long-range project costs, not just the development costs or the cost required to get a system into operation. Total life-cycle costs appear to be an appropriate economic measure since they include all system costs and put the cost analysis for each alternative project on an equitable basis for comparison.

The third factor, risk associated with projects, has received considerable emphasis recently, particularly by the Department of Defense. At least two types of risks should be considered in selecting projects. The first is the "risk due to nature." By this is meant the probability that a project will not succeed because the technical requirements are incompatible with basic physical laws. The second risk is the "risk due to technology." This risk is the probability that a project will be unsuccessful because it requires technology beyond the current state of the art even though no laws of nature appear to be limiting. Other types of risks would be appropriate in assessing programs with high-social content.

The fourth major factor to be considered by the decision maker is that of benefits which would result from the pursuit of each alternative project. Decision makers are faced with the problem of evaluating the worth of each project under consideration. Worth assessment [3] is a formal procedure for assessing the worth of discrete alternatives. It appears to be well suited to providing a "benefit" input.

Criterion Function

In comparing alternative projects, it is desirable to combine the major evaluation factors into a single, scalar-valued criterion function. Such a function must be reasonably general and easy to interpret if it is to have wide application. The function suggested here is derived by multiplying two parts to yield its value. The first part is the probability of being able to successfully carry out a candidate project, calculated by multiplying one minus the risk due to nature by one minus the risk due to technology. The second part of the criterion function is a cost-benefit factor composed of the weighted sum of inverse normalized project cost and project worth.

The criterion function is calculated for each alternative project. The criterion function is expressed as

$$Q_i = (1 - R_{n_i})(1 - R_{t_i})(aC_i^0 + bV_i)$$

where

- Q_i value of criterion function for ith project; for $i = 1,2,\cdots,q$, where q is the total number of projects under consideration;
- R_{n_i} risk of nature to the ith project $= 1 - \prod_k(1 - r_{k,i}^n)$, where $r_{k,i}^n = (k = 1,2,\cdots,m)$ is the risk due to nature to the kth, project characteristic of the ith project, where m is the total number of project characteristics for which risk due to nature is estimated;
- R_{t_i} risk of technology to ith project $= 1 - \prod_k(1 - r_{k,i}^t)$, where $r_{k,i}^t = (k = 1,2,\cdots,p)$ is the risk due to technology to kth project characteristic of the ith project, where p is the total number of project characteristics for which risks due to technology is estimated;
- C_i^0 normalized inverse life-cycle cost of ith alternative project $= (1/C_i) \min_i C_i$, where C_i is the estimated cost of ith alternative project;
- a weighting factor for normalized inverse life-cycle costs;
- b $(1 - a) =$ weighting factor for worth scores;
- V_i worth score for ith alternative project. ($0 \le V_i \le 1$; $i = 1,2,\cdots,q$).

The criterion function combines the risk factors with a weighted average of inverse normalized life-cycle cost and worth assessment score. The ideal configuration/program alternative combination would have zero risk due to nature, zero risk due to technology, the least life-cycle cost of any alternative project, and a worth score of 1.0. In this ideal situation, the criterion function would have a value of 1.0.

If the risk due to nature or the risk due to technology for any project characteristic is 1 (that is, the characteristic is judged to be impossible to meet), then the probability of successfully developing the configuration under consideration is zero and its criterion function has a zero value. Since the risk due to nature and risk due to technology will each be greater than or equal to the maximum risk of each contributing risk factor, careful consideration must be given to the estimation of each risk factor. The computation of risk draws attention to those factors that would potentially prevent project success and helps ensure that a critical factor is not ignored.

Weighting factors "a" and "$b = (1 - a)$" allow changing the relative importance of the cost and worth factors. The choice of values for a and b will be governed by such factors as confidence in the cost analysis (e.g., low confidence; make "a" small), the magnitude of the costs relative to total resources, and the significance of the benefits that could be used depending upon the sensitivity to cost. For example,

$$C_i^0 = \frac{\max_i C_i - C_i}{\max_i C_i - \min_i C_i}$$

provides a linear weighting to cost variation between the maximum and minimum cost projects. The cost normalization scheme suggested earlier provides considerable sensitivity to cost variations near the minimum cost and much lower sensitivity and a lower weight to costs much greater than the minimum cost. Numerous other ways of normalizing the project cost estimates are available and should be examined in the context of the particular problem under study.

The numeric value of the criterion function at the program planning phase is normally quite small. This observation reflects the uncertainties associated with projects during an early planning phase. In particular, technically demanding projects will have low criterion values due to the risks involved. The absolute value of the criterion function is not as important, however, as the relative value for each alternative project.

Project selections are made on the basis of the program scope being consistent with corporate or agency policy, as mentioned earlier, and the relative values of the criterion function for each project. If the criterion values are low, the reasons for this should be considered and action taken in the subsequent project planning phase to investigate the reasons underlying the low values.

Evaluation of Risks

In the program planning phase, the evaluation of risks inherent in pursuing various alternative projects is usually dependent upon expert opinion and subjective judgment rather than detailed analyses. A typical approach to risk evaluation is to make a detailed breakdown of the functional performance factors forecasted for each project and to call in experts in each of the functional areas to assess risks due to nature and technology associated with attaining the projected performance. Care should be taken in defining the functional performance factors to assure that they are all of about the same level of importance and that the risks are due to independent causes. This care is suggested since the value of the criterion function is equally sensitive to each risk associated with each factor and the risk calculation assumes independence of risks.

High-risk performance factors should be flagged so that subsequent project planning calls for an early second assessment of the high-risk performance factors for each of the projects selected for further development.

Worth Assessment

Worth assessment is a formal procedure for assessing the worth of discrete alternatives in the decision-making environment. The following is a brief outline of a worth assessment procedure developed by Miller, [3].

A. Define worth criteria.
   List criteria for worth assessment ensuring list:
   1) contains all significant criteria;
   2) contains only mutually exclusive criteria;
   3) contains only criteria of major significance;
   4) contains only worth independent criteria.
B. Develop hierarchical structure of worth assessment criteria.
   Break down high-level worth assessment criteria into one or more lower level criteria which contribute to the high-level criteria.
C. Develop performance measures.
   Select a single physical-performance measure for each lowest level worth assessment criterion in the hierarchical structure.
D. Develop worth relationships between performance measures and lowest level worth assessment criteria.
   Define a scoring function to assign a unique worth score in points to every possible value of a physical performance measure. A scoring function is defined, either explicitly or implicitly for every lowest level worth assessment criterion.
E. Develop a single overall index of worth.
   Define an additive weighting function with constant trade-off weights to combine the lowest level criteria worth scores.

The index of worth is devoid of any risk and/or uncertainty. It assumes that the project, activity, or performance consequence being evaluated will occur *for certain* and the process of assigning a worth number provides no mechanism for reflecting perceived trade-offs between the worth of an outcome, conditional upon its actual occurrence, and the variable risk or uncertainty surrounding its occurrence. The index of worth appears to complement the Criterion Function which has separate risk factors built into it.

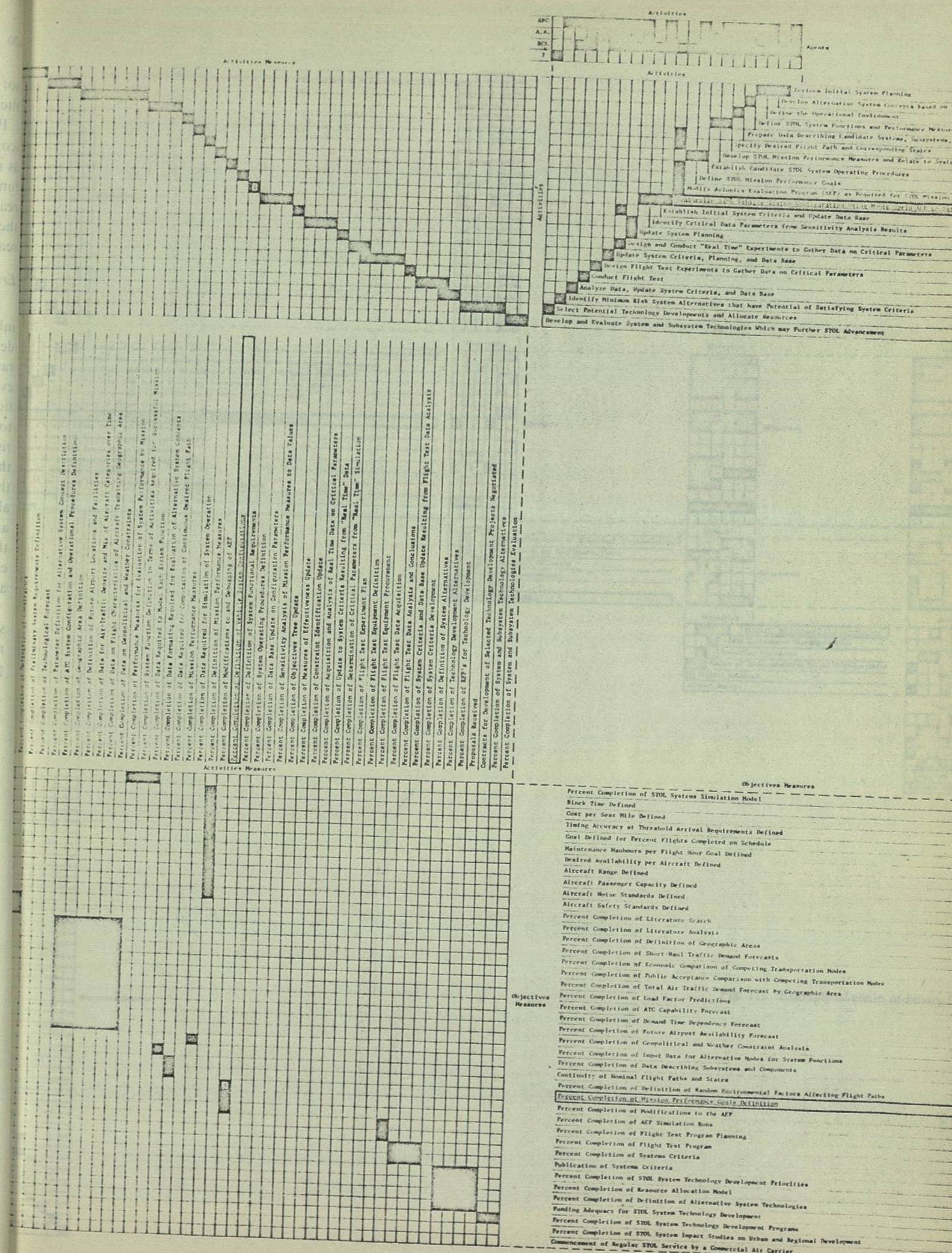
Miller's worth-assessment technique relates to program planning in another way. The objectives measures provide a baseline upon which to develop the worth assessment criteria and performance measures of each alternative project. Also, the objectives interaction matrix and other interaction matrices that relate the objectives to constraints, alterables, needs, and societal sectors provide considerable visibility to the relative importance of the worth assessment criteria. The task of weighting the worth assessment criteria can then be done in relation to their contribution to the related needs, constraints, etc.

As part of the worth assessment procedure, the relation of the performance measures to the needs should be examined and used to develop the scoring functions that relate the performance measure of each lowest level performance criterion to a worth score. The relation of performance measures to needs should also be considered when developing the adjusting factors to compensate for the fact that performance measures may not adequately represent the performance criteria. Worth assessment is recommended as a formal approach to evaluating the comparative worths of alternative projects. The resulting worth scores satisfy the requirement of the criterion function for a worth score for each alternative project.

Summary

The systems engineering steps required to do program planning are not related only to their neighboring steps nor are they carried out in a sequential temporal order. Rather, they form a logical set of operations that are highly interrelated and consequently must be continually reviewed with respect to each other as program planning progresses. In planning a complex program, the linkages between these operations tend to become buried in the complexity of the problem rather than being emphasized and given visibility. The set of interaction matrices illustrated in Figs. 10 and 11 provides a visible means of organizing and managing program planning activities.

Decision making will always require the subjective input of experienced managers. Nevertheless, formal evaluation techniques are helpful in assessing the relative merits of alternative projects that comprise a program. The criterion function described in this paper combines the factors of



Activities
APC
A.A.
BCL
Agents
Activities
Activities Measures
Activities
Perform Initial System Planning
Develop Alternative System Concepts Based on T.
Define the Operational Environment
Define STOL System Functions and Performance Measures
Prepare Data Describing Candidate Systems, Subsystems, a
Specify Desired Flight Path and Corresponding States
Develop STOL Mission Performance Measures and Relate to System
Establish Candidate STOL System Operating Procedures
Define STOL Mission Performance Goals
Modify Avionics Evaluation Program (AEP) as Required for STOL Mission
Establish Initial System Criteria and Update Data Base
Identify Critical Data Parameters from Sensitivity Analysis Results
Update System Planning
Design and Conduct "Real Time" Experiments to Gather Data on Critical Parameters
Update System Criteria, Planning, and Data Base
Design Flight Test Experiments to Gather Data on Critical Parameters
Conduct Flight Test
Analyze Data, Update System Criteria, and Data Base
Identify Minimum Risk System Alternatives that have Potential of Satisfying System Criteria
Select Potential Technology Developments and Allocate Resources
Develop and Evaluate System and Subsystem Technologies Which may Further STOL Advancement
Activities Measures
Objectives Measures
Objectives Measures
Percent Completion of STOL Systems Simulation Model
Block Time Defined
Cost per Seat Mile Defined
Timing Accuracy at Threshold Arrival Requirements Defined
Goal Defined for Percent Flights Completed on Schedule
Maintenance Manhours per Flight Hour Goal Defined
Desired Availability per Aircraft Defined
Aircraft Range Defined
Aircraft Passenger Capacity Defined
Aircraft Noise Standards Defined
Aircraft Safety Standards Defined
Percent Completion of Literature Search
Percent Completion of Literature Analysis
Percent Completion of Definition of Geographic Areas
Percent Completion of Short-Haul Traffic Demand Forecasts
Percent Completion of Economic Comparison of Competing Transportation Modes
Percent Completion of Public Acceptance Comparison with Competing Transportation Modes
Percent Completion of Total Air Traffic Demand Forecast by Geographic Area
Percent Completion of Load Factor Predictions
Percent Completion of ATC Capability Forecast
Percent Completion of Demand Time Dependency Forecast
Percent Completion of Future Airport Availability Forecast
Percent Completion of Geopolitical and Weather Constraint Analysis
Percent Completion of Input Data for Alternative Modes for System Functions
Percent Completion of Data Describing Subsystems and Components
Continuity of Nominal Flight Paths and States
Percent Completion of Definition of Random Environmental Factors Affecting Flight Paths
Percent Completion of Mission Performance Goals Definition
Percent Completion of Modifications to the AEP
Percent Completion of AEP Simulation Runs
Percent Completion of Flight Test Program Planning
Percent Completion of Flight Test Program
Percent Completion of Systems Criteria
Publication of Systems Criteria
Percent Completion of STOL System Technology Development Priorities
Percent Completion of Resource Allocation Model
Percent Completion of Definition of Alternative System Technologies
Funding Adequacy for STOL System Technology Development
Percent Completion of STOL System Technology Development Programs
Percent Completion of STOL System Impact Studies on Urban and Regional Development
Commencement of Regular STOL Service by a Commercial Air Carrier

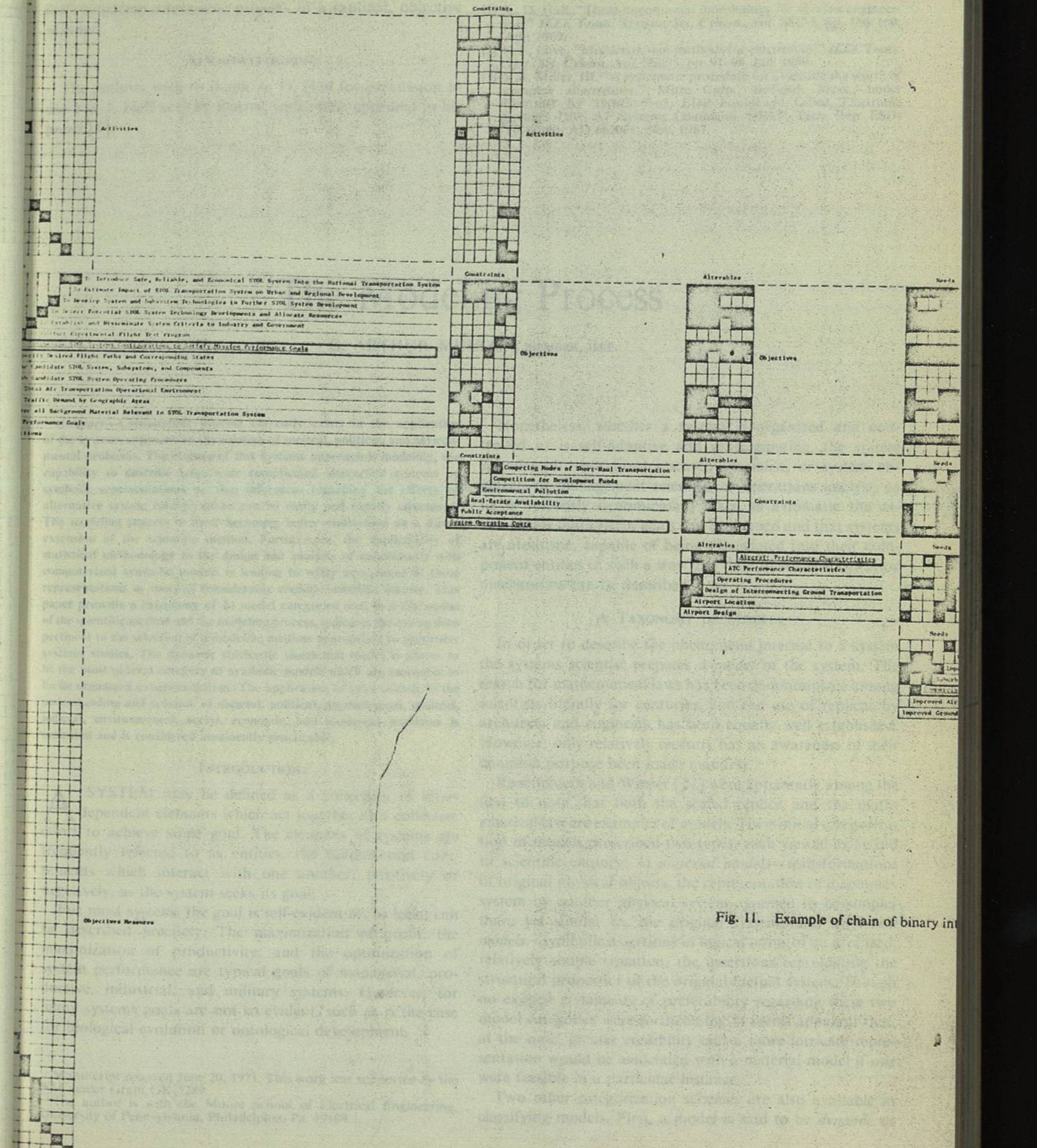


Fig. 11. Example of chain of binary int