USC staff members. Each of the four industry teams had a NASA/GSFC referee to support their activities. Program Director Mr. Milton Denault, GSFC, head of Management Information System Branch gave the initial orientation and served as the coordinator of the entire exercise. In addition to the NASA referee, one professor from USC was associated with each of the four industry teams as part of the evaluation process. The evaluation results are described in subsequent sections of this report.

II. A. THE ROLE OF PROJECT MANAGEMENT

Program management deals with projects that cut across functional organization lines and requires a special competence as well as knowledge to achieve desired results. The program manager must not only interface with his own company's internal organization, but he must manage in accordance with government procurement regulations covering cost reporting, data management, configuration control, reliability, systems engineering, value engineering and management systems. In the area of contract management, he must have a knowledge of contract types, policies, fee determination, incentives, subcontracting, change control, performance evaluation and reporting requirements.

Working from this background, the program manager focuses on the current government environment, including DOD directives, organization, operation, planning and procurement policies. Program life cycle and base line management must be considered from concept formulation, through contract definition, development and operation. Techniques such as systems analysis, cost effectiveness and mission requirements criteria must all be included.

Program planning and direction are among the key elements of the program manager's job. Not only must there be plans for technical, production and operational problems, but also the necessary authorization and controls based on cost and schedule information. The program manager's job can be highlighted as:

1. Preparing bids and proposals for contracts.
2. Maintaining adequate control over progress.
3. Utilizing network systems for evaluation.
4. Reprogramming and incorporating necessary schedule changes.
5. Utilizing data for reporting and management visibility.
6. Forecasting problem areas and providing corrective action.
7. Maintaining programs within cost, schedule and performance targets.

1. System View of the R&D Process

The program manager, in the GREMEX exercise, is attempting to carry out an R&D process. This can be viewed as shown below in Figure 1:

Major Activities	Related Information or Decisions
Customer Requirements	Feasibility, Needs Missions, Specifications
↓ R. F. P.	Work Statement, Contract Type, Proposal Evaluation, Estimates, Cost, Schedule and Technical Requirements
↓ Program Definition Phase	Preliminary Plans, Technical Reports Management Plans, Firm Specifications, System Engineering
↓ Acquisition Phase	Procurement and Production Management, Program Management Control, Configuration Management, Test Programs Technical Approval, Development of Contract, Detail Design and Systems Engineering, SPO Relations
↓ Operation Phase	Operations and Maintainance, Configuration Update, Feedback, Logistic Support, Acceptance tests, SPO Phase Out

Figure 1 - Description of R&D Process

The GREMEX exercise simulates each of the major activities shown above; however, emphasis is placed on "carrying out" the program. This can be described as the Acquisition or Production Phase. An examination of the details of this phase as shown in Figure 2 indicates that GREMEX is primarily concerned with decisions involving performance evaluation and changing sub-contractors and schedules.

Major Activity	Decisions Required
Contract Negotiation	Determine Contract Type, Establish Specifications, Determine Sub-Contractor Capability
Work Planning	Establish Capacity, Resources, Manpower, Systems, PERT
Estimates and Budgets	Resource Utilization, Cost and Funding
Design and Production	Systems Engineering, Production Control
Acquisition of Resources	Manpower, Funds, Space, Tooling, Management Systems
Procurement and Test	Material and Reliability Requirements, Assembly Test
Performance Evaluation	Management Control Systems, Contract Performance Reports, Slack, Cost, Technical Reports
Deliver Product	Manpower Phase-Out, Timing of Delivery, Cost vs. Budget Performance, Final Product Performance

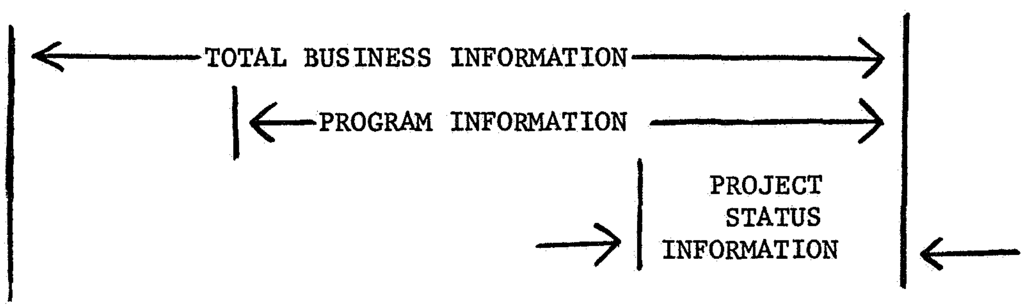
Figure 2 - Production Phase

Use of Information for Program Management

Although the past decade has seen a maturing of both aerospace management and the government's approach to the weapons acquisition process; nonetheless, there is still need for clarification of the program manager's need for information. This has become especially important in view of the advances in management science and information technology. For it is no longer a question of feasibility of obtaining data but rather what are the information requirements necessary for a contractor to do business. GREMEX is directly concerned with this question and provides alternative reports to the participants. However, to fully comprehend the role of the program manager in meeting his responsibilities, we must also consider both the Government's and Industry's requirements for information. The government requires information for the following purposes:

1. Assure that contractors have the capability to plan and control scheduling and cost, to report accurate status of progress and to forecast potential results of program action, including estimate of completion.
2. Obtain data to conduct cost effectiveness studies and forecast the cost of new weapon systems.

On the other hand, industry needs the myriad of detail information necessary to maintain operational control of the many facets of the business, including new product development, diversification, growth or any of the other activities in which business normally engages. This spectrum of requirements can be viewed as shown below:



In order to meet the requirement to manage complex programs, industry has organized the work associated with weapons systems under program managers. The program manager's work is accomplished through the functional organization; however, to have the benefits of both forms of organization, control is required which provides program visibility, earlier knowledge of problem areas, understanding of task interrelationships, and accurate and timely feedback to take corrective action. Thus, the information system plays a key role in the control of programs.

PERT In Project Management

One of the key planning tools in GREMEX is the use of PERT. Here again, we should examine PERT as it is used in program management and how best to apply it. In addition to providing a basic operating plan relating all key elements, PERT helps establish clear responsibility for the work to be done - cutting across organizational lines; it determines the resource requirements and provides the basis for measuring time and cost of the program. It helps provide communication among groups and helps the program manager avoid difficulties by predicting schedule slippages, cost overruns, manpower requirements, and scheduling effectiveness. PERT, of course, is extremely valuable in the planning stage in assuring that a suitable program is being proposed and then, in turn, meeting reporting requirements on a continuing basis.

Although PERT has proven an extremely valuable tool and has gained continued acceptance, there still are problems that must be resolved in order to assure that it does not become an undue burden on program management. Ways must be found to simplify the networking process, such as the use of dynapanels, since it is difficult to examine and understand a large complex diagram. The number of reports submitted to management sould be reduced and simplified so that maximum utility can be made of them. A means for summarizing the reports so that the customer and senior management people can review them is necessary. Improved means for obtaining work breakdown structures which balance the hardware, functional, fiscal, and financial requirements must be established in order to control the work to be done, provide for cost accumulation and assigning the work responsibility.

The Cost Control Problem

Associated with PERT is the requirement of cost control. In addition to measuring technical performance, there is need for financial information to maintain adequate cost control for each project. Cost control is important for the program manager since not only must he take into account considerations such as cost estimating, pricing, and budgeting, but he should also be able to provide the data for meeting contractual commitments. When dealing with a hybrid organization, as is the case of program management where there are projects within functional areas, the data system must be flexible and adaptive to meet changing requirements. Redirection, cancellation and engineering change control pose a difficult burden on any information system.

An adequate cost control system must have the ability to summarize the information in many different ways including function performed, responsible organization, performing organization, product structure, work breakdown structure, contract, etc. In addition, the cost system must be able to project the cost to complete and be able to determine an overrun condition. This information must be presented to program management in an accurate and timely fashion, which implies the need for computer produced reports.

II. B. APPROACHES TO THE LEARNING PROCESS

1. In order to establish the learning value of GREMEX, a basis for comparison with other approaches should be considered. There are two portions of the research literature and accumulated experience in learning theory that appear appropriate to explore in order to provide a standard of comparison useful in the evaluation of GREMEX. These include the material on management games and educational psychology literature dealing with the process of learning. These can be used to provide a generalized model of the learning process which can help establish reasonable learning objectives for management simulation. A Generalized Model of the Learning Process is shown in Figure 3 and represents a descriptive summation of the multitude of educational psychology research.[1] It is not intended to be exhaustive, but rather to provide a framework which could be useful for the discussion of GREMEX. Much of the material on which the model is based is tentative in nature and thus cannot be construed as a definitive or unequivocal model.

One basic premise of this model is that there is a hierarchy or taxonomy involved in learning and that different types of learning probably utilize alternative processes. Further, that learning is in some sense sequential in that it is necessary to build upon each step involved. These steps are shown in the model as milestones or classes of learning. The implication is that they should be related to educational objectives when designing a curriculum. The "intermediate processes" column of the model summarizes theories or description of thought processes which permit the student to move toward higher milestones. These thought processes are connected to the milestone sequence at the

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[1] This model is based on material primarily from the following sources:

Bass, Bernard M. and James A. Vaughan, The Psychology of Learning for Managers. New York: The American Foundation for Management Research, 1965,

Bloom, Benjamin S. (Editor), Taxonomy of Educational Objectives, New York: Longmans, Green & Co., 1956.

Bruner, Jerome S., The Process of Education, Cambridge, Massachusetts: Harvard University Press, 1963.

Crow, Lester D. and Alice Crow, (Editors) Readings in Human Learning. New York: David McKay Company, Inc., 1963.

Hilgard, Ernest R., Theories of Learning. (2nd. edition). New York: Appleton-Century-Crofts, Inc., 1956.

House, Robert J., A Predictive Theory of Management Development: An Empirically Derived Explanation. (a monograph based on work supported by the U.S. Air Force Office of Scientific Research).

Klausmeier, Herbert J., Learning and Human Abilities: Educational Psychology. New York: Harper and Brothers, 1961.

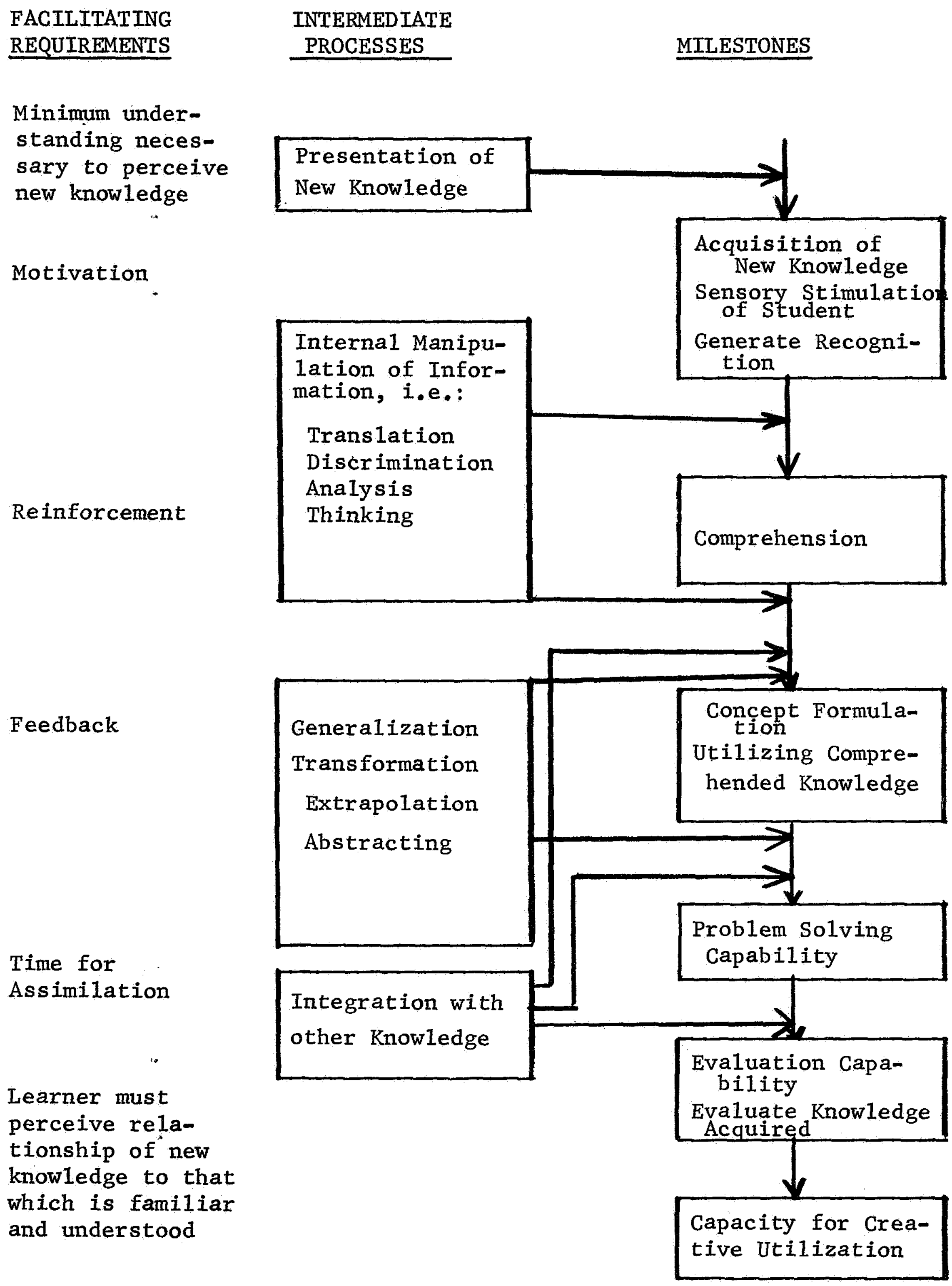


Figure 3 - Model of the Learning Process

points where they seem to exert the greatest influence on learning progression along the milestone sequence. The "facilitating requirements" column summarizes those external elements that seem to be necessary to cause learning to proceed. The sequence in these steps is somewhat arbitrary and not intended to represent a final model of the learning process. Although there are many definitions of the learning process, for purposes of evaluating GREMEX they can perhaps best be summarized by inferring that learning involves the acquisition of knowledge into one's own frame of reference. This concept underlies the sequential aspect of the model. Also there is the underlying implication that, especially in the adult learner, he will be at various stages along the milestone sequence simultaneously. That is, for a broad interrelated field of study new imputs at any level may move forward understanding at other levels of related concepts. Conversely, new development along the sequence will be inhibited unless the underlying knowledge has been understood.

In explaining the milestone sequence the "acquisition of new knowledge" implies that those items require mainly "remembering' or "recall." Ability to recall specific knowledge is usually a fundamental first step.

How efficiently one learns is inherently related to the presentation of a subject, or how the learner perceives the presentation. If he sees a new topic or venture as being related to something familiar and meaningful, he is likely to have greater interest and will probably learn the subject more thoroughly.

The "comprehension" milestone implies understanding or insight rather than rote learning. The other milestones are intended to describe the process of moving toward higher levels of knowledge utilization. If there is recognition of the organizational principles, arrangement and structure, then there is learning or synthesis of the new knowledge as a whole. As the internal manipulation of new knowledge continues, it is requisite that the student "think" about the material. This step must be inherent throughout the entire learning progression. Thus, for real comprehension, the student must utilize this approach if he is to be able to apply the material learned.

Translation is the process by which the student analyzes new material as it becomes available, attempts to have it match or "fit" into his own frame of reference. Discrimination implies the sifting out of irrelevant material by the student. "Analysis" often has multiple definitions, but here implies breakdown of material into constituent parts, detection of the relationship between parts, and the classification of parts.

2. Comparison of GREMEX with Learning Objectives

The critical element throughout the process is student motivation. (Assuming adequate capability for learning.) It is obvious, however, that unless all steps in the process as shown in Figure 3 are adequately treated, comprehension will be incomplete. Thus, GREMEX as a learning vehicle should be compared both on a theoretic level with the model shown in Figure 3 and actual observed reaction of the participants which are discussed in following sections of the report.

The comparison of GREMEX on the theoretic level can be accomplished by examining Figures 4 and 5. Figure 4 is a recapitulation of the sequential steps of the learning hierarchy which starts with basic knowledge and leads to program management skills. An examination of Figure 4 indicates that items 1, 2 and 3 are not treated extensively in GREMEX. These areas would therefore appear to be contenders for modification of the current approach to the use of GREMEX as a program management training vehicle.

Learning Hierarchy	Illustrative Requirements
1. Basic knowledge	1. Vocabulary 2. Understanding of contracting and business process.
2. Understanding of the management process	1. Planning 2. Controlling 3. Budgeting 4. Human relations 5. Organizing
3. Tools of decision making	1. Schedule networks 2. Budgets 3. Probability 4. Decision trees 5. Financial statements
4. Understanding of 000 project management	1. Overview of project 2. Mission objectives 3. Main decision variables 4. Reports 5. Contracting procedure
5. Simulated project management experience	1. Allowable participant actions 2. Performance measurement 3. Evaluation criteria 4. Reporting requirements 5. Decision-result interactions 6. Cost allocations
6. Project management skill	1. Practice of exercise 2. Competitive incentive 3. Performance feedback 4. Analysis of alternatives

Figure 4 - Sequential Learning Hierarchy

An examination of Figure 5 , which is a description of the GREMEX simulation exercise, indicates that there are areas where the model shown in Figure 3 would require additional inputs. For example, the areas of generalized knowledge and problem solving capability undoubtedly would require additional inputs to the exercise. The possibility of special briefings was examined during the GREMEX simulation and as a result a proposed modification of the use of feedback is shown in Appendix IV. In addition, a number of other modifications are shown in Appendix IV such as a revised players manual which would emphasize program management skills.

The theoretic comparison of GREMEX indicates achievement of a number of the critical factors in learning, but that some modification would be desirable to provide a broader level of program management skills.

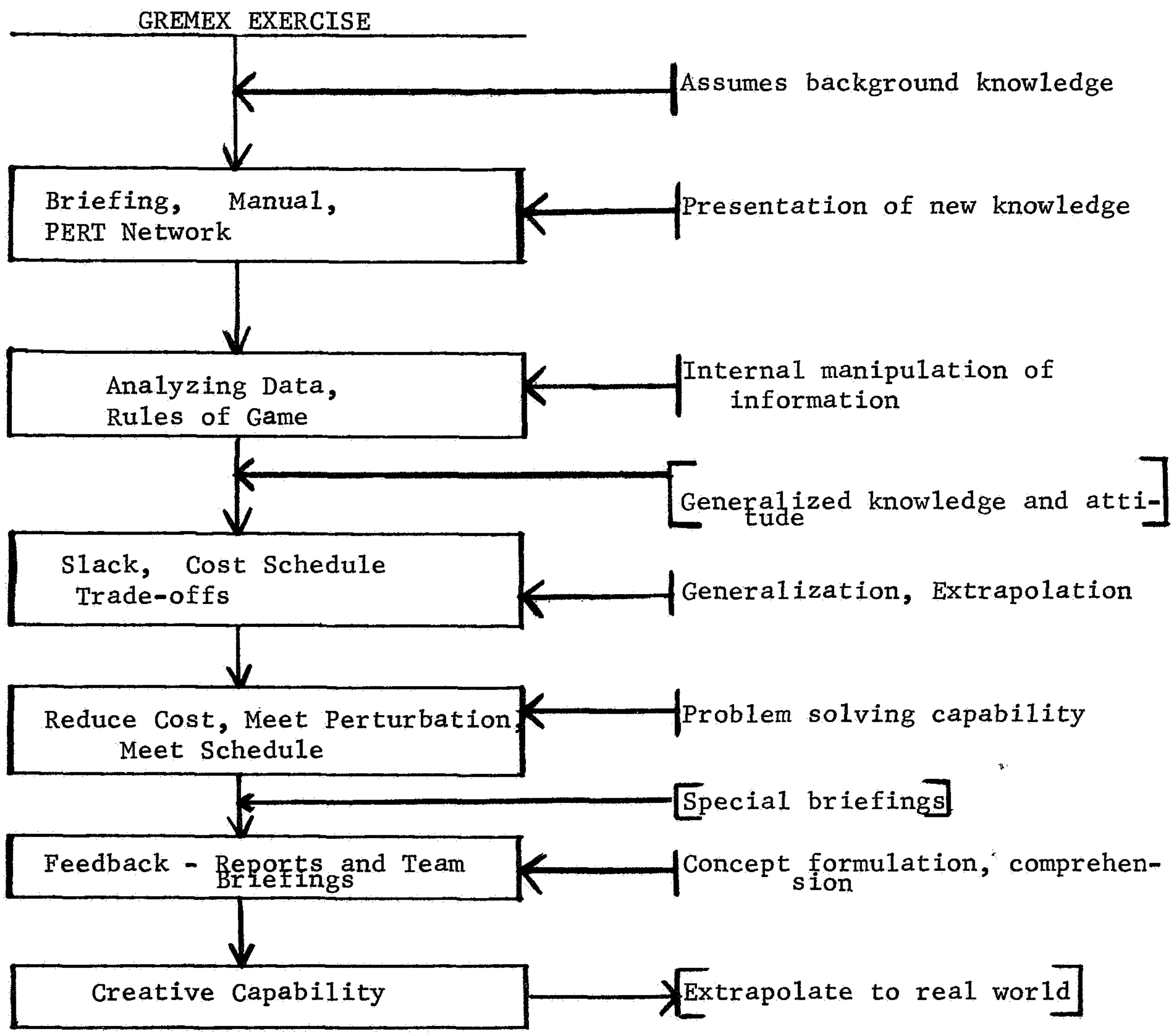


Figure 5 - Description of GREMEX Exercise

III. EXPERIMENTAL DESIGN AND PARTICIPANT'S RESPONSE

A. STRUCTURE OF STUDY

The study involved three separate but related efforts carried out by a team from USC, a team from MTI and a team provided by NASA. The USC team focused primarily on coordination during the game, the participant reactions and experiences, and the nature of the learning process. The MTI team focused primarily on the computer program use of dynapanels, and participant manuals and instructional materials. The NASA team administered the overall exercise and provided background information and explanatory comments to the participants, refereed the actual exercise and provided suggestions for evaluation to the USC and MTI teams.

The training process, as stated by the NASA team and inferred from the play of the team, is based on the concept of progressive participant development through stages of:

1. Cognative learning of the mission and overall task.
2. Uncertainty as to the dynamics of the decision process.
3. Attempts to find or impose order in the decision process.
4. Understanding based on self discovery or self assigned order.
5. Development of decision rules.
6. Practice and validation of decision rules.
7. Knowledge of project management.

These in turn were designed to provide specific skills in:

1. Contractor selection.
2. Comparison of contract types.
3. R&D operating strategies.
4. Trade-offs among slack, reliability, cost, performance, schedule dates, and meeting specifications.
5. Responding to perturbations.
6. Use of PERT networks.
7. Determining the value of detail levels of information.
8. Maintaining program control.
9. Determining significant factors affecting cost or schedule, e.g. reliability
10. Evaluating penalties for changes in network schedules.
11. Comparing contractor risk versus technical performance.

Participants' progress and growth through these stages was guided and reinforced by the referees and briefings. Participant interaction, when present, also provided reinforcement of the learning experience.

Two additional aids provided to a selected sub-set of the trainees were Dynapanels and de-briefing sessions. Dynapanels are magnetic panels on which the various activities of the GREMEX project are shown in an interrelated manner, time scaled to the launch date. The activity symbols are movable and can be used to adjust the PERT network in a dynamic fashion by participants during the GREMEX exercise. De-briefing sessions consisted of additional seminars in which the mechanics of the model and the interrelationships between the cause and effects in the exercise were discussed by the simulation coordinator and one team of participants. Any unanswered questions which the participants might have about the preceding plays were answered at this time.

The overall study was designed to moniter each participant's progress through the learning steps outlined as well as to document the training approach strengths and weaknesses. The participants were evaluated on their exercise performance, attitude toward the exercise, and learning experience. The study design permitted each participant to be evaluated based on his education, job experience, and ability as they affected his learning.

Team Formation

The GREMEX exercise, as conducted at SDC, consisted of four teams each composed of three managers from local aerospace industries, a referee for each team from NASA, and an observer from USC for each team. A fifth experimental control team consisted of one person from USC and one person from MTI.

As part of the experimental design, the four teams of aerospace managers were grouped into two categories based on the use of a wall sized PERT network (Dynapanel) for the spacecraft and experiments. Teams 1 and 2 used the large PERT networks produced on Dynapanel magnetic boards. Teams 3 and 4 used the 22" by 34" PERT networks included in the player's manual. A further structuring of the exercise, again as part of the experimental design, included a post session debriefing for Team 3 after each day's play and a follow-up interview of the group at the conclusion of the exercise. The remaining teams were interviewed on an individual member basis after the completion of the week's exercise. Appendix IX gives a list of team composition and background.

The teams were established so that no two participants from the same firm were on the same team, and participants who were experienced program managers were placed in teams where the other participants did not have direct NASA contract management experience. The NASA referees and the USC observers were assigned in a random pattern in order to avoid biasing the results. In addition, each observer rotated with two other teams in addition to his assigned one, for one day each.

Thoughout the week each team of participants prepared a briefing for the entire group. A single team member was selected to represent the team and present the briefing. The briefing dealt with a report of the team's progress, a summary of its problems and a prognosis of its expected progress. The briefing also dealt with an evaluation by each team of the reasons certain problems and difficulties had occurred.

B. EVALUATION METHODS

The evaluation methods were primarily observational and survey. An experimental research design involving additional briefings to Team 3 and the selected use of Dynapanels by Teams 1 and 2 were also evaluated by the observational and survey method. Unsolicited comments by participants, referees, and other observers were recorded where appropriate.

The primary objective of the week's exercise was to determine the participant's general reaction, their acceptance of the simulated decision technique and to match their learning experience with the objectives of GREMEX and a profile of a project manager's job (see Appendix IV).

The study also monitered each participant's progress through the learning steps outlined as well as examining the training approach's strengths and weaknesses. This permitted each participant to be evaluated based on his education, job experience, and ability as they affected his learning. In addition, the evaluation of the participant's learning experience with respect to the learning-theoretic model shown in Figure 3 and of the desirability of several alternate learning hierarchy structures was made.

Since the GREMEX exercise is a non-competitive game, quantitative measures of participant and team performance were not considered appropriate. In addition, since the simulated launch was not completed, quantitative measures could have given misleading information on performance.

Observers

As described above, observers were assigned to each of the teams. One observer was with each team throughout the entire week of the play. On the first, fourth and fifth days, the observers were with their "assigned" teams; on the second and third days they rotated in order to observe other teams and thus to be able to make appropriate comparisons among the teams. In addition to the team observers, there was an additional observer for the Dynapanels who stayed with Teams 1 and 2 throughout the exercise. The exercise coordinators from NASA and USC also made observations of all four teams, although on a random basis.

Evaluation data were obtained from the observers assigned to each team, the observer assigned to the Dynapanels, and the observer assigned to the computer support. The team observers had three functions: (1) to maintain a brief narrative of the progress made by each team, (2) to record on an incident basis significant activities, decisions, errors and other events which occurred, and to (3) conduct formal follow-up interviews with each participant. Tape recordings of selected team decisions and recordings of briefings were made as part of the data collection.

Teams 1 and 2 were observed at random intervals from an observation booth which was wired for sound pick-up from a microphone placed near each team. The observers alternated between attendant observation and concealed observation in the early stages of game play. Initially, undisclosed observation and sound recording were thought to be necessary, but a general lack of concern on the part of the participants led to a more direct observation procedure. No perceptible difference in team performance was noted between the observational methods.

Observer Narratives

Each observer-evaluator kept a narrative diary of the play of the exercise. The nature of these diaries were incident focused and significant events such as key points of team discussion prior to decision entry, team interpretation of problems and effects of their decisions, and referee inputs were recorded. Appropriate narrative notes and observed findings were exchanged among observers during a post session debriefing of the USC team. The computer program monitor and the Dynapanel monitor also kept a diary of their observations.

A two man player-observer team, having little or no prior experience in aerospace project management, provided additional evaluation inputs. They did not receive group briefings nor referee support.

Immediate Post Session Questionnaire

At the close of each day of scheduled play the team observers administered the post-session questionnaire to the participants. In Teams 1, 2, and 4 the survey was conducted on an individual basis, in private. For Team 3, which had been given the experimental post-play daily debriefings, the questionnaire was administered on a group basis. In both cases participants were encouraged to give any and all of their reactions to the validity, realism, benefits, and disadvantages they found in the exercise.

Six Week Follow-Up Questionnaire

The participants were again interviewed by the observers six weeks after the play of the exercise to determine if they had additional or different views about the exercise. Most of the participants had written some type of report to their company which had required that they formalize their evaluation of the exercise. These reports and a summary of each participants' evaluation in confidence were obtained at the time of the six week follow-up. A list of questions asked in the post session and six week questionnaires are included in Appendix VII.

Experimental Data

In planning the exercise, the value of additional supports (Dynapanels and debriefing sessions) were examined to determine whether they furthered the development of the skills and knowledge of the participants. Specifically, the questions asked were, "Do Dynapanels result in more learning by the participants in the GREMEX exercise" and, "Do debriefing sessions augment learning experiences?" To answer these questions, a separate observer monitored the use of the Dynapanels by Teams 1 and 2 and observation of the Team 3 debriefing experiment was made by the assigned observer and recordings were made of the team dialog.

The dependent variables in both the Dynapanel and debriefing experiments were the extents to which the participants learned the skills and developed the knowledge necessary for effective project management. This learning was reflected in their ability to reason through the problems confronting the project manager in the situation presented by GREMEX and by their own attitudes toward the exercise regarding its effectiveness as a learning device. Their playing ability and attitude was deduced during the playing of the game by the team observers and from their answers to specific questions asked at the end of the exercise.

It was difficult to make accurate, comparative measures of the dependent variables involved. However, by using the many devices noted, and by discussing these factors with the several observers, a consensus was reached regarding the impact of the Dynapanels and de-briefing sessions on the learning of the participants.

The participants were not pre-tested on their attitudes toward the simulation or their ability at playing the management game. The only pre-testing involved was the option given the members of Team 3 to elect not to have the extra sessions. None of the players on the team objected (formally) to the procedure.

The Dynapanel Experiment

Observations of Teams 1 and 2 indicated that neither team started using the Dynapanels until told to do so by the referees. (Quoting from the report of Mr. Shelburne, MTI, the constructor of the panels.)

> "Almost immediately an error in logic was discovered which may or may not have caused doubt to arise regarding accuracy of the plan. It was noted by this observer that Team 1 used the panels very little after the discovery of the error, but Team 2 continued to refer to them with even greater regularity once the computer output failed to reflect changes.

Observation was made of all teams to determine difference in plan with respect to those teams using the Dynapanels <u>versus</u> those without them. All of the teams used the non-time scaled flow charts along with the computer output. However, as was stated earlier, when one of the perturbations did not reflect accurate status in the computer output, they started with the new launch date on the Dynapanels and updated integration of the proto model to determine the negative slack on the critical path.

The panels appeared to be most useful to carry on discussions regarding problem areas and to show relationships of one activity to another, irrespective of time status. Because the panels could not be updated at the beginning of the play, they began to lose their usefulness very quickly. Team 1 ignored the panels almost completely after the third play, while Team 2 tried to show completion dates and keep the panels updated to some extent. This became impossible shortly because of each activity changing in duration and the inability to keep them updated.

All of those involved in the play were asked to comment on the usefulness... of the Dynapanels. A summary of these comments follows:

- It gives an overall view of the entire project.
- It allows for a quick reference of activities.
- It gives a dynamic view of problem areas and shows those areas upon which there will be an impact."

In general it was concluded that the panels were useful in providing an overall view of the entire project, and as a quick reference. In addition, the panels were found to give a dynamic view of problem areas and showed those activities upon which an impact could be made.

The participants in Teams 1 and 2 felt that several problems existed in using the Dynapanels:

- "There was insufficient time between play to update the panels and keep them current.
- Updating the panels and making decisions at the same time was found to be too laborious.
- Not enough interfaces are shown to reflect constraints from one area to another."

In addition, it was observed that:

- "The players should have a better introduction to the mechanics of the panels.

- Due to the time limitations it is totally impossible and impractical to make actual updates on an activity to activity basis.
- The players failed to see the panels as a time-scaled plan.
- The players tend to stick with methods and tools that they are more accustomed to working with.
- Some players found them useful in discussion because they continually made reference to them.
- The Dynapanels have a real use in this kind of exercise, but it needs to be refined."

It would appear from these conclusions that the Dynapanels were of limited usefulness to the players of Teams 1 and 2. Although they do present the relationships visually, they are also cumbersome and difficult to update quickly. However, in actual project management situations where the time constraints are not as great, the Dynapanels would probably prove to be very useful aids to the project manager.

The De-Briefing Experiment

Three de-briefing sessions were held during the exercise on Monday, Tuesday and Thursday. The length of the sessions varied from one-half to one hour.

The first two sessions followed days in which Team 3 participants were frustrated and handicapped by the mechanics of the game. On Monday, they did not receive the reports requested, and they were unaware of the assistance available to them from the referee. On Tuesday, their afternoon runs were all incorrect (a computer error due to their use of Code 27; this was not corrected until 4:40 p.m. on Wednesday, and thus explains why no debriefing session was held on Wednesday).

In both of these sessions, the time was spent airing grievances and explaining to the exercise coordinator the extent of the problems encountered. In neither case was the session used to give information about the model to the participants. Both sessions proved to be more helpful to the administrators of the exercise than to the participants.

The third and final session (Thursday) was carried out as planned, and was spent entirely in answering technical questions about the model and the relationships between the variables. Considerable advice was given to the players at this session and, consequently, all players responded by taking home their computer printouts and mapping out a new (and more successful) strategy for the next day. The success of this one session suggests that such sessions should be included as part of future GREMEX exercises. The sessions were found to be useful both as grievance sessions and as a means of providing technical assistance to the participants.

A third use for such sessions suggested itself during the experiment. If observers of the interpersonal dynamics of the teams were available, the de-briefing sessions could focus on the behavioral issues and thus could provide useful task-group interaction. Such an innovation would be especially helpful if the team consisted of a task group that would later be working together as a team in the management of an actual project.

Conclusion Regarding Dynapanels and De-Briefing

Although no firm comparative conclusions could be drawn regarding the impact of the additional devices (Dynapanels and de-briefing sessions) on the learning of skills and the development of knowledge necessary for effective project management, it was generally concluded from these experiments that:

- The Dynapanels did not appreciably improve the players' learning during the exercise.
- The de-briefing sessions did improve the players' performance in playing the game and affected their attitude toward the exercise in a positive manner to the extent that it allowed the airing of grievances.

It was earlier stated that the possibility of including task-group interaction in the de-briefing sessions should not be overlooked in future runs of the GREMEX exercise. This innovation is but one of several possibilities for further experimentation that are of interest to the USC faculty members who served as observers during the August run of the simulation. Other questions that might be explored are listed below:

- Is the GREMEX exercise a useful experience for actual project management teams who will be working together in the future?

- Is the exercise useful as a screening device for the selection of project managers?

C. PARTICIPANT REACTIONS - POST SESSION

While a simulated decision exercise such as GREMEX can be expected to simplify and synthesize real managerial experience, it is essential that key decision processes and problems be dealt with. An important requirement of the simulation was to closely duplicate those aspects of a program manager's job where meaningful learning experience can occur. The benefits received by the participants depended on a number of variables including his education and work background, his attitude, his purpose in participating, and his understanding of what he was to do within the structure of the exercise. In interviews immediately following the close of the exercise, participants were asked a series of questions which probed their rating of the following factors: (1) game realism, (2) length of exercise, (3) preparedness for the exercise, (4) benefits and learning experiences, and (5) game mechanics and structure. The results are summarized below:

1. GAME REALISM

This measure deals with a participant's perception of the closeness of the exercise to an actual project manager's decision environment. Response to this question in most cases was based on what the participant thought a project manager did rather than on specific knowledge of project management responsibilities.

Need for Realism

To put the participants comments on the reality or unreality of the exercise in perspective, each player was asked to indicate the amount of realism he considered necessary to produce a meaningful learning experience. Responses to the question of realism ranged from highly important to fairly important. One participant summed up perhaps the best statement on realism by saying that realism should be strived for in those areas considered critical to meet objectives. All other aspects of a supporting nature of the main purpose of the exercise could be less realistic providing the participants understood that empirical reality was being compromised in these specific areas. Budget and schedule aspects of the project were thought to be key areas and also areas requiring realism. Reports and reporting requirements were also areas where realism was considered important. Interestingly, no participant felt that the experiment and spacecraft description were as critical as the game elements which the player used directly in the decision making process.

The discussion of game realism was heavily influenced by the participant's gackground. Technically oriented players felt that technical data needed to be realistic, while the less technically oriented players felt that the data the project manager used to manage the project needed to be realistic. Even the experienced project managers were not sure of the proper objectives of the spacecraft mission and thus were unable to effectively appraise the nature of the experiments to be contained in the spacecraft. A number of participants suggested that a briefing on the technical aspects of the spacecraft, in addition to the information contained in the participant's manual, is needed to reinforce the realism embodied in the project description.

A summary of participant responses to exercise realism is given below.

Most Realistic Attributes

The most frequently mentioned realistic attribute of the exercise was the spacecraft project description, contractor evaluations, and associated material. Several non-project managers believed the proposal was for an actual program. The PERT networks were well regarded in terms of their completeness, but not for their flexibility. While the computer produced reports were rated as highly realistic, the participant's reporting requirements did not seem realistic. Perhaps this occurred because most participants did not fully understand what reporting requirements they had to make before the play of the game.

Once the play of the exercise began, realistic perturbations began to impact on the orderly decision process. Most players rated the type and incidence of perturbation as high. One participant thought that a class of non-hardware perturbations should also be used, such as, human error and its consequences. Time pressure for decisions received mixed evaluation. Several participants, primarily the ones least familiar with spacecraft, technical, and program management aspects, felt they did not have enough decision turn-around time. By contrast, time pressure to make decisions, and the need to make decisions on the basis of incomplete information was considered very realistic by experienced participants.

The role of the referee representing individual contractors was reported as having mixed quality and realism. The extent to which a participant had access to pertinent information from the contractor via the referee's role playing was reflected in the participants view of realistic access to data.

Most Unrealistic Attributes

The nature of the items and features of the exercise that were rated as unrealistic were largely not manageable in such a simulation. Other unrealistic attributes probably arose from the inexperienced participants' own lack of understanding about the detailed nature of a project manager's function. For example, one participant thought that other pressures should somehow be brought to bear on the player. In actuality, additional pressures on the participants clearly were not feasible in view of the fact that most players struggled to develop a higher level of skill in dealing with the exercise as it existed. While the level of detail was well received, the participants who had some experience with aerospace project management felt that the technical reports covering the experiments and the reports of progress were somewhat limited. The inability to get reports of the type they were familiar with caused some frustration and a feeling of "What good am I as a manager if I cannot get adequate information on which to base my decisions." On the other hand, some participants seemed to fall back on a request for further information if they did not fully understand the nature of the problems they were facing or the reports they already had. Mention of unrealism on the part of information and reports must be viewed in this context.

To some extent most participants felt that the timing represented an unrealistic aspect of the exercise. No clearly defined time targets were set for decision deadlines, thus the teams were unsure of how long they had to make a decision.

In the early stages of play, participants were primarily engaged in orienting themselves to the requirements of the game. After their understanding of the exercise improved, most players challenged the inability to change the PERT network. After changes in event times and starting schedules were made, requests soon followed to change some of the network logic, especially where test functions might be parallelled or eliminated altogether to reduce schedule time and cost. The inability of the project manager to make some of these type changes was considered by both experienced and inexperienced project managers to be an unreal aspect of the decision exercise. When the programming difficulties of adding such refinements to the computer model was explained to those teams requesting logic change, they generally accepted the answer. However, fixed network logic was mentioned frequently as one of the aspects of the decision exercise they would like to see changed.

The participants indicated that project manager discretion would typically permit some network changes. Several participants also thought that the project manager should be able to insert events into the network. For example, a more comprehensive testing program might be specified for those components which evidenced a low probability of success or reliability. Conversely, events should be subject to removal especially where part of the proto-t pe hardware could be substituted into the flight model.

A lack of familiarity with the participant action list was raised as a question in regard to the exercise. Players did not receive a list of allowable actions until the second day; the purpose for this delay was to encourage the participants to give some unguided thought to the kinds of decisions they should be making. When faced with the unstructured requirement for making decisions the teams in their own individual way arrived at some decision assumptions that at least helped guide the team's effort. Some of the decisions the teams made, as a result, closely duplicated allowable participant actions but others did not. The elements of decision making that could not be accepted by the exercise then tended to be viewed as unreal aspects of the game. Unreal in the respect that the player as a project manager wanted to take a more or less well thought out course of action that was later found to be unallowable. Consequently team members seemed unsure in the early stages of the game about the scope of allowable decisions. The allowable participant actions, after they were distributed, became the first significant guide the players had as to the extent of their responsibility. Since the allowable actions were not thoroughly explained before play of the game, limits on prior expected variables were viewed as artificial, thus unreal.

The experienced project managers seem to feel that the cost control aspect of the exercise was too loose. In practice, one participant indicated that a project would be cutoff or subject to a special review if the actual or expected cost overrun exceeded ten per cent. A number of players perceived the main emphasis of the game to be schedule rather than cost or performance. This apparent ranking was considered unrealistic since cost controls and cost performance are heavily weighted by many of the firms in the aerospace industry, especially since incentive contracts are coming into use.

Performance or reliability requirements were considered unrealistic in that very little explicit relationships between the project manager's actions and reliability could be determined. Reliability seemed to be a function of the initial award of the reliability contract. Data contained in the technical narratives was not adequate in most cases to assess the program reliability nor were participant actions available which would allow the project manager to take constructive steps to improve reliability. On the other hand, some players recognized that early funding of experiments could provide a greater amount of leeway in the final selection of experiments which would also probably increase the reliability of a successful launch. However, component reliability seemed beyond their control.

After reflecting on their earlier decisions and thoughts on the play of the exercise, several players thought that the nature of some of the initial information was unrealistic. The sample reports gave some idea of the nature of the data that were unavailable, but zero time reports were felt to be necessary for thoughtful play of the game.

Summary

Generally, the participants felt that there was a high degree of realism in the problem outline, materials, and the nature of the project to be managed. A lesser degree of realism was accorded the allowable participant actions and reporting requirements. A desire for increased realism was expressed in regard to the exercise structure which prevented changes in the cost allocation between project phases, changes in schedule networks, and interpersonal contacts with other responsible managers. Contract selection was considered difficult because certain relevant cost and project data was not available prior to period 1 decisions. Even though the referees did act in the role of contractor, meaningful evaluation by the participants was considered limited.

A majority of the players felt that the exercise should end with a vehicle launch. On the whole, players felt the game was adequately realistic to the extent that an exercise of this type could be. Most players indicated they were genuinely challenged by the exercise and that they had to work diligently to manage their assigned projects.

2. LENGTH OF EXERCISE

In discussing the length of play, participants responded to both the total length of play and the time allocated for each period's decisions. The experienced managers felt the total play of the game was too long. The other players felt that the total play length was satisfactory, although they felt it should not be any longer than one week. While most team members felt that a launch would be desirable, they were not sure that the play of the game to its conclusion would warrant the time and effort involved. The general feeling seemed to be that the learning experience from the actual play of the game (aside from the briefings) began to peak-out on the third day. In several cases, the teams had, in their opinion, irretrievably set the conditions of their project good or bad and that future decisions would not make significant differences. In other cases, errors by the teams or referees or just the selection of an undesirable (from the viewpoint of the model) alternative in contract awards or selection of information seemed to the players to impose severe limitations on future progress. By the third day most players indicated that they were sufficiently familiar with the exercise to recognize the difficulties that were taking place. By this time, the players seemed to lose interest in wrestling with the clerical aspects of the exercise. Some players seemed to "wear out" on the clerical aspects of the exercise before they lost interest in the project management phase of their activity. In any case, five days of play were considered to be probably too long for the present structure of the exercise.

In contrast to the total length of play, many players felt that the decision periods were not long enough in the earlier phases of play. In addition, time variability in the decision turn-around was singled out as a disruptive influence. Players were not sure how much time they should budget for their decisions and then after their decision was submitted for computer processing they did not know how long they would have to wait for the outcome. Several players suggested that additional projects or briefings be scheduled so that the team's time could be better utilized. Another suggestion was a change in the scheduling of the participants time with respect to decisions and report deadlines, slack time, and outcome reporting, which would improve the timing of the exercise.

Summary

The optimum length of play is, of course, dependent upon the objectives and content of the exercise. Where participants were familiar with PERT networks, astro-physics concepts, and NASA contracting and reporting procedure actual play of the exercise could be as short as three days. Experienced participants indicated that interest and learning peaked at the end of the third day. Where the participants were less experienced, the length of play of five days seemed beneficial.

These comments have dealt primarily with the actual decision making part of the exercise. However, additional content, classroom type presentation of management techniques imbedded in the exercise, group briefings, and related activities would lengthen the desirable playing time.

Participants felt that playing time in excess of five days would neither be markedly helpful nor necessary, although most of the participants thought that play should be continued to launch. Based on participant comments, future exercises planned for five days of concentrated decision making should attempt to accomplish spacecraft launch as a means of motivating a high level of effort over the period of play.

3. PREPARATION

As in other aspects of the participant's evaluation of the exercise, educational background and work experience directly influenced the player's understanding and thus his learning experience during the exercise. This trend is also apparent in the responses to questions about a player's preparation. Participants were asked to evaluate their preparation both from the pre-play studying of the materials provided ahead of time, and their ability to obtain adequate information on a need-to-know basis during play of the game.

Preparation in this context deals with the extent a participant achieves an understanding of the project, reports, decision, and general play of the exercise before playing and to what extent is he able to acquire information missed or poorly understood during the play. Some participants were not well prepared to deal with NASA reports, PERT networks, and measures of mission effectiveness. In contrast, the project description was complimented by all players on its completeness and realism. The differing level of preparedness appeared to be more heavily dependent on the participant's background than on the nature of the material presented.

Over half of the participants indicated that they were unable to determine from the pre-play study of the material the types of decisions they would have to make. While they generally understood the mission and something about the nature of a project manager's job, they were unsure of specific decisions required in the exercise. In addition, most of these same participants were unsure of the managerial tools available. The presence of the report formats in the manual did not seem adequate as a vehicle for communicating the task expectations of the exercise. One significant question raised was: Why wasn't a glossary of terms included which would assist a new project manager in understanding the highly technical astro-physics elements of the mission? The overall objective of optimizing on factors of reliability, time, and cost did not help the less experienced players to relate these decisions to such problems as the selection of experiments to be included in the spacecraft, and the selection of other contracts required. The players who felt they were not adequately prepared due to their own newness to the area and did not have the ability to make full use of the information in the manual also felt that they did not have enough time during the play of the exercise to upgrade their understanding, i.e. preparation in a meaningful way after the start of play. In general, the participants continued to experience confusion until the second day.

Many aspects of the decision requirements were not clear until after the list of allowable participant actions was passed out at the beginning of the second day's play. Also little data was supplied or was available which the participants felt gave them enough information about the likely outcomes of their initial decisions. This point was clearly made by all of the players who did not have prior aerospace project management experience. For example, all of the teams indicated that they encountered some difficulty in rescheduling events on the PERT network. In some cases this was due to uncertainty in their decisions, but initially it was due to a lack of understanding as to how events were controlled within the structure of the exercise. Also, an indication of the approximate effect of authorized overtime on the cost and schedule was not available in the participant's manual and was not covered at the orientation session. Players were therefore left to discover on their own some of the mechanical aspects of game which did not seem to be a normal part of a project manager's task.

Preparation for the exercise was graded as good in the area of spacecraft and experiment description. The absence of descriptive information about the tasks, and the lack of a clear understanding of the participant actions that could not be accommodated by the program, caused players to devote a substantial amount of their time to "discovering" the rules of the simulation. Most participants were unable to get a clear picture of the schedule slack until after initail contracting decisions had been made. At this point in the game, time pressure tended to prevent an adequate evaluation and preparation for potential schedule problems. The participants indicated that the partial separation of the contracting phase from the actual management of the exercise would be desirable.

4. BENEFITS AND LEARNING EXPERIENCE

The rewards of learning and insight gained from an exercise such as GREMEX extend beyond the actual play of the game. The long term benefits, thus, may not be readily apparent to the participants at the close of play, but become gradually apparent after a period of time. The benefits of participation discussed in this section are based on player responses to questions asked at the close of the exercise.

Empathy or understanding of the problems of NASA was regarded by the participants as the most significant benefit. The players generally regarded the exercise as a means of gaining some sensitivity about the overall nature of project management. This benefit was achieved partly because of the game itself, but also from the interaction with the referees. While not stressed in the exercise, the project managers relationship with the contracting NASA branch was perceived as being a comparable task to the internal management of the project itself. Although empathy and understanding of NASA's problems is certainly a valuable aspect of learning to be a project manager, the exact transfer of learning was difficult for the players to describe and the observers to identify. This aspect of the exercise, however, was rated by participants as one of the primary learning benefits of play.

The next most significant aspect of learning dealt with the operational aspects of project management. Since this is more mechanical in nature, it was easier to record and observe. With the exception of two highly experienced players, the participants all indicated that they benefited significantly from the exposure to program management and the understanding of the project management task. In varying degrees, the participants began to formulate a concept of what a project manager does, the kind of problems he should be aware of and an intuitive feeling for those activities which seem to give rise to problems. Some insight was gained into the available managerial tools a manager would use to keep control of projects and types of strategy he would use to achieve the program objectives. Key areas of decision making and typical constraints on a project manager were listed as direct benefits of the exercise. Understanding, and thus benefits, were indicated in the area of recognition of the effects of resource allocation and interactions present in project management.

An appreciation of the importance of the analytical approach to decision making in managing a large project was recognized by all the teams. Most teams felt that they had not been sufficiently analytical in their decision making; especially in the management of the experiments where technical feasibility of success, probability of successful integration of experiments in to the spacecraft, and past performance of the university groups would have provided worthwhile inputs to their decisions. Earlier attention to the scheduling problems that later came up was listed as an area where a greater degree of analysis would have improved decisions. The teams seemed to gain an appreciation for accurate, comprehensive and timely reports especially since no direct contact was possible with the contractor. The referees did not effectively convince the teams that they were behaving in a manner comparable to the contractor they claimed to be. Pre-programmed perturbations and random variations occured independently of the contractor's (referees) comments and answers to questions. Because the players were unable to request a briefing from a contractor when trouble appeared or slippages occurred, they were forced to place their reliance on the computer reports. As a result of working with the reports, however, the participants gained an appreciation for the kinds of information they could obtain from the reports, the weaknesses of the reporting system in the absence of other information inputs, and the need for an analytical approach to decision making. To a lesser extent, a sharpened awareness of the effects of resource allocation and interactions present in project management were indicated. The benefits listed almost always treated the technical and structural aspects of project management in contrast to personal or team interactions.

One of the significant learning experiences for several of the players was their participation in a management simulation. For these players, the GREMEX exercise was their first contact with such a training approach. Thus, the participants indicated the benefits in their play of the game itself.

5. GAME MECHANICS AND STRUCTURE

The players made a number of suggestions for changes in the game's mechanics and structure. Some of these ideas were directly related to the participant's attitude toward decision simulations. In other cases, suggestions for change arose when a participant experienced difficulty working successfully under the established structure. These suggestions generally were revisions which would have made their problem somewhat more tractable.

A compendium of participant comments are organized under the headings of (a) orientation, (b) referee-team interaction, (c) decision structure, (d) manual, and (e) game performance measures. Some additional comments on facilities and supporting materials have also been recorded.

a. Orientation

The orientation material in the manual was well rated with respect to its creditability and comprehensive coverage; the orientation briefing on the other hand was rated as inadequate coverage of how the exercise should be played. Several players indicated that no attempt was made to determine their background or understanding of NASA procedures and reports. Thus, potentially helpful questions which might have been raised at the orientation session did not become apparent until after trouble was encountered during the play of the game. In addition, the players indicated that some understanding of the decision simulation process would have been helpful.

The orientation did not cover a discussion of the technical attributes of the experiments, therefore, several participants, including those with technical backgrounds, did not know how to relate the experiments to the Orbiting Optical Observatory mission statement. In short, many important aspects requisite of latter play were felt to be missing from the orientation.

b. Referee-Team Interaction

The role of the referee in the play of the exercise varied in ranking across the teams. One team was very enthusiastic about their referee and the way he challenged them, supplied information and acted in behalf of the contractors and higher management. Another team viewed the referee as a liability who did not understand the game as well as they did and was error-prone. In this latter instance, the referee-team interaction was strained, at best. The remaining two teams reported reasonable interaction with the referee.

In response to questions about the referees, it became apparent that few participants understood the role of the referee. In fact, one participant suggested that the referees did not understand their own role. Several participants appeared to view the referee as a coach who was supposed to give them aid in improving their play of the game. When substantial help was not forthcoming the referee appeared to be an antagonist. Many players did not seem able to clearly decide whether the referee was part of the problem or the solution.

c. Decision Structure

In the area of decision structure, the more experienced players felt uncomfortable with the type of decisions to which they were restricted. At the orientation session, the point was made that the participants could "design their own system," and the participants felt that they could freely make decisions with respect to manpower allocation, scheduling, budgets, etc. After several plays, however, the decision structure of the game began to emerge, and the restrictive choices and forced choice options became apparent. On the second day of play the "legal" decision list was distributed which then clarified much of the decision structure. At this point one participant remarked: "Why didn't they tell me I was to "select" a decision instead of developing a decision?"

The second aspect of the decision structure which caused comment was the lack of information which would relate decisions, and outcomes and associated lag time. The more experienced players felt the relationships were unrealistic in many respects and the unexperienced players felt that they should not be expected to know how the decisions and outcomes interact. For example, the decision to add overtime to a specific task had to be made without knowing how much time could be made up or an estimate of the attendant cost of the overtime. In some cases, the referees were able to provide satisfactory answers, in others they were not. The ability to answer questions about aspects of the decision structure had no relationship to the difficulty of the question. In the case of rescheduling an activity to delay its start, the referees were quite adamant that this would increase cost. On the other hand, the effects of overtime and the cost allocation between the prototype and flight model were not clearly known.

While a number of decision options were of slight value, decisions to eliminate or restructure the activity network could not be accomodated. Although the participants did not in most instances expect complete flexibility, they did expect to understand the nature of the decision structure. Thus, the participants were not sufficiently able to separate the controllable and uncontrollable variables in the exercise.

Finally, the participants indicated a desire to spend a more detailed session on the contract awarding phase of the exercise. Several participants indicated that they could profitably spend a whole week on just this phase.

d. Manual

The manual was well regarded for its comprehensive coverage of the project. The breadth of technical detail was reported as very good and giving a high degree of creditability to the mission. Participants without a detailed technical background in astro-physics, indicated that a glossary of terms and some additional explanatory material would be helpful in evaluating mission alternatives. Also, supporting material for the number and type of allowable decisions was indicated as the greatest deficiency. Additional information on the mechanical aspects of the exercise and a more detailed description of the nature of the participants activities were indicated as required.

e. Game Performance Measures

The game performance measures provided a basis for measuring the progress of the teams in meeting time, cost and performance goals. The announced purpose of the game was learning, not competitive management. However, the performance measures were recorded for all teams on one graph which was viewed as a measure of competitive performance. One team which did not show up well by the performance measures, felt they misunderstood the reporting procedure and thus did not have enough information to make good decisions early in the exercise. They were not able to correct for earlier mistakes and thus finished poorly compared to the other teams. In this case, a competitive measure of performance did not seem to help. An alternate measure in this circumstance might be the teams' improvement over a previous period that would help track the teams' performance improvement.

The performance measures generally seemed biased in favor of time and schedule. Projects that were on schedule were almost always low on cost. Reliability, on the other hand, seemed too closely dependent on the reliability contract, rather than growing out of any management action that was taken. Thus, the participants dealt primarily with schedule while reliability and cost parameters not in line with projections gave added emphasis to scheduling.

Other measures of game performance, such as amount of overtime used, cumulative budget overruns, time gained through rescheduling, cost saved by rescheduling and cost effectiveness (reliability times expenditures to date) would have been helpful to the players. Addition of these performance measures seem in order if team performance is to be compared in a meaningful way. Several players felt a handicap system of scoring would improve competitive evaluation, and would permit the participants to gauge their own progress based on their prior experience.

Finally, the relationship between the game decisions and the performance measures was not sufficiently clear to permit players to clearly visualize or plan what future steps should be taken. A performance measure based on the spacecraft components and which added cost or delayed the schedule or clearly showed how to improve performance, would provide more meaningful feedback. In this way, the participants could see the results of their decisions on the basis of detailed effects.

D. PARTICIPANTS REACTIONS - 6 WEEK FOLLOW-UP

Interviews were conducted with the participants six weeks after the exercise to determine their reactions after they had an opportunity to reflect on their experience. The sponsoring companies' reactions were also solicited to determine if the game as it is currently structured was of interest to them for use in their training efforts. Lastly, the participants were given an opportunity to suggest changes and improvements to the exercise and the way in which it was conducted.

1. EXERCISE EFFECTIVENESS

The participants were asked to recall their learning experiences and give a brief evaluation of the exercise. The following comments are representative of the participants responses:

Participant Selection

- "The selection and screening of the participants is most important to the success of the exercise.
- When selecting participants and making up teams, it is very important to put people on a team who can learn from each other. Also, it is important to select a team with an approximately equal degree of competitiveness so that the team has a reasonable chance of working together.
- Those who go through the game should know about project management to get the most out of it. Thus, we should set prerequisites for the participants."

Project Management

- "The exercise was considered to be effective and interesting. It is a good learning tool for novice project managers, their supporting staff and for NASA personnel.
- I considered it to be more effective than college courses in project management and it was a time-saving method of preparing people to work on project management projects and related activities.
- I considered the exercise to be a powerful teaching technique, especially for the project manager position. I also thought it would be useful for assistants for the project manager (contracts, manufacturing, logistics, etc.) and those who need to know about project management because they interface with the function.
- The exercise is an excellent experience for someone going into project management, especially engineers who haven't been trained in management. This assumes that the participant has a high level of maturity so that he can appreciate the processess involved.
- The game would be valuable to lower level personnel in management in such areas as finance, scheduling and production. The exposure would give them an appreciation of why things are done the way they are.

  An innovation suggested is that of requiring the project manager to justify his past actions to the customer periodically. During these sessions, much of the debriefing in the proposed game could occur.
- Since the model is developed and proven, and I believe the necessary computers are available in-house, it is recommended that discussion with NASA be held for the use of the exercise for in-house use in the development of program management personnel.
- I saw the techniques learned in GREMEX as representing only about 20 per cent of the project manager's activities, and feel that these could be taught in a classroom setting or by playing GREMEX two days or by playing a much simpler simulation.
- The mission statements in GREMEX were much too clear cut. In a real-life setting, the negotiation to determine these is very complex and less clear cut. Thus, this dimension of the game was unrealistic."

Experience

- "This simulation is superior to academic presentations of materials on project management.

- I thought that the game should be linked with a more academic presentation of some materials and could serve as the place to apply theory and principles learned in other courses on project management. I suggest that USC offer a curriculum in project management with this game serving as the capstone course.
- Knowing that a majority of the perturbations and random elements are part of the program rather than purely at the choice of the referees is important. If the referee had more choice of perturbations, the simulation would be more unrealistic.
- I particularly liked the realism of the game as the participants were forced to react under pressure. However, it didn't allow for instituting a recovery plan which would be done in a real life situation if time became critical.
- The most important aspect of the exercise was the reality of the environment regarding the pressure, need to make decisions with imcomplete information, and the random errors generated by the computer.
- The game was competitive, despite statements to the contrary. Thus, there was the possibility that decisions would be made to look good in the short run and not to work out the problems faced by the project manager. This could be corrected by separating the teams or by removing the comparative charts, etc. Consistent refereeing is necessary if there is to be competition.

  The exercise allows one to experiment with different strategies and decisions and to receive valuable feedback regarding the impact of these decisions."

Value of Exercise

- "The knowledge gained by exposure to these management information techniques and specifically to the technique utilized by the Goddard Research Center in program management would prove valuable to myself and my company.
- The exercise provides a good simulation for the handling of resources and provides an insight to the kinds of activities that the GSFC project manager encounters. The exercise provides considerable familiarization with various cost and schedule reporting systems.
- The exercise would be very beneficial to many company personnel. Although not directly applicable to any one program, it makes you, as a project manager, think of all impacts (technical, cost and schedule). The exercise makes you look for cause-and-effect relationships and to take action far enough in the future to be effective.
- The greatest promise of the game lies in its adaptability to the management systems of individual companies. If company forms were used, then it would be an excellent in-house development exercise."

Drawbacks

- "There are still many problems with the game. For instance, some of the statements in the manual were misleading (e.g. there is no firm fixed price contracts available). Also, the opening statement was misleading (suggested there would be time for each player to make program manager's decisions - instead, teams had to divide the work). The Dynapanels misrepresented the situation shortly after the beginning of the game.

  One of the weaknesses of the game was in the technical decision area. More choice and decision-making in this area would strengthen the game's importance.

- There are a lot of problems to be over-come before the exercise is very useful for adoption by industry. Inconsistencies and misleading statements in the manual must be removed; consistent refereeing must be achieved; adaptation of the game to the company's way of reporting must be undertaken, but once these things have been accomplished, it could be used by the company.

- My opinion toward the exercise was that it was not worth the expense involved and that there was a real danger that the experience would be misleading toward the neophite project manager. The simulated invironment was not very similar to the real problems faced by project management. Not only was the environment not accurate, but the computer program was misleading because of some of the functions (for example, regarding slack time), that were built into the simulation."

2. CORPORATE REACTION TO GREMEX

The range of corporate interest ran from high to very little. This reaction in most cases was a reflection of how the participant from that company reacted to the exercise. Two firms believe that GREMEX could be adapted to the internal training programs of their company. They are currently studying the appropriate application of the exercise and evaluating the level of effort required to use GREMEX. Another firm is interested in GREMEX as a simulation, but without any attendant formal training program. Finally, another firm indicated that they have comparatively few project managers in their organization and that less expensive ways are available for training new project managers. This firm indicated a preference for an apprenticeship approach to training, the advantages being that a new man would immediately be faced with all of the nuances of project management.

3. RECOMMENDATIONS FOR FUTURE USE

The participants were asked for suggestions for future use of the exercise as a project manager training tool. They were also asked to react to a preliminary revision of a five day program which would strengthen the orientation emphasis and introduce a classroom treatment of project management concepts, PERT network analysis, cost controls and reports.

The following comments were received:

- "Future runs should begin with a clarification of permissible actions and the range of perturbations which may be forthcoming.
- The play could have run longer than five days and the idea of more de-briefing sessions and instructions would have improved it. In general, I am very enthusiastic about the new plan.
- The play could have been improved if the computer runs and the mechanics behind the playing of the game were coordinated more smoothly.

  I suggest that the status reports be verbal so as to minimize the lost time of those team members who must prepare the reports.
- Future runs could be improved if more briefing was given to the participants and if they had the manuals further in advance of the exercise. Also, several trial runs should be allowed to give them time to become familiar with the mechanics involved and to get to know one another.
- No outside material is necessary in future runs.
- Future runs along the line of that suggested by the proposed outline would be more beneficial. I like the idea of more debriefings, a comprehensive introduction and more direction for the players.
- A clear statement of possible courses of action available to the participants would enhance the exercise.
- The exercise should reinforce what people know; not be considered only as the exclusive learning experience. The game should reinforce a person's knowledge. This suggests that it should be used together with other materials and should be integrated into a total educational package.
- I recommend that we start by giving the project manager the events that must occur and then let him generate his own PERT network.
- I would allow FPIF contracts to be negotiated and bring in more technical programs.
- The game should be played as a team with each member playing the part he actually plays in the company. It would be suitable for new project managers and others who must work with him.

- Five days would not be sufficient for the exercise if the project manager must generate his own PERT network.
- The job of the project manager is very complex and GREMEX only dealt with one small aspect of the job. If the goal of the exercise is to simulate the work pattern of a project manager, then the following activities must be built into such an exercise:
  - -- make technical decisions and monitor technical progress
  - -- prepare presentations within the company and to customers
  - -- prepare reports to customers and coordinate them
  - -- fight for manpower
  - -- deal with internal personnel problems
  - -- fight with finance people over such things as work numbers
  - -- deal with top management especially in fitting the project into the overall corporate plans and objectives
  - -- deal with top management to fight for internal research funds which are part of the cost-sharing requirements for many government research projects.
  - -- internal meetings - to get overtime, money-sharing
  - -- other communications with customers - ironing out contradictions, elaborating on specific points, etc.
  - -- communicating with sub-contractors and working with their reports and with your people in activities related to these."

<u>Summary</u>

The six week follow-up responses were thoughtful and on-balance favorable toward GREMEX. In addition to this favorable response, all participants felt that some changes could be made to improve the exercise. Significantly, no participant thought the exercise wholly satisfactory. The overall reaction to the exercise and types of changes recommended were largely dependent upon the participants' background and management experience. The players who had some program manager experience tended to be more critical of the perceived rigidities in the game structure. These players were more perceptive of the nature of program management and indicated that as an overall or comprehensive training tool, GREMEX fell short of covering all critical decision making elements. Participants who did not have project management experience were more concerned with GREMEX as a learning tool and their comments reflected their perception of this learning experience.

The reflections and responses to GREMEX show in many instances a vague understanding of what the exercise was designed to accomplish. The "cold water" approach to the decision making process caused some concern for participants who were making decisions which could not be immediately evaluated as good or poor. To the extent the participants were uncertain as to the exercise objectives, and the participants background and experience was not taken into account, the simulation exercise left room for improvement. The overall reaction could clearly indicate the desirability of making the modifications suggested in Appendix III in order to make GREMEX a more meaningful training vehicle for aerospace industries.

IV. TECHNICAL EVALUATION OF GREMEX

A. DOCUMENTATION AND COMPUTER PROGRAM

A technical evaluation must first consider the effort taken to bring the program to the present form taking into account the myriad of details that necessarily are encountered in such projects. Thus, the efforts already spent to make GREMEX a workable and viable program are recognized at the outset. The evaluation then is directed toward the constructive areas for technical improvement.

The technical areas considered pertain to the documents that have been constructed in support of the exercise. This includes such documents as the computer program, player's manual, referee's manual, computer operating instructions, mathematical and computer specifications, and other materials which are considered relevant to the technical aspects of administering the GREMEX program.

The major areas which should be considered first priority items for improving the exercise are listed below in order of importance.

- Final check-out and verification of the model.
- Modification of the decision input format to simplify self-checking by the participant players.
- Changing of the team history tape operation to facilitate stagger inter-team decision input.

Second priority items for exercise improvement and flexibility are also important and are shown below:

- Improved diagnostic routines to aid in troubleshooting problems involved with software/hardware halts (caused by invalid keypunch error, illogical decision, etc.).
- Allowing more than 99 decision "elements" to be made in any one month of play.
- Simplifying the program for adaptation to smaller, less expensive/more available computer, i.e. set-up to run on 360-40, instead of 360-65, with less than 200 k bytes of memory.

Improve computer program doucmentation (more comment statements, table structure, subroutine descriptions, flow charts, etc.) and documentation of a mathematical and computer specification which clearly explains how the computer program and the model operate on player decisions.

All other suggested technical improvements discussed in this section would be considered in a third priority classification. These would include the use of off-site input/output devices, improvement of the referee's manual, aids in making the program more efficient, and others.

1. Computer Program Operation

There were several indications that the computer program still had minor bugs and there were some questions relating the computer program to the mathematical model. Because delays were caused during the course of the exercise and time was taken away from the main course of play, a discussion of these factors would appear useful.

Excessive Changes in Slack

A few problems came up during the exercise that indicated further validation of the computer program was needed. One such example was sudden increase in slack between two periods. This occurred in Period 4 for Team #5 and detail changes are presented below:

Contract No.	Play 3 Slack	Play 4 Slack	Difference
#2	13.4	7.1	- 6.3
#3	15.9	7.4	- 8.5
#4	30.5	12.2	-18.3
#5	10.1	1.5	- 8.6
#7	16.4	10.2	- 6.2
#8	22.9	7.2	-15.7
#9	11.4	3.9	- 7.5
#10	3.3	2.0	- 1.3
#11	16.7	12.6	- 4.1
#12	17.8	14.6	- 3.2
		TOTAL	-79.7
		Average Loss	7.97 weeks

No reasons for such a large universal shift could be found in examining the player actions for Period 4. Period 4 listed 2 activities involving schedule changes ranging from a decrease in available time of 1.9 weeks to an increase in available time of 4.2 weeks. Both the small magnitudes and dispersed placement of these slacks suggest that some other unspecified factors accounted for the preponderance of the above excessive slack.

Totaling Error (or Difference)

In one use there appeared to be a totaling error wherein the net overrun or underrun for the entire project was substantially different from the sum of its cost elements. Team #5 encountered this difficulty in Period 14. Details are given as follows:

Contract Number		NASA PERT Management Summary Report (Overrun)	Underrun
# 1		(37)	
# 3		(37)	
# 4		(41)	
# 5			5
# 7		(9)	
# 8		(10)	
# 9		(49)	
#10			8
#11		(24)	
#12		Not specified (had been -6 in Play 13)	
	Total (except for #12)	(207)	13
	GRAND TOTAL	(194)	

Total Underrun per the Project Management Summary Report = 362

The difference between these two reports $556 K, 362 + (194) is, of course, quite significant and would appear to be an error in the program. While admittedly the effect of contract #12 is not taken into account, it would not seemingly make a major change in the $556 K difference between these two reports. The fact that the cost for contract #12 did not print out for this period is also a reasonable debug question.

Incomplete List of Activity Time Changes

GREMEX should provide a listing of those activities which changed substantially since the previous play. This feature did not operate satisfactorily, i. e. listed some significant changes but not all of them. Some of the changes not listed were larger in magnitude than those listed.

Overflow Error

A repetitious error (Team #5) showed positive slack for a completed activity of 3,276.7 weeks (which is an unrealistic magnitude). This figure, once it occurred, showed up on every subsequent report (since the activity had been completed). No discernable adverse impact could be determined elsewhere from this error.

Bin Calibration Error

In one case, the addition of dollars to a bin or bucket reduced its contents. Thus, when a project was cancelled, instead of there being more available dollars, less funds were available. This bin balance problem was encountered by all teams. The problem, however, was solved (W. Rockwell - MTI programmer) during the course of the exercise. The subroutine ACTNJ was effectively dividing the old bin balance by 10 before adding it or subtracting from it. The program was changed on Wednesday (8/27) but when it was compiled and loaded Thursday, the load was unsuccessful. A re-load on Friday apparently solved the problem, however, some testing should still be made to verify all cases.

Other Errors in the Program

Another error in the program appeared during the game. The subroutine ERR used Z-format and had to be changed. It only called for a terminating error, however, this did not appear until after the first play. A more serious problem faced Team 3, which tried to freeze a component and then unfreeze it. The program tried to use the output from UNPAK as input to PAK and the two subroutines are not compatible. When the subroutine ACTNT was changed to correct this, the components could still not be unfrozen, but it is possible that the file had been in such a condition where even the correct program would not work. At the same time that this change was made, GENRPT was modified to print the bin balance in thousands of dollars, compatible with other dollar outputs, rather than in hundreds of thousands of dollars.

Another unexplained problem that came up during the exercise was the program provision which allowed Team 5 to start some of their contracts prior to the first period. Also in Period 12 (Team 5) the slacks became inconsistant when an activity was completed before its predecessor had been completed.

2. Improvements to the Computer Program

The previous section covered several of the bugs in the existing program and this section will cover areas where improvements should be made to the program for more effective operations. Two of these (input format, and converting to a smaller sized computer) are covered as special topics in separate sections.

Eliminate 99 Action Restriction

One constraint, which caused some difficulty, was the limit of 99 action elements which can be taken in any one play by a team. Several teams found that some of their decisions were not executed. This resulted from a maximum restriction of 99 actions that can be taken. This occurred when in the initial plays, many actions regarding contracts awards, start dates, selection of management reports, etc., were made. In some cases the teams did not get back any reports because the specification of the type of report and its frequency were the 100th, 101st, ... decision actions and the computer program had cut off all decisions past 99. This necessitated a re-run of the period for all teams as well as modification of the number of decisions that they wanted to make. This restriction on action elements could easily be changed in the program.

Error Detection and Diagnostics

The GREMEX program, at present, had good but incomplete diagnostics and error detection logic. Manual verification of inputs is the primary means for prior detection of the decision input which will cause termination of the program and/or illogical calculations to be printed out. An improved default procedure would be to construct a programmed routine which could be used to pre-edit or screen input data cards for accuracy, completion, registration of fields, validity of codes, and reasonableness of dates. Appropriate diagnostics and procedures could be designed to reject the data and/or drop illegal decisions rather than permitting it to hang-up the systems -- which then delays the exercise for all participants. Appendix 1 contains samples of proposed restructured input forms.

While manual checking and verification of the input data is useful and necessary, even under an improved data edit it was quite evident in this exercise that input errors were being discovered by the computer after going through a manual checking process.

Labeling of Output Reports

While not a major problem, the description of the various output reports did present some confusion. It is recommended that clear titles, frequency, and levels be matched precisely with what is shown in the players' manual. One example in the players' manual indicated an option to allow the player to receive the NASA 533 cost report; however, the computer output for this report did not have this specific title. For those not intimately familiar with such reports, it did cause an unnecessay point of initial distraction. Along this line the level of the report was not clearly labeled on the computer output form. Also, there was some confusion as to what the so-called "levels" referred to, especially between cost level and time levels of reporting. This could easily be cleared up by indicating on the output report that this report is at the component level as opposed to "level 3."

Increased Management Actions

An improvement in the program would be the provision to allow the player to change the project network structure as he may do in a real management decision-making role. This could be a very complicated modification and should probably be added to only a few of the activities that would normally represent a situation.

History Tape Modification

Under the present GREMEX computer program, it is not possible to take any team back to a previous period without also taking all teams back to the period desired and reprocessing all subsequent input. This is an extra burden on both computer and administrative operations as it slows down the entire exercise and is costly. The requirement to replay a team's decision is frequent enough to warrant a more flexible history tape set-up.

There are several solutions to the problem. The easiest solution is to have an option to suppress print-out for selected teams during any run. Then, if it is necessary to back-up, the teams not being backed-up may be run with no print-out. This still required that their input be used, however, and that the calculations be made for them. Also, the previous history tapes would have to be saved.

Another method, involved a history tape structure such that any teams can be backed-up by a control card. The disadvantage of this method is that as more plays are made, more time is required to copy the prior history from the old to the new tape. There is a solution to this which may be useful. The program can be put on disks, and each new history record for each team, can be stored as a separate file on disk, making it extremely simple to back-up using the standard management procedures of OS/360.

Decision Input Format

An important consideration in the GREMEX exercise was the structure of the decision input format. It is not immediately obvious to the player after reveiwing the Participant Action section of the players' manual which decisions are made in conjunction with each other, how they interrelate, and in what sequence they are to be made. In addition, a player could not easily check to see if his decisions were executed by the computer. Since the greatest number of delays during the exercise were connected with decision input problems, it is felt that a worthwhile and cost-effective improvement can be made to the GREMEX program by restructuring the input format. (See Appendix 1)

One suggestion possibility would be to group similar kinds of actions and to differentiate among:

1. Initial contract set-up actions.
2. Selection of Management Reports.
3. On-going Management Actions.
4. Referee Actions.

Perferably, a different card type should be set-up for each purpose. Note that the third category above covers the preponderance of player actions made during the game. Categories 1 and 2 are both of a set-up nature and involve infrequent changes during the exercise. The player need not be oriented in the specific needs of actions in the fourth category (referee actions). Sample formats of the four types of inputs appear in Appendix 1. In Format B note the additional codes which would permit specifying a given set of reports for all active contracts. These input formats could be structured in such a manner as to facilitate manual interpretation of the data contents.

The input contents should then be printed out as the first portion of the player output with the action headings for each type of card clearly labelled above the "value" of the decision made each period. This would allow the player to check his own input when questions arise in connection with the decisions which were made for the period.

Hardware Requirements

A significant consideration in the GREMEX program is its requirements for a large scale computing system (IBM 360-65). An investigation should be made of conversion considerations to run GREMEX on a smaller computer, possibly an IBM 360-40. There are at least two ways to attack this problem. The present program takes a 265 K core to operate and with the use of overlays this might be cut down to about half but probably no more than that. The other alternative is to program it for a disk system where the saving is through data organization.

Another area of possible program change would be to put the program into a remote, possibly time-sharing, structure. This would allow the GREMEX exercises to be performed at any location where the data-communications facilities were available.

Although use of a portable remote terminal (e.g. teletype) would be possible, there would be a problem with print-out. While the input would consist of only a few lines for each team (in the revised input), the output would still be as voluminous. There are on the market, however, several new remote terminals which have medium or high-speed printers in their configurations. The use of a remote system could eliminate the problem of finding a machine of suitable size. The problem would be reduced to one of finding either a machine of suitable size or an installation with data communications facilities.

In order to maximize the training time allocated to the GREMEX exercise, it is important to minimize the delays caused by the necessary processing of the decisions by the computer. Because immediate access to a large computer systems (IBM 360-65) is not readily obtainable, it would enhance the future utilization of GREMEX (especially for university and industrial organizations) to investigate ways to reduce these problems.

An insight into the scale of operations for setting up the GREMEX program is contained in Appendix II.

V. CONCLUSION

Gremex originally was designed to simulate the project management environment at NASA relative to space contracts. In particular, it was to provide technical personnel, who rarely have managerial backgrounds, an opportunity to develop management concepts and gain experience in using management techniques. The cost of providing such experiences (including a normal incidence of mistakes) in a simulated environment would be far less than in the real world.

Having demonstrated the usefulness of GREMEX for its original purposes, NASA management felt the basic concepts and simulation model might have extended uses. The current GREMEX exercise was initiated to gain further insight into the questions:

1. Can the GREMEX simulation model be useful in other environments-specifically, in industries where long-range, large-scale R&D projects need to be managed?

2. If so, what modifications might be desirable to maximize the benefits gained from GREMEX when used for broader purposes?

3. Is it helpful for NASA contractors to know how aerospace contracts are managed?

Fundamentally, the GREMEX model should be considered as a training tool, though a technically intricate and powerful one. Thus, primary emphasis in running a simulation exercise should be placed on creating an optimum total training environment, using various kinds of training tools at the times and for the purposes each is best suited. Undue emphasis upon the tool itself during the exercise can result in a preoccupation with technical details, and a less than optimum overall training experience for the participant.

In carrying out the exercise, despite a reasonably thorough briefing, occasional stiuations occurred which highlighted soft spots such as:

1. Can changes be made in activities currently underway?

2. Does the action list contain all legal actions in the game? What are the available actions which can be taken?

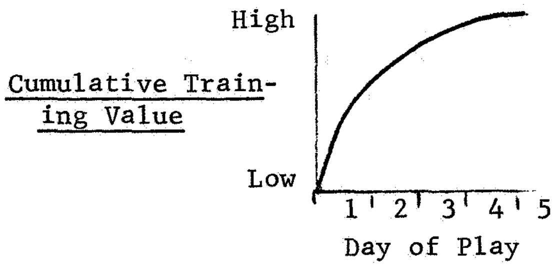
3. What do some of the actions mean? What contraints apply to them?

4. What significance can be attached to the probability figures calculated during each play?

5. What are the cost impacts of positive slack in a schedule?

6. Where timing inconsistencies occurred in documentation, which were right?

As the play of the simulation game progressed, the approximate "learning value" appeared to be very high the first day, then gradually decreasing with each successive day:



Thus, the learning experience essentially followed the principle of diminishing returns. Increasing the learning rate, especially in later plays, might be accomplished through a variety of ways:

1. Gradually exposing participants to available management actions in phases - introducing new problem types and new decision-making tools each day.

2. Changing the pace of runs, time available for analysis, etc., after an intensive initial learning period.

3. Shortening the number of days and/or plays, particularly if used with lower levels of management.

4. Making later plays intermittent with one's normal day-to-day duties such as:

    a. a full day of orientation and several plays.
    b. a gradual schedule - perhaps a half-day once per week for several weeks.

5. Providing supplementary analysis sheets or questionnaires (free form) to document in some detail why certain key decisions were made.

6. Varying the relationship of individuals to teams:
    a. establishing the informal, "no captain" team relationship.
    b. specializing the tasks to be done, then rotating the task among team members from play to play.
    c. permitting individuals to run certain plays as an individual, with other team members as observers.

7. Providing pre-determined and prepared training aids to identify cause and effect relationships and adverse impacts of problem situations - such as unwise decisions relative to perturbations of the model. In a sense, the perturbations potentially afford a receptive learning atmosphere relative to decision-making principles.

In general, the model appears to simulate the corresponding real world processes very well. However, occasional circumstances arise which point out possible refinements which might be made to the model itself. For example, in one case, during the period of a single play, extensive unexplained schedule changes occurred to almost all experiments, averaging an additional 8.2 weeks delay and ranging from a minimum of one week to a maximum of eighteen weeks additional delay. The game does provide for unusual circumstances ("perturbations") to occur, but none was indicated in this case. Listed changes in activities accounted for only a small proportion of the aggregate changes.

Although GREMEX appears to be a highly useful tool for the purposes for which it was designed, considerations needing further examination in expanding the use of GREMEX into industrial environments include:

1. The need for decentralized control over the simulation exercise itself; i.e. so that a corporation can be is own simulation administrator.

2. The need for improved documentation of the exercise, including:
    a. players manuals
    b. referees manuals
    c. computer program documentation-flowcharts; source listings; narrative descriptions of systems concepts, assumptions, and processing paths; file and table structures and organizations; code meanings; diagnostic and error handling procedures; operating system requirements, keypunching instructions, etc.

3. The availability of training aids, such as wall charts for participant results, diagnostic visual aids demonstrating key concepts to be learned, orientation information and training objectives.

4. The need for training materials in a more modular form to accomodate greater diversity, since the purposes and mode of use may vary somewhat from corporation to corporation.

5. The need for a planned curriculum and qualified instructors to teach corporate personnel basic concepts of simulation, and how to run their own games.

6. The need for orderly feedback from corporations in order that the good ideas from one may be incorporated and communicated for the benefit of all, and so that the problems of each may be considered and solved before others are affected adversely.

7. The need for some freedom of experimentation and adaptation as each user attempts to maximize the benefits of this powerful tool in his individual situation.

8. The need for increasing the scope and variety of management actions available:

   a. reducing or reassigning certain levels or types of overhead.
   b. speeding up or slowing down materials flow, and adjusting inventory levels.
   c. increasing or decreasing capital expenditures, with some built in time lags.
   d. controlling reliability through changes in specifications, increased sample sizes, prescribing additional or changed modes of testing, testing in parallel where feasible, etc.

9. The need to make the cost factor, as expanded in item 8 above, somewhat more independent of schedule considerations than is now the case; however, all schedule actions should continue to have related cost impact.

10. The need to change "reduction in manpower while extending activity duration" from a referee's decision to a normal managerial decision.

When one considers the enormous economic impact of management decisions, an appreciation is gained of the potential value of directed research into management decision-making utilizing a vehicle such as GREMEX to answer questions as:

1. Why were key decisions made as they were?
2. What principal factors contributed to the outcome?
3. Through what process was the decision made?
4. Was the decision an individual or team decision?
5. What reservations were felt by the decision makers about the merits of the decision?
6. What probability of success would the decision maker have assessed?
7. What constitutes good and bad decision-making?
8. What kinds of characteristics differentiate "good" from "bad" decision-makers?
9. How much effect does time pressure have upon the quality of decisions?
10. Is past experience or native ability a stronger determinant of good decisions?
11. How essential is management data in the decision-making process?
12. How susceptible is good decision-making to training?
13. How transferable are decision-making skills from one situation to another?

In utilizing GREMEX in an industrial environment, the player's manual, as well as all other exercise documentation, should be reviewed in its entirety. Among the specific changes which might be made are:

1. Broaden the stated purposes.
2. Generalize the wording somewhat to identify the individual corporation as the operating administrator of the exercise (though still giving developmental credit to GFSC).
3. Describe new types of management actions.
4. Update computers used, general dates used, schedules, changes made in the model, etc.
5. Discuss the significance or meaning of available management actions.
6. Increase the use of visual aids in the text.
7. Samples of reports should include a copy of each level as well as each type used. Terminology in describing a report should be consistent with the nomenclature on the report itself.
8. Provide a full catalog of actions available to participants.
9. Where the participant makes out a report, provide sample forms or examples.
10. If the S-101 technical and business evaluations represent real companies they may need to be disguised more thoroughly, and the "internal use only" restriction lifted.

GREMEX appears to be well suited for its original purposes, although some refinements have been suggested which can provide enhanced benefits even for NASA's internal use.

Additional effort can be well spent in improving the overall training environment in which the GREMEX simulation is run. In the later stages of the game, more variety in the nature of problems, tools available, and pedagogical approach can enrich the training experiences for participants.

Training materials and documentation need to be re-examined in terms of the new needs of potential industrial users. Some adaptation of the model also would be desirable.

Finally, GREMEX should be considered an important addition to the state-of-the art in management decision-making, useful for new applications such as the training of middle management, selling PERT, personnel screening, and research into management decision-making.

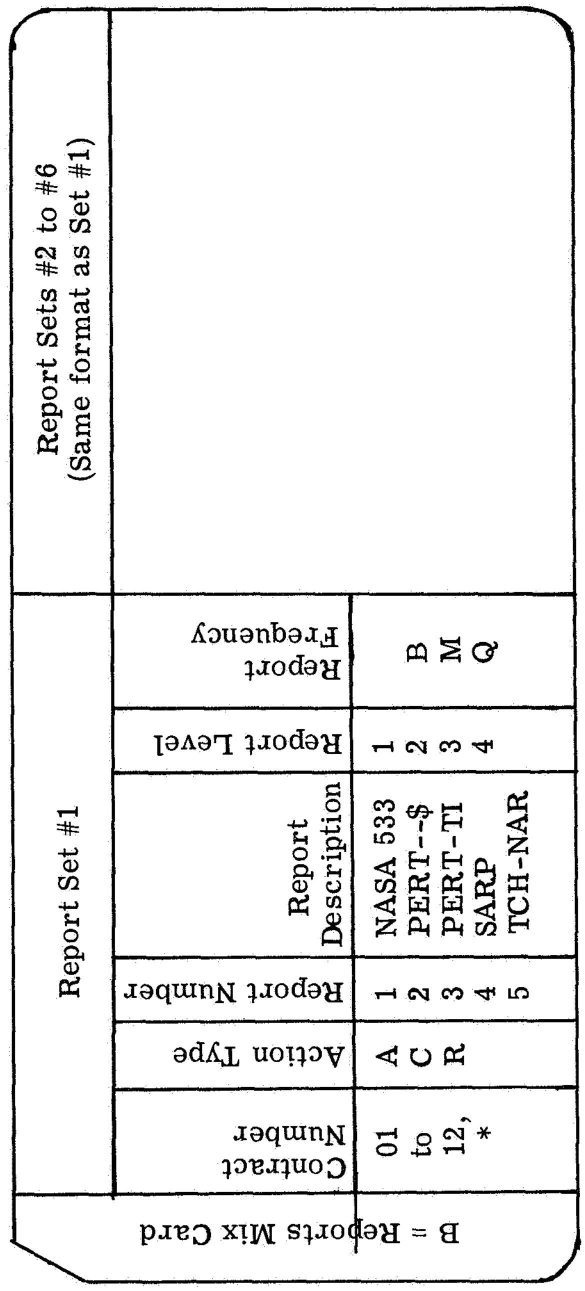
APPENDIX I
RE-STRUCTURED INPUT FORMS

A. "CONTRACT SET-UP" CARD (one per contract).

A = Contract Set-Up Card	Action Type	Contract Number	Contractor or Experiment Manager	Contract Type	Contract Start Date	Renegotiate Launch Date	
			Contr. D Maine Stanford So. Car. Army Etc.	CPFF LTR CPIF FP	2/20/67 8/31/68 etc.	12/30/69 etc. (If renegoti- ating only)	

Type of Contract Action: A = Award Contract
C = Cancel or Delete Contract
R = Renegotiate Contract

B. "MANAGEMENT REPORTS MIX" CARD (specify up to 6 sets of Reports per card; use multiple cards, if needed).



Type of Report Action:
- A = Add Report(s)
- C = Cancel or Delete Report(s)
- R = Revise of Change Report Requirements

Contract Number:
- * = Provide this Set of Reports for all Active Contracts

C. "ONGOING MANAGEMENT ACTIONS" CARD

M = Management Card	Activity/Element Ident.						Resource Allocation				
	Action Code	Contract Number	Predecessor Event No.	Successor Event No.	System Number	Sub-System Number	Time: Start Date	Cost: Dollars	Perform-ance: Reliabil-ity Spec. (%)	Coded Reason for Action	Referee Action
	40 35 xx	07 04 01	213	219	1	2	6/12/68	203	95		For Referee Use Only

D. "REFEREE ACTIONS" CARD

Same format as above, except: "R" in 1st col. = Referee Action (additional referee action field is usable).

APPENDIX II

DESCRIPTION OF THE COMPUTER CONVERSION PROCESS

Due to the considerable effort involved in the process of getting the GREMEX program running on Systems Development Corporation's 360/67 computer, the following experience has been reconstructed. It is intended that these brief notes may be of some use to others who may be involved in using the GREMEX program in subsequent plays or involved in simplifying the hardware set-up problems. In view of the fact that there was a good source deck, highly qualified software staff, and they merely had to convert the program from one IBM 360 computer to another, the problem seemed at least manageable in the four-day span prior to the formal exercise. Nevertheless, the effort did involve 10-15 persons and probably better than one man-month of effort compressed into the three days it took to get the program operational. (See Table A.)

Specifically, the source program deck that had run on the GSFC's IBM direct couple 360/65-360/50 system had to be converted to SDC's IBM dual 360/67 system. The programming staff involved all high level computer analysts who had combined experience and familiarity with both computer systems, knowledge of what the GREMEX program was supposed to do, and detailed hardware and operating system knowledge.

The disucssion in this Appendix will center around only those problems concerned with the 360 GREMEX program deck. We did have available a GREMEX 7090 program deck and some effort was made to utilize it as a possible backstop for problems that might possibly occur with the 360 program deck. However, we did not have sufficient time to validate the 7090 mode of operation.

To summarize the reasons for the difficulties is not easy; however, it is important to note that the difficulties were not caused by lack of qualified personnel, access to the computer, or sincere cooperation among the parties involved.

The conversion process was generally divided into two stages. The first was some initial attempts to get a deck running and to obtain some understanding of the program mechanics prior to the arrival of NASA technical personnel. The second stage and primary effort was made after NASA administrative and programming personnel arrived

Table A. --GREMEX Computer Set Up at S. D. C.
Rough Approximation of Manpower Effort, August 1967

	Pre-Trials				Main Trials NASA Deck & Aid				
	F 11	M 14	T 15	W 16	T 17	F 18	S 19	M 21	Total Main Trial Effort
Programmers/ Analyst/Operators									
NASA (T. Sullivan)					10	14	6		30
MTI (R. Rockwell)	5	5			10	14	6		30
SDC Computer Operator		2	2	2	8	8	6		22
SDC Systems Analyst	4	4							
SDC/IBM Rep. (D. Barth)		2	2	2	4	12			16
SDC/IBM Rep. (Ky)						6	4		10
SDC/IBM Special Rep.							5		5
SDC/IBM Special Rep.							5		5
Sub-Total (Hours)									118
Administrative Support									
NASA (M. Denault)					8	14	6		28
USC (P. Gruendemann)	5	5			4	14	6		24
SDC (C. Fiala)					6	14	6		26
MTI (P. Thompson)	5				8	14	6		28
SDC (B. Cavanaugh)					10	16	8		34
Sub-Total (Hours)									140

with revised source decks which they had been running on their hardware at GSFC.

Initial Attempts

At the request of the USC/MTI staff, NASA-GSFC had sent an earlier version of the 360 deck for experimental use prior to their arrival with the current version. It was believed that SDC could get the earlier version to compile and/or better anticipate the technical problems which might occur in converting the final version. An attempt was made to execute the earlier version on Friday, August 11th; however, for various reasons, it would not compile. Additional attempts were made on the following Monday and Tuesday with only moderate success. Execution of the PREEP program was achieved which establishes the the players' history, but not the final execution of the remaining GREMEX programs. There were several reasons given for lack of execution and they included: condition of the program deck, SDC operating system, and lack of previous exposure to the program. However, these pre-trial efforts were worthwhile and gave the USC/MTI/SDC technical personnel a good initial understanding of the problem areas.

Primary Efforts

Thursday, August 17

Personnel from USC, MTI, NASA and SDC met early Thursday to commence the main thrust of the effort involved in the hardware validation process. The GREMEX deck was compiled on Thursday and an additional effort was made to execute it, using a 9-track PREEP tape brought by NASA. When this failed, ostensibly due to tape (parity) errors, an attempt was made to create a new PREEP tape, using the object decks that NASA had brought with them. This yielded the error message to the effect that an attempt was made to write more than 255 segments in one buffer. It turned out that this message was obsolete and a newer (different) manual indicated that records written without format control from FORTRAN had to have a record form of V (variable). NASA had run this same program using an F (fixed) form. SDC was using the O. S. Version 11 which required the V form of record. The FORTRAN Programmers' Guide showed that the maximum buffer size was 3124 segments (NASA had used 5000). Also, the manual indicated that a LRECL (logical record length) option was needed in the DD card.

Friday, August 18

As of Friday morning, the program still did not run. During Friday, what appeared to be a good PREEP tape was prepared, but GREMEX would not read it, using the identical record format. Further trials Friday achieved no success. This was an exceptionally long day for all involved (from 8 a.m. to 10 p.m.) and with very little concrete evidence as to why the program would not run. It was decided to bring in two IBM specialists the next day for added knowledge as to where problems were occurring. It is worth noting that SDC's dual IBM 360/67 had been in operation less than a month so there were some reservations about the system, however, this problem had not been previously encountered.

Saturday, August 19

Saturday at noon, when program maintenance was completed, additional IBM personnel had been called in. After trying various possible combinations of parameters, it turned out that, contrary to what the IBM manual clearly says and diagrams, a LRECL must not be used when the logical record length exceeds the physical buffer size. At this point, the program was running with only one problem: the carriage control did not function.

Monday, August 21

The game ran for period 1, still with no carriage control. After many experimental runs, and proper combination of parameters, period 1 was re-run to obtain good output. There is no explanation as to why any of the other trials did not work, since the manual indicated that they should have been equally correct, including the default option (no explicit parameters).

Conclusions

Our problem with conversion came from several sources. The prime problem was the fact that the program and control cards from Goddard were for a different version of the O. S. Indeed, the compatibility from one installation to another, on any system, exists only if they are using the same operating system. This problem suggested trying to construct a proper control sequence from the manuals. This was a disappointing experience. The manuals were fairly clear and concise, but incorrect. (Or possibly, the manuals were correct but the Operating

System was in error.) Our experiences generated at least one document correction within IBM, as well as a search for what was wrong with the carriage control option.

Another problem stemmed from the Operating System, itself. In particular, the system was trying to do a type of AVR (automatic volume recognition) operation, even on output tapes. Our attempt to use a blank (new) tape resulted in many errors followed by a run-away tape. Further, if a tape was readied prior to when the operating system requested it, the tape would be read for a label and then unloaded. Other Operating System difficulties included poor documentation of errors. The operation had only a limited control over the system, yet the on-line typeout was considerable.

The final problem, one which existed throughout conversion and operation, was a circumstantial one. At the time, SDC was converting from a 360/65 to a 360/67 (dual 65). All three CPU's were in-house, with the 65 and one side of the 67 being used at any time. The problems with a new system were multiplied by the problem of switching I/O units between the two systems. These caused mis-runs and delays. In one case, a CE switched a unit we were using and it took several runs to determine what the error was. In another case, the operator was trying to address a unit with the wrong address.

The fact that conversion was made within the time limit, despite these problems, is a result of the commitment of SDC to this project. Operations gave us highest priority on the equipment. The Operations Manager saw that we got on the equipment whenever we were ready to do so. Throughout the three days of conversion, we delayed production with our computer errors. In fact, even during the game itself, our irregular runs were given first priority, disrupting the scheduled production work.

Recommendations

----That the master GSFC version of GREMEX be maintained on an operating system which is kept at the latest version to prevent compatibility problems.

----That the operating instructions be updated, revised and expanded to be a complete operating and conversion guide. Along this line, a description of intent for the control cards will help adaptation to any installations' peculiarities.

----That only standard (IBM standard) catalogued procedures be used.

----That conversion be started at least a week in advance of the game, when conversion is indicated.

----That the program be transmitted via tape, rather than cards, where feasible.

----That a record of known program errors be kept, much as a record of suggested improvements is being maintained.

APPENDIX III
GREMEX IMPROVEMENT RECOMMENDATIONS

Specific research, training, and administrative techniques and objectives of the GREMEX improvement program would include:

1. The development of the GREMEX exercise into a more attractive form for use in industrial executive programs.

2. Experimentation in the running of the GREMEX exercise at a university site, using a remote terminal linked to a distant computer located, perhaps, at GSFC or SDC.

3. Extensive briefing as an integral part of the play and as a means of accomplishing training objectives.

4. Course participation by special guest lecturers, giving particular emphasis in such areas as: contractor evaluation, types of contracts, contract negotiation, use of PERT and other reports, and program monitoring and control.

5. The development of improved status reporting techniques for team/team and team/instructor interchanges in accomplishing learning objectives.

6. Utilization of two referee-instructors and one course coordinator for exercise administration, providing a reduction in quantity but an increase in the potential utility of the administrative staff.

7. Experimentation with five-man vs. three-man teams.

The improvements could be accomplished by changing the present manual to include the features shown below. (This, of course, recognizes that the current manual was rated very high by all participants.)

1. Greater simplicity needed in the manual's structure.

2. Should be modular, in phases, each phase being

independent so it can be bypassed or intensified according to the needs of a given situation.

3. Basic foundation concepts should be explicitly taught, leaving "discovery" as a means for acquiring more subtle concepts. However, the concepts sometimes may be taught after problem exposure to create a "need to know".

4. Each phase (day of play) should be unique in curriculum content, although the model operations may be much the same. This provides a continuous change of pace, a stimulating learning environment, and something new to be mastered each day.

5. The student should never know what to expect next.

6. The manual should be participation oriented.

7. Data contained in the player's manual should be substantially pre-screened as an offset to the compacted time frames available for decisions.

8. Timing in presenting new concepts is as important for the "overall educational experience" as it is in a dramatic production, letting the "story" or "plot" unfold naturally, building up to a "climax", etc.

A sample of a proposed player's manual is shown on the following pages.

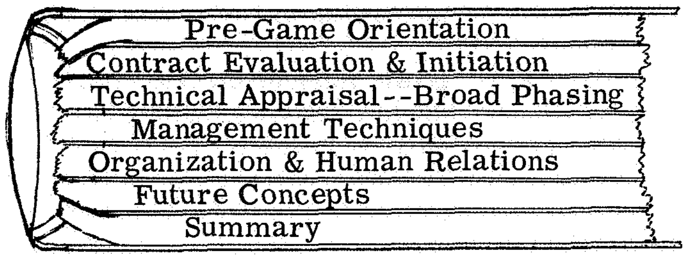
In addition to the manual, the following revised course outline is suggested as a means for implementing the modified GREMEX exercise:

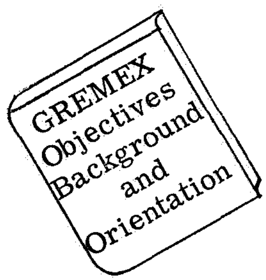
I. FIRST DAY

A. Brief orientation and organization of teams
B. Negotiation of contract types
C. Debriefing--advantages of contract type
D. Determination of research contracts to award

PRIOR TO FIRST DAY OF PLAY

"Dynamic" Player's Manual Sectionalized to "Lead" the Learning Process

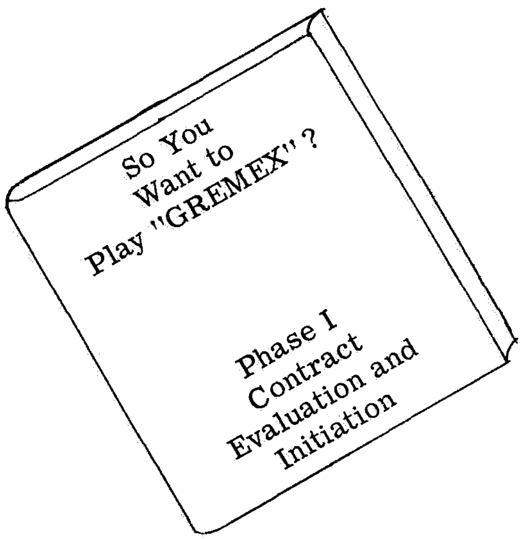




1st Section: Pre-Game Orientation (self study)

Includes
- Supporting Readings
  - ..Program Management
  - ..Simulation
  - ..PERT

FIRST DAY OF PLAY

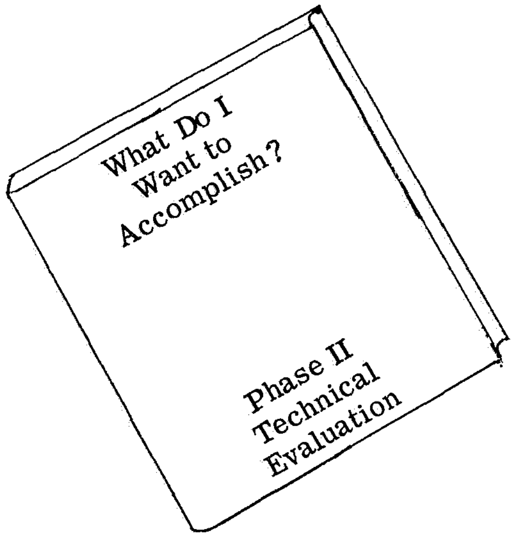


Immediate Briefing on Simulation and GREMEX

Contents

Purposes and Nature of Simulation
- ..Limitations of Simulation
- ..Characteristics of GREMEX
- ..Environment and Decision-Making Needs of a Program Manager (General)
- ..Discussion of Contract Types--Pros and Cons of Each
- ..Negotiation Practices and Ground Rules
- ..Management Information (Reports) and Decision Making
- ..Available Management Decisions and Significance First Day's Play
  - ..Contractor Selection
  - ..Contract Type Selection
  - ..Funding, Manpower and Program Plan--Prime Contract
- ..Initiation of First Day's Play
- ..Establish Operating Strategies

SECOND DAY OF PLAY

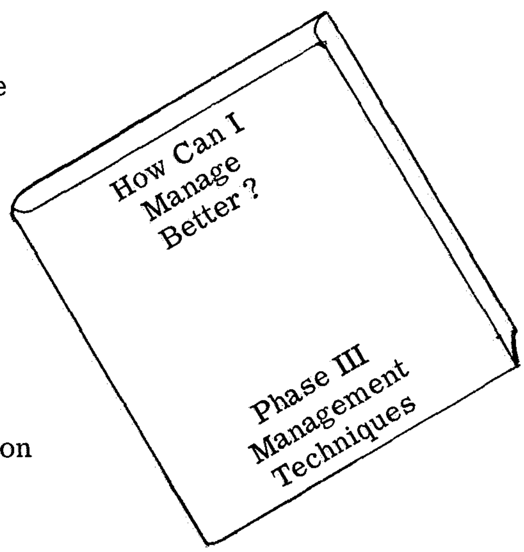


Orientation on Technical Evaluation

Contents
.. Technical and Analytical Basis for Simulation Decisions (Research Selection)
.. Sub-contracting
.. Review of Contract Evaluation and Initiation
.. Broad Phasing of Major Program Sub-elements (Milestone Charts)
.. Instructor and Participant Role Playing--Negotiating Contracts
.. Initiation of Second Day's Play(s)--2
.. Debriefing After Play(s)--2

THIRD DAY OF PLAY

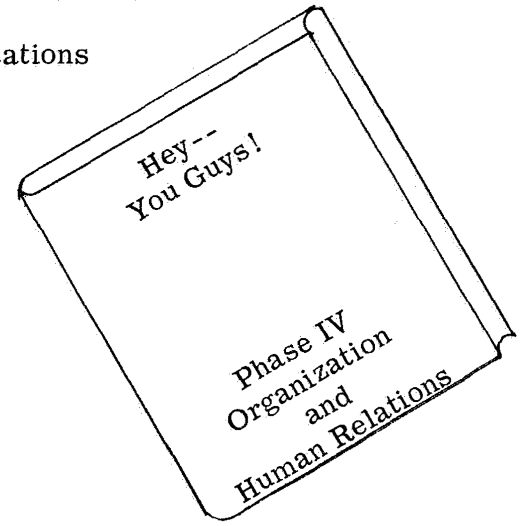
Contents
.. Overview of Management Science Principles
.. Evaluating Reliability, Cost and Schedule Performance
.. Critical Path Scheduling and PERT
.. PERT Cost
.. DYNAPERT and PERT Graphics
.. Management Reports
.. Initiate Third Day's Play(s)--2
.. Debriefing After Play(s)--2
.. Systems and Systems Optimization
.. Trade-offs



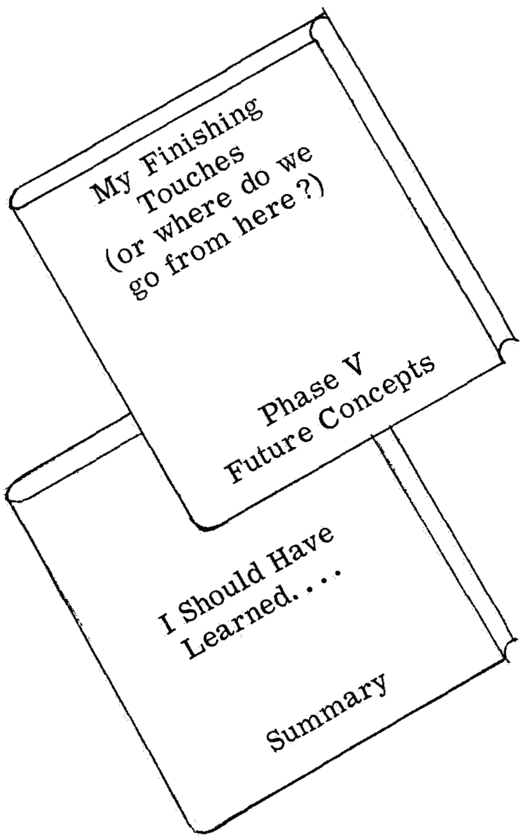
FOURTH DAY OF PLAY

Contents

..Experiments in Various "Team" Structures and Modes of Operation
..Experiments in Human Communications
..Operating Under Pressure
..Motivating Project Staffs to Achieve Desired Performance
..Decision Making in a Human or Social Environment
..Fourth Day's Play(s)--2
..Fourth Day's Debriefing--2



FIFTH (LAST) DAY OF PLAY



Contents

..Launch and Mission Effectiveness
..Post-Launch Wrap-Up
..Participant Post-Mortems
..Brainstorming the Simulation Approach--Its Educative Impact
..Experiments in Extended Uses of Simulation

Review Given At Final Debriefing

..Gives Highlights of the Game
..Summary of Personal Strengths and Weaknesses
..Bibliography and Sources for Further Study
..Response Forms Giving Player Feedback (to improve game) --including his own graph of his "interest curve"
..Final "Exam" (not used for conventional purposes)

FIRST DAY (continued)

E. Debriefing--logic of research selection
F. Review manpower, financial program plan
G. Explain the use of PERT networks
H. Submit initial simulation decisions
I. Run simulation--introduce minor perturbation
J. Debriefing--use of reports, possible actions in simulation
K. Submit second set of decisions--possibly restart.

II. SECOND DAY

A. Role play by instructors--NASA decisions
B. Continue simulation decisions
C. Debriefing--establishing operating strategies
D. Continue simulation decisions
E. Status reports from all teams.

III. THIRD DAY

A. Negotiate changes in program
B. Continue simulation--major perturbation
C. Debriefing--planning and control strategies
D. Continue simulation
E. Debriefing--determination of trade-offs
F. Team status reports.

IV. FOURTH DAY

A. Continue simulation
B. Debriefing--establishing alternatives
C. Continue simulation
D. Instructor role playing--special review
E. Continue simulation
F. Team status reports.

V. FIFTH DAY

A. Final play
B. Final debriefing--comparison of teams
C. Examining decisions made and their effects
D. Basis for continuing learnings.

Expected Benefits

The above description of a revised course is expected to achieve the following benefits:

----GREMEX would become more adaptable as an aerospace industrial executive training tool.

----A powerful training curriculum could be developed, designed around the unique features of GREMEX, thereby tapping much more of its long-range potential.

----Industry response would be determined relative to a permanent center of excellence, teaching fundamentals and needed skills in R & D management.

----Documentation would be polished to facilitate the learning processes of participants, administrators, and technical support personnel.

----Those exposed to GREMEX, as run in a "total educational environment", complete with guest instructors in specialized fields, should receive a highly stimulating educational experience--one that can be the prototype of many such experiences yet to come.

----GREMEX can be examined more fully into its possible uses as a research, as well as an educational, tool.

APPENDIX IV
PROGRAM MANAGEMENT SUMMARY

The responsibility of the program manager, which GREMEX covers in part, is outlined below:

I. Direct Responsibility

A. Has authority to direct all activity related to his program

B. Accountable for work done through functional divisions

C. Responsible for: accomplishment of technical objectives, schedule requirements, effective cost management

D. Directs development of master program plans

E. Monitors and analyzes program results versus plans

F. Implements corrective actions when required

G. Issues sub-division work authorizations and approves budgets to cover effort to be performed

H. Reviews and approves proposed program changes based on assessment of impact on program objectives

I. Reviews conflicts with functional division policies

J. Represents the company in contracts with the customer

K. Works with sub-division functional managers and systems project engineer

L. Administrative responsibilities include personnel matters of direct reporting and functional personnel.

II. Management Systems Responsibility

A. Program manager is responsible for program planning, budgeting, and control

B. Detail plans, schedules, expenditures, manpower budget, financial plans, and assist work from functional managers

C. Development of work breakdown structure

1) Comply with company policy and customer requirements

2) Review the W. B. S. with contracts, pricing, financial and program control

3) Obtain agreement from functional managers

4) Prepare work statements and schedules for W. B. S.

5) Prepare time-phased funding for work effort

6) Develop accounting keyed to W. B. S.

D. Budgeting requirements

1) Engineering and logistics cost budget

2) Manufacturing and quality budget

3) Material, data processing and labor budget

4) Financial budget

E. Expenditure control

1) Establish information sources

2) Determine configuration and performance specifications

3) Identify milestones

4) Prepare time-phased funding by month

5) Determine redistribution of funds among sub-divisions

6) Establish head count budget based on equivalent heads

7) Determine material estimates based on specifications

8) Substantiation of cost changes and renegotiation

9) Estimate of cost to complete based on summary data

10) Determination of fee reduction due to cost overruns

11) Preparation of expenditure reports showing original and current cumulative expenfiture plans and authorized value.

In view of the broad responsibility which the program manager encompasses, it is obvious that supplemental material and training are required in addition to the GREMEX exercise.

Program Management and the Matrix Organization

Because of his dealing in a multi-dimensional functional structure while retaining direct performance responsibility, the program manager is part of a matrix organization. This dimension of the problem, when added to the cost, schedule and technical aspects of the program, provides insight into the complexity of effective program management. The concept of the matrix organization is one of meeting continuously changing requirements by adapting the roles of the program personnel based on project needs and professional specialization in contrast to the normal functional or task specialization. This, in turn, gives rise to performance measurement based on interdependency between the program and functional managers. The difficulty in performance measurement is especially acute when one recognizes the requirement to simultaneously meet internal company expectations while complying with external customer requirements.

The detailed comparison of program and functional management shown in Figure IV-1 further emphasizes the criticality of this aspect of the program manager's responsibility.

Two other characteristics of the program manager's responsibility are shown in Figures IV-2 and IV-3 which are taken from an unpublished U.S.C. doctoral dissertation on Research Funds Allocation by Marshall Burak.

Comparison of Program and Functional Management*

Principles of Organization	Program or Matrix Organization	Functional Organization
I. OBJECTIVES		
1. The objectives of the enterprise and its component elements should be clearly defined and stated in writing	1. Written objectives essential and mandatory.	1. Written objectives essential but not mandatory.
2. The organization should be kept simple and flexible.	2. Structure generally flexible.	2. Structure generally simple but often inflexible.
II. ACTIVITIES AND GROUPING OF ACTIVITIES		
1. The responsibilities assigned to a position should be confined as far as possible to the performance of a single leading function.	1. Diverse assignments that cut across formal structure.	1. Single assignments within vertical structure.
2. Functions should be assigned to organizational units on the basis of homogeneity of objective to achieve most efficient and economic operation.	2. Most likely not assigned on basis of homogeneity due to diversity and complexity of organization.	2. Generally assigned on basis of homogeneity of objective.
III. AUTHORITY		
1. There should be clear lines of authority running from the top to the bottom of the organization, and accountability from bottom to top.	1. Primarily lateral and diagonal lines (often fuzzy).	1. Primarily vertical lines of authority and accountability (generally clear).
2. The responsibility and authority of each position should be clearly defined in writing.	2. Position seldom defined in writing but when done, do not reflect multiple interfaces, hence, not useful.	2. Positions generally defined in writing but are inflexible and rapidly become obsolete.
3. Accountability should always be coupled with corresponding authority.	3. Delegations fuzzy, informal, and defacto.	3. Delegations formal and absolute.
4. Authority to take or initiate action should be delegated as close to the scene of action as possible.	4. Authority seldom delegated and generally remote from scene.	4. Authority more likely than not delegated close to scence of action.
5. The number of levels of authority should be kept to a minimum.	5. Few levels of authority.	5. Many levels of authority.
IV. RELATIONSHIPS		
1. There is a limit to the number of positions that can be effectively supervised by a single individual.	1. Broad span.	1. Limited span.
2. Everyone in the organization should report (be accountable) to only one supervisor.	2. Multiple accountability.	2. Absolute accountability to one supervisor.
3. The accountability of higher authority for the acts of its subordinates is absolute.	3. If defined, absolute; otherwise, fuzzy.	3. Absolute.

* Stieglitz, H. Organization Planning: Basic Concepts; Emerging Trends. p. 14, NICB, 1962 (A Report Digest from Corporate Organization Structures, SPP 183).

Figure IV-2
RESEARCH PROGRAM PHASE STRUCTURE

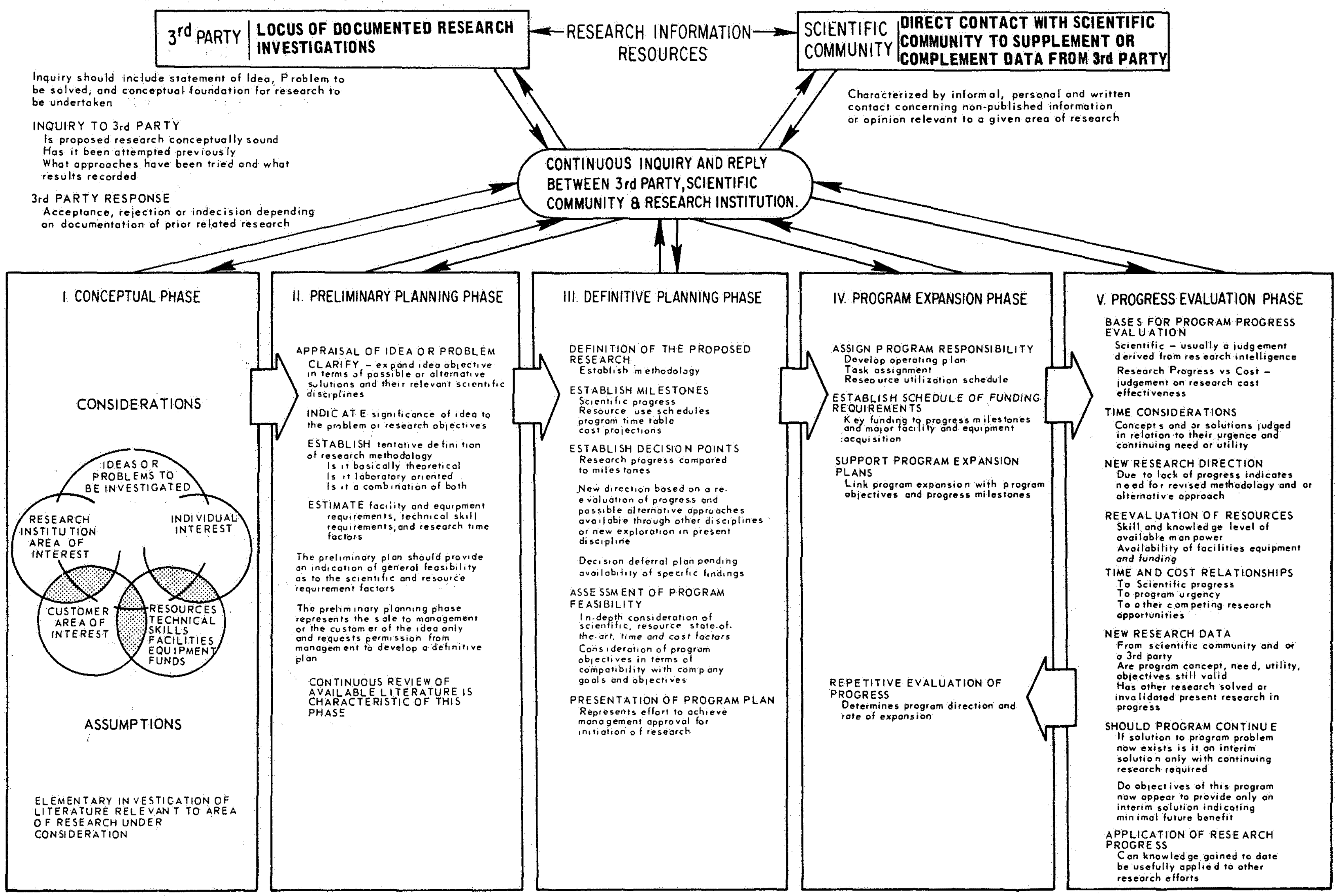
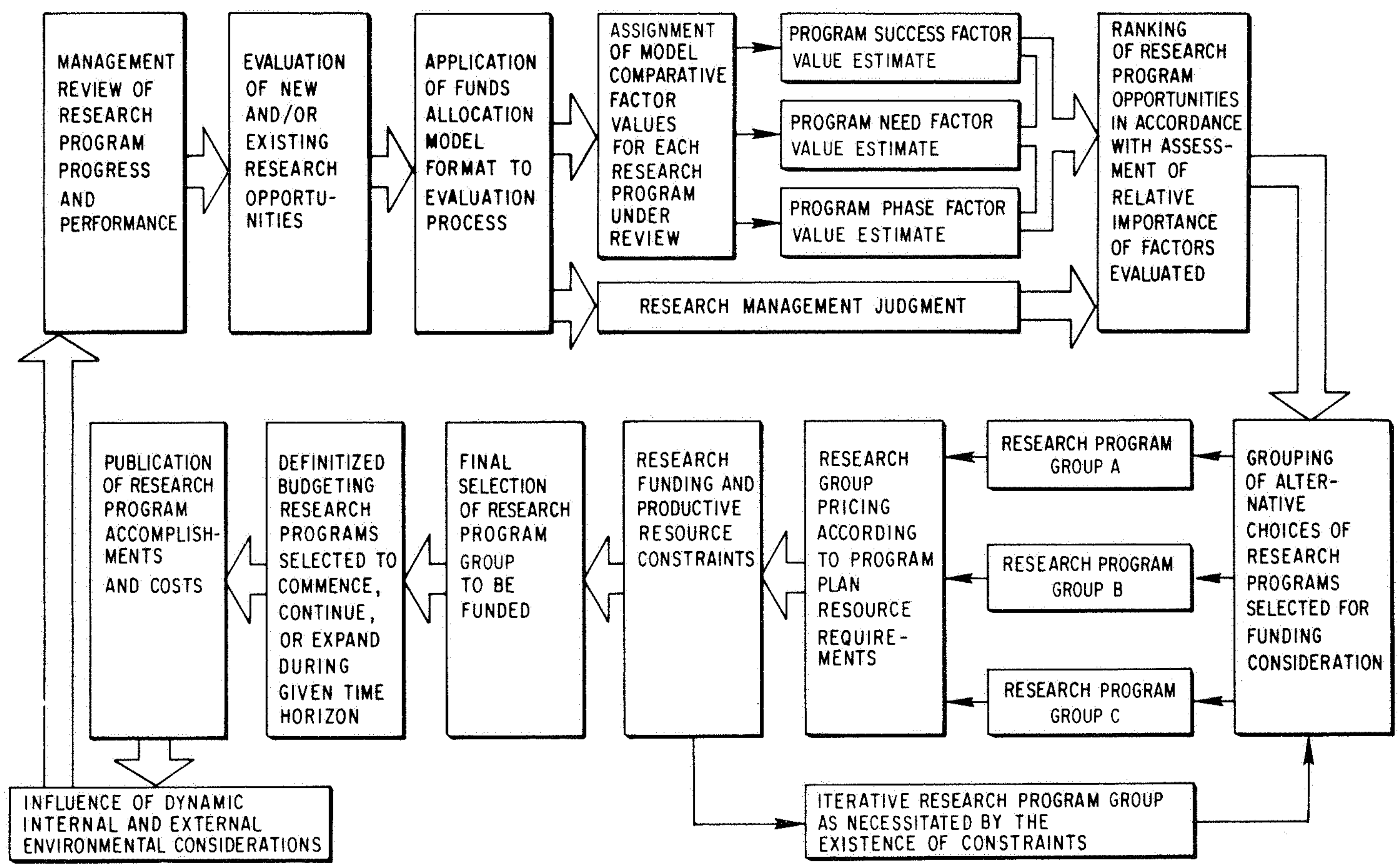


Figure IV-3
RESEARCH AND EXPERIMENTATION DYNAMIC
FUNDS ALLOCATION PROCESS



APPENDIX V
OPERATING MODE, STAFF, AND PARTICIPANTS

The Physical operation of the GREMEX exercise was conducted in the System Development Corporation facilities in Santa Monica, California. The two major facility requirements (computer hardware and participant working area) need to be considered in conjunction with each other as physical separation of the participant and computer affects the turn-around time between submission of decisions and the return of the computer results. SDC had a good overall combination for conducting the GREMEX exercise.

Their hardware included four IBM 360 systems which could be available and capable of handling the GREMEX program. The initial and basic set up was made on the dual 360/67 time-sharing hardware system. This would allow maximum availability of a computer when the player decisions were ready for processing. In this manner, SDC's production could easily be handled on one side of the hardware system while GREMEX was being processed on the other side. Since a definite schedule for the arrival of player input to the computer could not be reliably determined, this was a very important aspect. Also important was the consideration of total throughput time for the processing of decision input for the hardware system. The SDC system provided minimum manual handling (mounting of special tapes and operator interface) and also allowed on-line print-out of the results. This set up resulted in a 15-20 minute turn-around for the hardware system in processing of the decisions. Stating it another way, this is the time it took once the keypunched decisions were submitted to the computer operator until he handed the printed results back to the courier. This included all five teams which were involved in the exercise. Although accurate records of hardware times were not kept, it has been estimated that two minutes were required for CPU processing and ten minutes for print-out of all five teams. The SDC hardware system used is shown in Figure V-1.

The keypunch room and participant classrooms were within a minute's walk of the computer room which provided approximately a one-half hour total turn-around time, given that no special problems or reruns were necessary.

Computer programming support was provided by MTI and NASA personnel. Figure V-2 indicates the flow of the decisions through the system and the approximate time involved in each step. It should be indicated that the times considered are not representative of the first few plays nor cases where revisions to decisions, punched cards, or computer runs become necessary. They are more in the nature of minimum

SDC COMPUTER CONFIGURATION
USED IN THE GREMEX PROGRAM
AUGUST 1967

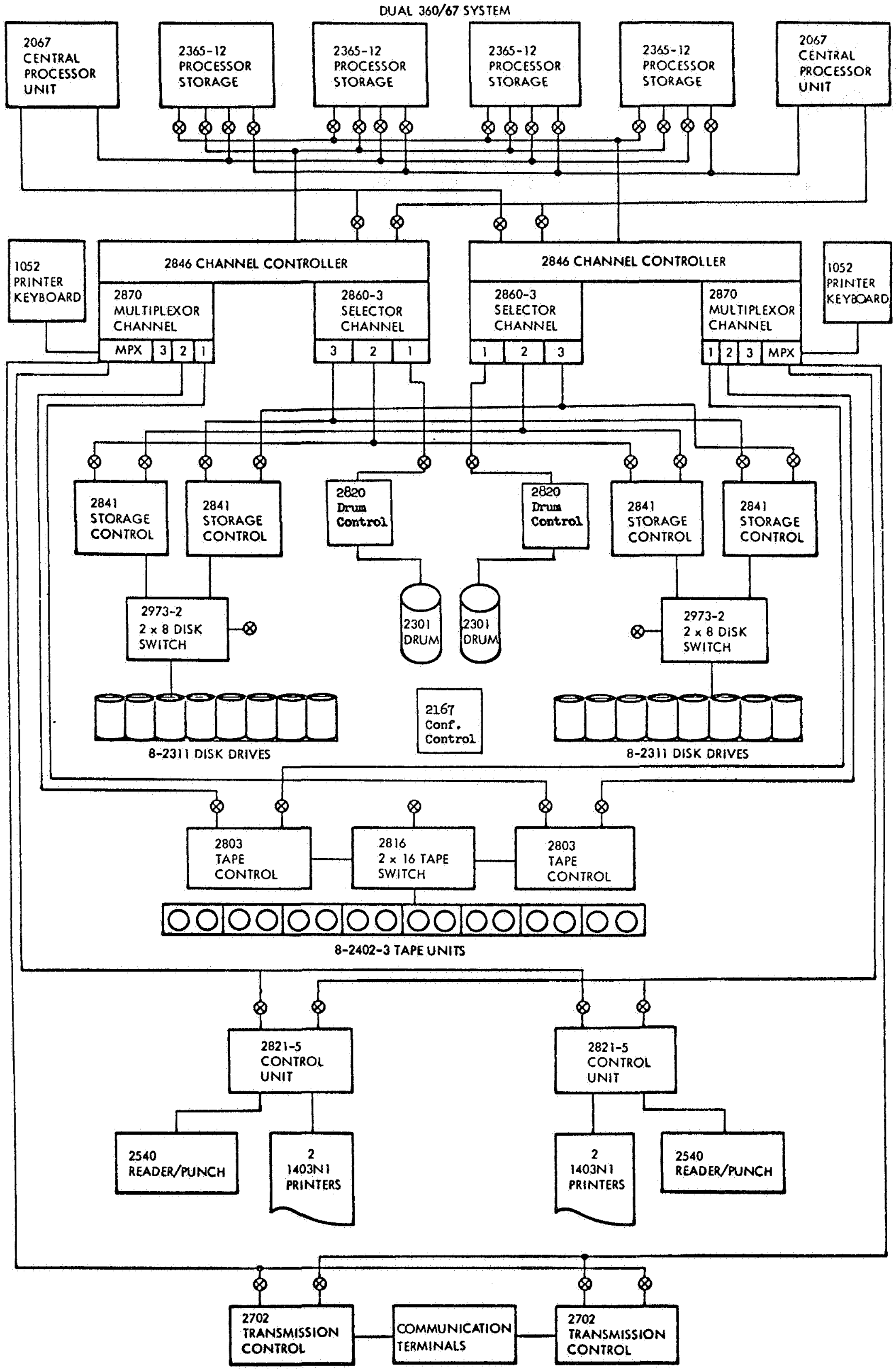


FIGURE 1

Approximate Time
Involved After
First Few Plays

FLOW CHART OF EXERCISE DATA PROCESSING

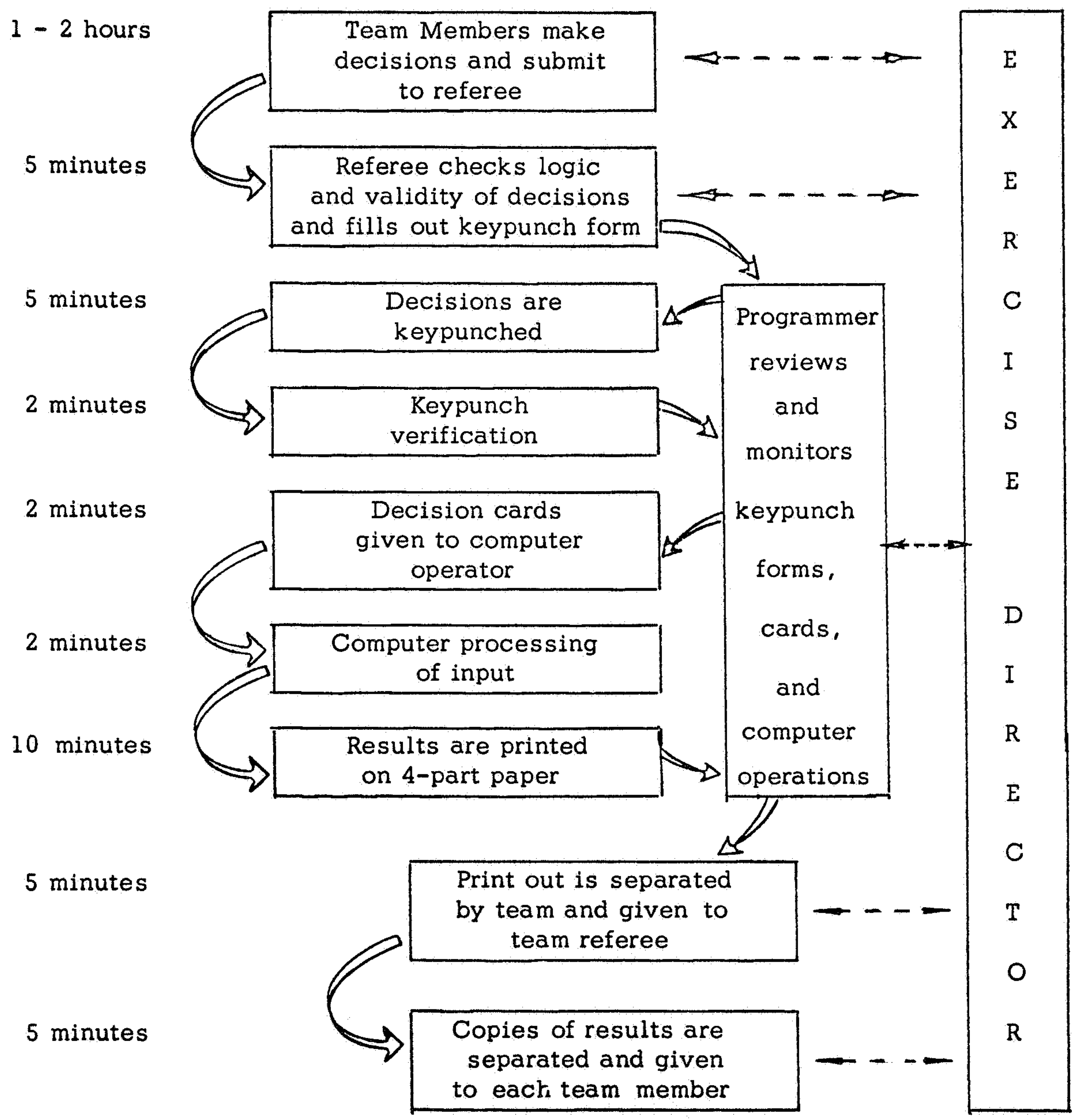
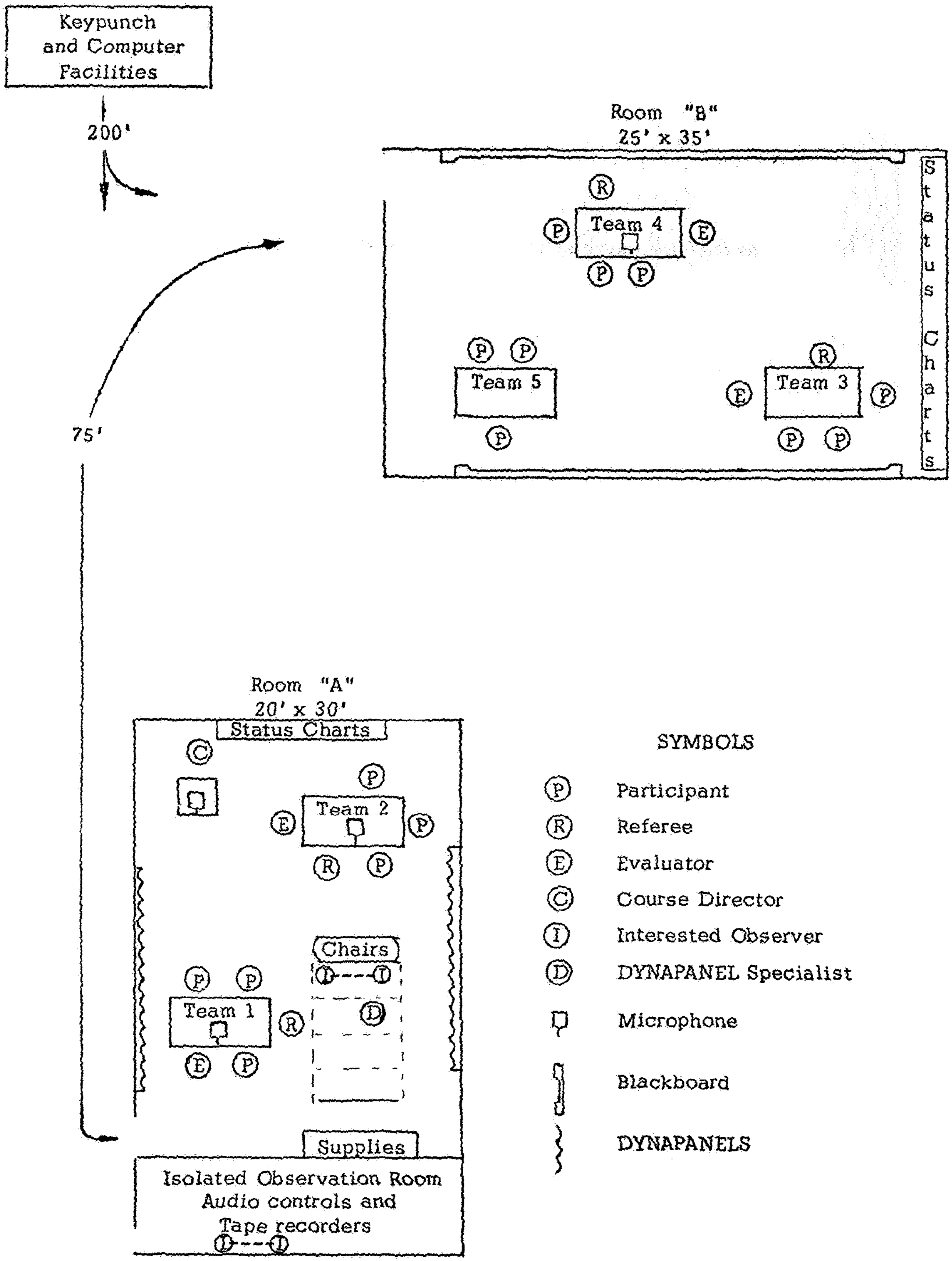


FIGURE 2

time spans once the exercise has been effectively implemented.

Two participant rooms were used during the exercise. Room A also served as an assembly area for participant orientation and debriefings. This room was a management laboratory with audio and isolated visual monitoring facilities. A schematic of these facilities is indicated in Figure V-3.

Industry attendees included senior personnal associated with local aerospace firms. These firms were Hughes Aircraft, Douglas Aircraft, TRW Systems, Lockheed, Northrop, North American Aviation, and Systems Development Corporation. Dr. A. J. Rowe served as Principal Investigator for the USC/MTI portion of the project. USC Professor Paul Gruendemann and Fred Thompson of MTI served to coordinate the facilities, technical support, and design of the evaluation methods. A complete listing of all individuals concerned with the GREMEX demonstration is contained in APPENDIX IX.



SCHEMATIC OF EXERCISE FACILITIES

FIGURE 3

APPENDIX VI
CHRONOLOGY OF A TEAM'S DECISIONS IN THE GREMEX EXERCISE

GREMEX Experience

Play #I

1. We chose Contractor D. A and B were not even considered. C was considered on the basis of his technical report, and E for his management skill.

2. We let all the contracts immediately (planning for safety), deferring the starting date of most experiments. We staggered starting dates to allow about 6 months' slack on upper section experiments and 4 months on lower section experiments. In retrospect, this was too much slack and we later delayed the contracts which were let but not started.

3. We let the reliability contract on spacecraft only (inadvertently, as we didn't realize that experiments required an explicit action).

4. Cost reimbursement contracts were chosen for university research because this type was recommended in the manual; cost plus incentive for the spacecraft; and fixed price for reliability. We were weak in this area in that we knew little of the tradeoffs between contract types (also, we learned nothing from the exercise).

5. We decided to order all reports except SARP and the technical narratives at the highest level of detail. SARP and the technical narrative seemed redundant (we overlooked the test failure portion of the technical narrative). We planned to cut the level of detail, if we were not able to use the information (we did cut the level of detail later).

6. Overall, we were very unsure as to the options available and, therefore, omitted several actions. "Cold water" in learning about GREMEX contributed nothing to learning about project management.

Play #II

1. We started overtime on Texas which was the longest experiment.

2. We canceled Mississippi due to the high cost, the large expected overrun, and the technical redundancy (390,000 dollars went in the bin). *

3. We requested PERT reports on remaining experiments (some requests had not been placed due to the limitation of 99 action cards per run). We still didn't use any reports on reliability as we didn't realize they were applicable.

4. We noted that there were high expected overruns on labor only. We questioned what actions could operate on this condition (e.g., invest in capital), why report cost breakdowns if there were no selective actions?

Play #III

1. We shifted the Maine starting date forward as we noticed very high expected overrun even though the project was not yet started. (Was this reasonable?)

2. We cut the level on time-phased cost report.

3. We began to use PERT reports systematically, concentrating on the low slack items (using the report which was sorted on criticality).

4. We began keeping our own report of slack and cost for each period by contract. (We should have maintained these records by component.) (Historical reports should have been made for us.)

5. We began to think about items with large slack, as T_e variability seemed rather small.

Play #IV

1. We received the list of actions which needed explanation. It contained several actions to delay progress, but we

---

*This money wouldn't have gotten into the bin if the contract had never been let in the first place.

had no idea of their relative merits; i. e., did they correspond to the real world, what were their merits in the real world?

2. We delayed the start of the remaining, unstarted projects (no time to do so in Play #III).

3. We used PERT to spot extremes (high slack as well as low).

4. We removed slack from the flight model components by delaying activity starts, but were unclear as to the difference between the delay-component action and delaying the first activity of a component (i. e., the relative merits of operators was not known).

5. We set a new desired slack benchmark of 10 weeks due to apparently low variability (originally 4-6 months).

6. We received the first message of a change in T_e of more than one week in the spacecraft. The changed activity was on the minimum slack path in the spacecraft; therefore, we applied overtime.

Play #V

1. We noted a sudden drop in the slack time of experiments (average drop of eight weeks), but continued with our ten week rule of thumb for desired slack time.

2. We applied overtime as the only activity-shortening device.

3. We resigned ourselves to an overrun floor due to early letting of contracts.

Play #VI

1. Play became mechanical: merely looking at the PERT report and applying overtime on low slack paths and delaying high slack. At this point, we were playing "PERT"; i. e., operating on the network as an abstract entity apart from the spacecraft context.

2. We made a one-year input error on the delay of an activity (we were filling in forms ourselves) causing -34 weeks of slack and $1,000,000 expected overrun.

Play #VII

1. We adjusted the one year error.

2. We continued the strategy of adjusting high and low slack items.

Plays #VIII-XII

1. We continued our strategy, tending to place overtime on activities which were further downstream on the low slack paths.

Play #XIII

1. We canceled Maine due to poor performance and technological redundancy.

Suggested Modifications Based on GREMEX Experience

1. Make costs better known; e.g., a manager would have an estimate of the cost of a report or of reallocating the manpower on activity. Reports do not enable players to infer the costs of their actions.

2. Introduce other actions into the game; e.g., introduce capital as a variable. The reports show labor overruns on most components and new equipment might be a reasonable action to correct this situation.

3. Flag all events whose T_e changes by over one week.

4. Make output options and definitions explicit before the play. It is difficult to see the advantages of the "cold water" approach to understanding output format and the selections actions which are available.

5. If it is desired to keep all of the players involved by keep-

ing them "in the game"; why not automatically penalize successful players and help others, or not reveal performances of other teams?

6. The probability figures are not interpretable: they should be kept from the players; or at least presented as ordinal indices, not probabilities.

7. Contractors A and B should either be improved or dropped altogether.

8. Reports should be available showing historical slack and cost expectations, by month. There are no historical reports for seeing trends.

9. Don't speed up operations on the last day; we received an output for period 12 before getting period 11's reports de-collated.

APPENDIX VII
SAMPLE INTERVIEW QUESTIONS

End-of-Simulation Interview Format

What are your reactions to the usefulness of Dynapert?

Did the manual give you sufficient background

- As a project description?
- Did it give you a feel for types of decisions you would have to make?
- Did it give you a good feel for the tools (reports) available to you?

What benefit was the orientation in preparing you to play?

What were the most realistic attributes of the game?

What were most unrealistic attributes?

How important is realism?

What do you feel about the length of play?

Would you come back Saturday, if it meant you would launch?

Did this give you more feel for NASA problems and operations?

What was the effect of the observers on your operation?

Before the game began, did you feel you were well, average, or poorly prepared to play?

Was there time for learning from the manual and referee on a "need to know" basis?

Were the facilities adequate? How could they be improved?

Was your referee helpful in getting you started and providing the necessary material or information?

What did you think of the referee-team interaction?

What do you consider to be the key learning experience?

What was redundant with what you already knew?

Was there reinforcement, or refuting, of concepts held at the beginning?

What groups inside or outside your company would be most helped by this simulation?

Six-Weeks-Following-Simulation Interview Format

Reaction to the Exercise:

What do you now retain from the exercise?
What did you actually learn?
What is your candid opinion of GREMEX as a learning experience?
Was the simulation more effective than a more "academic" presentation of material on R & D management?

Corporate Response to, and Correspondence on, GREMEX:

What has been the reaction of your company toward GREMEX?
Is GREMEX a candidate for in-house management development?
(Copies of reports from participants to their superiors are available.)

Recommendations for Future Runs:

What are your general recommendations for future runs?
What modifications would you suggest for the proposed 5-day program? (Interviewee receives copy of proposed program.)

APPENDIX VIII
SELECTION OF SPACE EXPERIMENTS

Excerpts from "The Selection of Space Experiments", by W. H. Pickering, published in American Scientist, 51, 1, 1966.

The selection of the actual experimenters for a mission is a step that is fraught with difficulties. NASA has made it a policy to announce its plans as widely as possible and to invite scientists who wish to be experimenters to make proposals. It has then gone through a selection process to arrive at the final groups of experimenters for any given mission. Without going into details regarding this selection, let me point out that the process does recognize that these space missions are truly national efforts and therefore the experimenters are selected on a national basis rather than from one laboratory or university. The selection also recognizes that the conditions of a space light impose rigid constraints on equipment, and therefore the state of development of potential flight hardware is very important.

From the point of view of the scientist desiring to carry out an actual flight experiment, there are several considerations which he must not overlook. Let us review some of these matters.

First, the experiment is going to be very expensive. For example, the recent Mariner flight to Mars had a total program cost of about 100 million dollars. If this total cost were charged against data collected on the flight, it would come to about 4 dollars per second, or 350 thousand dollars per day. Consequently, an experiment should not be carried on a flight unless it has a very high probability of working and of returning significant scientific data.

To make the point still stronger, it should be appreciated that many of these space experiments will have only a single opportunity to work. Other experimenters may be selected for the next flight, or, if it is a planetary mission, the flight opportunities may be so infrequent as to invalidate the reason for the experiment.

A second but related matter is the long lead time associated with space experiments. In some of the more complex missions, experiment selection may have to occur two or three years before flight. Consequently, an experimenter must commit himself for a long period to a piece of research which might give him no data. A launching failure, a spacecraft failure, or even a failure of his own equipment could occur, and he would be left with nothing but a piece of prototype flight hardware.

Sound engineering of rockets, spacecraft, and scientific experiments is the only insurance against these problems. All of the projects of "big science" whether in space or other fields, are dependent upon the quality of the engineering which goes into the equipment. In fact, about 90% of the budget of these projects typically goes to engineering and only 10% to science. The quality of the engineering from system design to fabrication and test, is obviously of supreme importance. This is particularly so in space projects because the complete system is only operated once, and that is the actual flight when everything must work.

Now that the fundamental engineering difficulties have been resolved, NASA needs to devote the same kind of effort to science mission and system design as was previously placed in spacecraft system engineering. This will call for a close working relationship between the engineers who have developed the technology of system design, and the scientists who have devised the experiment to be conducted in the more complex spacecraft, the Mariner for example, illustrate what can be done with a closely integrated design. Structure, power consumption, thermal balance, telemetry requirements, trajectory requirements, spacecraft flight attitude were all elements in the experiment and instrument designs. The result was a mission and a spacecraft which were uniquely matched to the particular experiments aboard. Designs were frozen in all details ten months before flight. The problem of developing an appropriate set of mission objectives within the weight constraints determined by the launching rocket forced the designers to make this very finely tuned design. But the lesson is there for future missions which may not be so constrained. A careful synthesis of the complete system, spacecraft plus science plus mission, will inevitably lead to a more efficient over-all project with the maximum probability of success.

APPENDIX IX
LIST OF GREMEX PARTICIPANTS AND STAFF

Industry Participants

Team #1

Howard Capper
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Hughes Aircraft Company
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William A. Gunn
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Lockheed-California Company
Burbank, California

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Herb Seiden
Senior Technical Advisor
System Development Corporation
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S. H. Nelson
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North American Aviation
Long Beach, California

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Jet Propulsion Laboratory
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Ralph Turkolu
Program Manager, OGO Project
TRW Systems
Redondo Beach, California

D. O. Tostenson
Manager, System Management Technology
North American Aviation
Downey, California

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Dr. Vaccaro GSFC Assistant Director for Administration	Observer
Mr. Milton Denault GSFC Head of Management Information Branch	Exercise Director
Mr. Tom Sullivan GSFC Programmer	Coordinator of Programming and Computer Operations
Mr. John Miller GSFC	Referee Team #1
Mr. Stanley Corwin GSFC	Referee Team #2
Mr. Ray Collier GSFC	Referee Team #3
Mr. Rettler GSFC	Referee Team #4

University of Southern California Staff

Dr. A. J. Rowe Chairman, Department of Management	Principal Investigator
Dr. Paul Gruendemann USC GSBA Faculty	Evaluator and USC Coordinator
Dr. Robert Coffey USC GSBA Faculty	Evaluator
Dr. David Hitchen USC GSBA Faculty	Evaluator
Dr. David McConaughy USC GSBA Faculty	Evaluator
Dr. Larry Press USC GSBA Faculty	Faculty Partici- pant, Team #5

Management Technology, Inc. Staff

Donald G. Malcolm President	Observer
Clifford J. Craft Vice President	Evaluator
Fred Thompson Senior Consultant	MTI Project Manager
William Rockwell Systems Analyst	Programming and Computer Opera- tions
H. Earl McBride Consultant	MTI Participant Team #5
Darrell Shelburne PERT Analyst	Dynapanel Specialist

System Development Corporation Staff (Partial Listing)

William Cavanaugh Project Staff	SDC GREMEX Coordinator
Chick Fiala Head, Computer Center Operations	Computer Operations
Don Barth SDC/IBM Support Staff	Hardware Specialist
Rick Ruud SDC/IBM Support Staff	Hardware Specialist

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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