

Fig. 5. Form of objectives tree.

VALUE SYSTEM DESIGN LINKAGES

A clear picture of the interactions between societal sectors and needs, between needs and system alterables, between alterables and constraints and between constraints and needs is desired. In addition, the self-interactions among societal sectors, needs, system alterables, and constraints should be clear. The tool suggested for presenting these interactions is an array of interaction matrices of two types. The first type is the self-interaction matrix [2] illustrated in Fig. 2. This example illustrates two levels of dependency presented by the interactions of the objectives defined for a technical development program that could lead to introduction of an air-transport system based upon STO aircraft. The name self-interaction derives from the fact that the same set of coordinates appears along both axes of the matrix.

The second type is the cross-interaction matrix illustrated in Fig. 3. The cross-interaction matrix portrays the interaction between different types of elements; for example, needs and constraints. The degree of impact of the constraints upon the needs can be shown by using different symbols at the intersections. For example, in Fig. 3 we see that environmental pollution is considered to be a severe constraint in planning the support for short-haul aircraft, but only a moderate constraint on the development of commercial short-haul aircraft.

The overall relationships between constraints, alterables, needs, and societal sectors as they both self interact and cross interact in a problem-definition activity may be portrayed by linking them together as shown in outline form in Fig. 4. Such a presentation shows five of the twelve tangible products expected from the problem definition step of program planning. These products are:

- (1) a determination of the societal sectors involved;
- (2) an identification of needs;
- (3) an identification of alterables;
- (4) an identification of major constraints;
- (5) description of interactions among relevant elements of the problem.

The use of such a presentation allows the planning group to keep track of the various elements that are considered during the problem definition process. More important, it provides a formal structure for problem definition and, as will be seen, the rationale for defining objectives.

Value system design activity includes (1) defining objectives and ordering them in a hierarchical structure; (2) relating the objectives to needs, constraints, and alterables; and (3) defining a set of measures on the objectives by which to determine the attainment of objectives.

To provide some precision in program planning, a specific syntax has been developed for the form of an objective. An objective is defined as:

infinite verb + object word or phrase + constraints

This "to teach children the French language" is an example of an objective. To provide a structure for graphically portraying the relationship among objectives, one constructs an objectives tree. Two simple rules are employed to construct this tree: (1) Each objective is written within a rectangular box to form a vertex of the tree. (2) Two boxes containing two objectives are connected, if achievement of one of the objectives contributes directly to achievement of the other.

In constructing an objectives tree, one should not be concerned about where to start. Instead, one will start with any objective that is clearly contributory toward the desired change. As soon as one objective is defined, one then considers lower and higher level objectives related to it.

A lower level objective will have to be contributory to the one that was stated first. A higher level objective will have to be such that the one stated first is contributory to it. If one thinks of at least one lower level objective and at least one higher level objective, he is on his way to constructing an objectives tree. When one is through, he will probably have a structure like that shown in Fig. 5 from which the name "tree" derives. It may turn out that there is more than one tree, since it is not always true that all the objectives one would seek to attain could be shown on one tree. Usually though, if there are separate trees, one can find a higher level objective to which all trees can be tied, thus creating a single (though perhaps rather leafy) tree.

A different way of portraying the information contained in an objectives tree is by way of a corresponding self-interaction matrix as shown in Fig. 6. Fig. 6 contains all of the information required to draw the objectives tree shown in Fig. 5 so long as we know that low-numbered objectives correspond to high-level objectives and vice versa. The self-

interaction matrix method of portrayal is not as clear as the objectives tree for viewing the relationships among objectives, but it incorporates significant advantages in relating objectives to constraints, alterables, and needs. The method suggested for portraying these relationships is the use of cross-interaction matrices as depicted in Fig. 7. This figure relates objectives to needs; to alterables, which can be modified to bring about attainment of the objectives; and to constraints, within which the objectives must be attained. In one concise figure, a complete outline of a rationale to support the objectives and a great deal of information needed to plan a program for attaining them appears.

A particular advantage of the method shown in Fig. 7 is the ease with which the interaction of the objectives can be traced through the needs back to the societal sectors with which the objectives interact. If the interactions are categorized as either significant or insignificant (i.e., binary), then a simple Boolean multiplication of the objectives \times needs interaction matrix with the needs \times societal sectors interaction matrix will result in an objectives \times societal sectors interaction matrix.

The Boolean multiplication of cross-interaction matrices can be extended to the mathematical generation of some of the matrices shown in Fig. 7. For example, if the four cross-interaction matrices that lie closest to the self-interaction matrices were filled in by hand, the three remaining cross-interaction matrices shown in Fig. 7 could be generated mathematically. Such a formal procedure has considerable merit. Without it, one tends to end up with a set of cross-interaction matrices which are not mutually consistent and it is not always easy to spot the inconsistencies. Checking of logic is especially useful when the matrices form a loop as will be discussed later in relation to an example.

The need for defining a set of measures on the objectives by which to determine their attainment is an important concern in program planning. Too often, people define objectives without thought as to how they will measure their accomplishment. Upon examination of the objectives tree, one usually finds that some of the objectives are axiological (rooted in value judgments), while others are

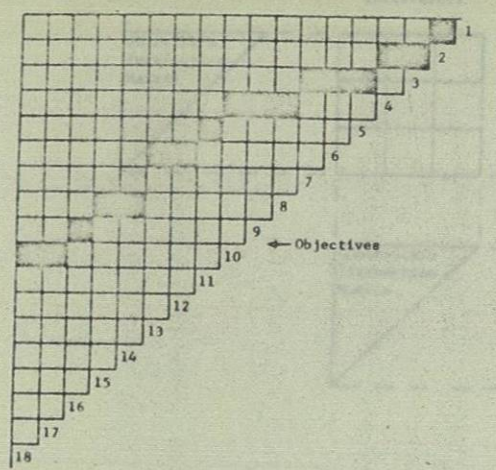


Fig. 6. Objectives self-interaction matrix corresponding to objectives tree shown in Fig. 5.

not. The axiological objectives usually lie at the top of the objectives tree. An example of such an objective is: "to improve the public schools." The word "improve" makes this objective axiological in nature, since whether this objective is attained or not is a matter of subjective opinion, or value judgment. A nonaxiological objective is one like "to teach children to distinguish a Mozart composition from a Beethoven composition." The achievement of this objective is determinable, and not a matter of opinion as to whether the children can or cannot make the distinction. The axiological objectives serve an inspirational purpose, but the nonaxiological objectives are more useful in planning because they are more readily converted into planned activities.

One may examine the objectives tree to see which objectives are measurable, and how they may be measured. For the musical objective mentioned above, the measure is the agreement between the child's answer and the correct answer. The determination as to whether the public schools have been improved is vastly more difficult to make, and such an objective is virtually immeasurable within any reasonable cost. However, the attainment of lower level objectives that are contributory to that one may suggest that progress is being made.

For example, it should be possible to measure the attainment of an objective such as, "To improve the method of teaching reading to sixth graders to the extent that at least 70 percent of the students exceed the fiftieth percentile performance on a standardized sixth-grade reading achievement test." The corresponding objective measure could be "Percent of sixth-grade students, whose performance exceeds the fiftieth percentile performance on a standardized sixth-grade reading achievement test."

The total process of measurement involves more than just the selection of the measure or unit by which the attainment of objectives will be assessed. Often, as in the above example, a threshold for judging acceptable performance can be defined and built into the objective and objective measure. The balance of the process of measurement includes planning for how the data required for evaluation are to be sensed and how they are to be analyzed to generate an indication on the selected measurement scale. In the above example, planning for the sensing function would involve selection of the achievement test, planning when, to which students, and under what conditions the test would be administered and planning for how the resulting tests would be interfaced with the test-scoring activity. Planning the indicator function would involve selection of procedures for analyzing the test scores and reducing them to standard achievement scores in a timely and efficient manner.

Thus the planning of objectives and objectives measures is tightly interwoven with the process of determining how the measures are to be obtained, i.e., how the data are to be sensed, and how the indication on the scale of measurement is to be attained.

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One may examine the objectives tree to see which objectives are measurable, and how they may be measured. For the most objective method shown above, the measure is the agreement between the child's answer and the correct answer. The determination as to whether the public schools have been improved is vastly more difficult to make, and such an objective is virtually immeasurable within any reasonable cost. However, the attainment of lower level objectives that are contributory to that one may suggest that progress is being made.

For example, it should be possible to measure the attainment of an objective such as "To improve the method of teaching reading to sixth graders to the extent that at least 70 percent of the students exceed the fifth percentile performance on a standardized sixth-grade reading achievement test." The corresponding objective measure could be "Percent of sixth-grade students whose performance exceeds the fifth percentile performance on a standardized sixth-grade reading achievement test."

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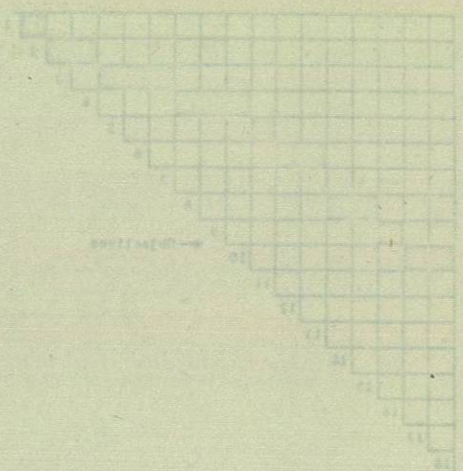


Fig. 8. Relating objectives measures to objectives.

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As will be discussed later in relation to an example, the need for defining a set of measures on the objectives which to determine their attainment is an important element in program planning. Too often, people define objectives without thought as to how they will measure their accomplishment. Upon examination of the objectives, one usually finds that some of the objectives are biological (rooted in value judgments), while others are

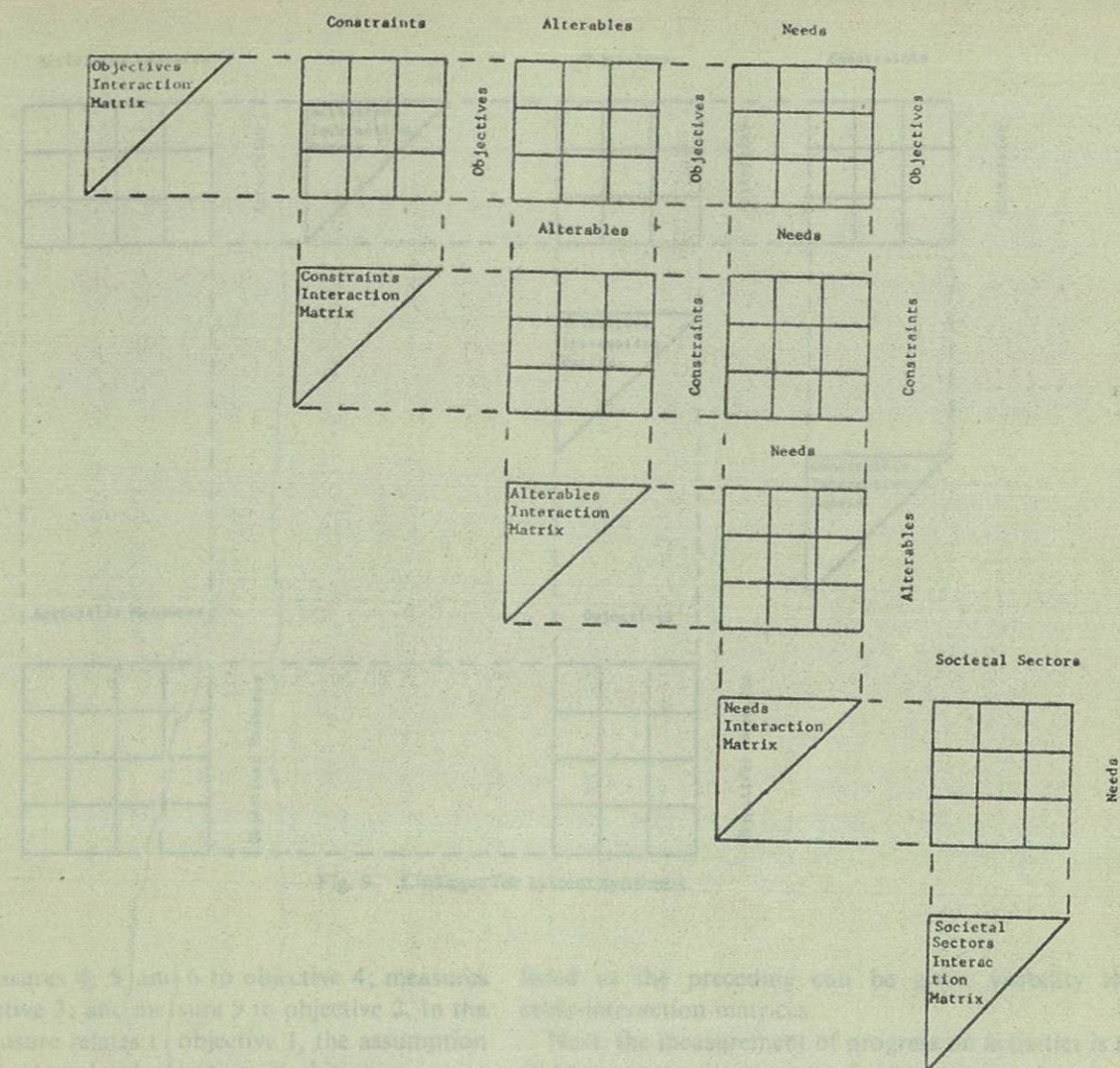


Fig. 7. Interaction of objectives with constraints, alterables, needs, and societal sectors.

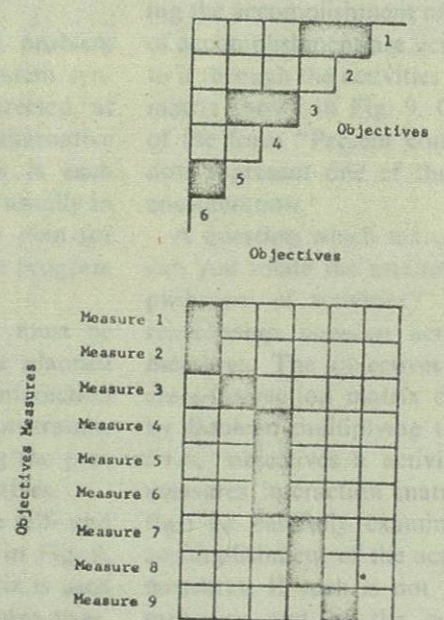


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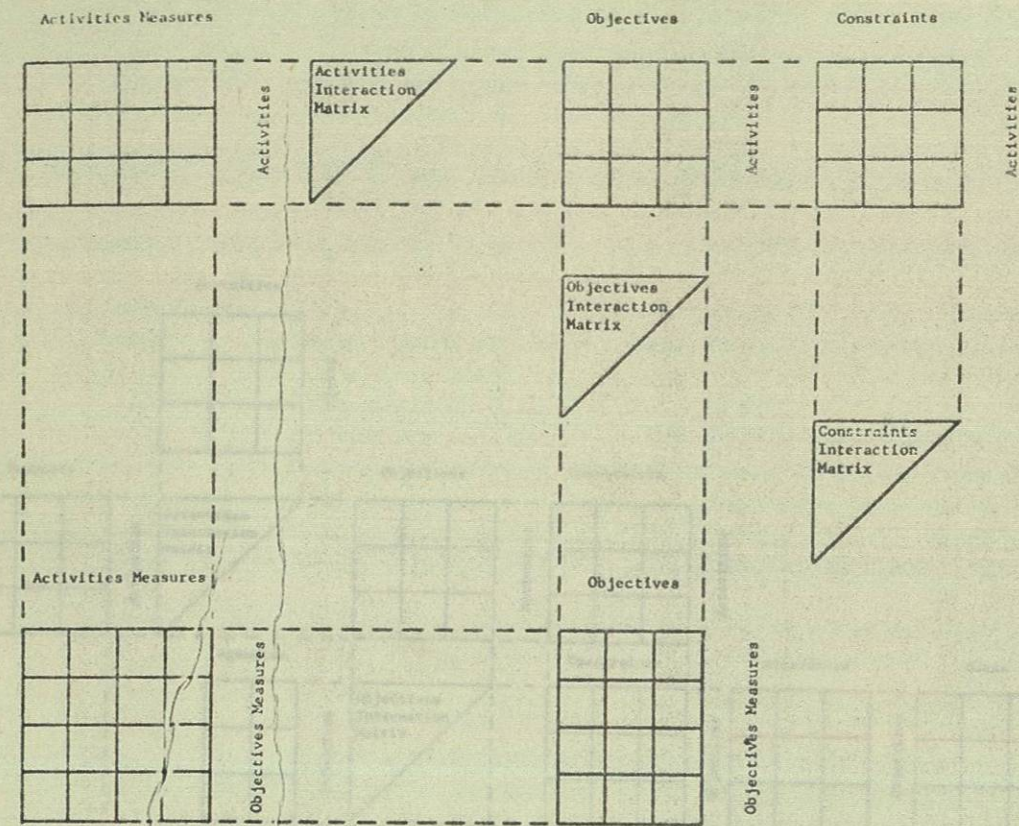


Fig. 9. Linkages for system synthesis.

objective 5; measures 4, 5 and 6 to objective 4; measures 7 and 8 to objective 3; and measure 9 to objective 2. In the example, no measure relates to objective 1, the assumption being that the highest level objective, in this case, is not directly measurable.

SYSTEM SYNTHESIS LINKAGES

Hall's matrix, Fig. 1, shows that following problem definition and value system design comes the system synthesis step. System synthesis activities are directed at answering the following questions. What are the alternative approaches for attaining each objective? How is each alternative approach described? The answers are usually in the form of a series of activities which form a plan for evaluating alternative approaches for attaining the program objectives.

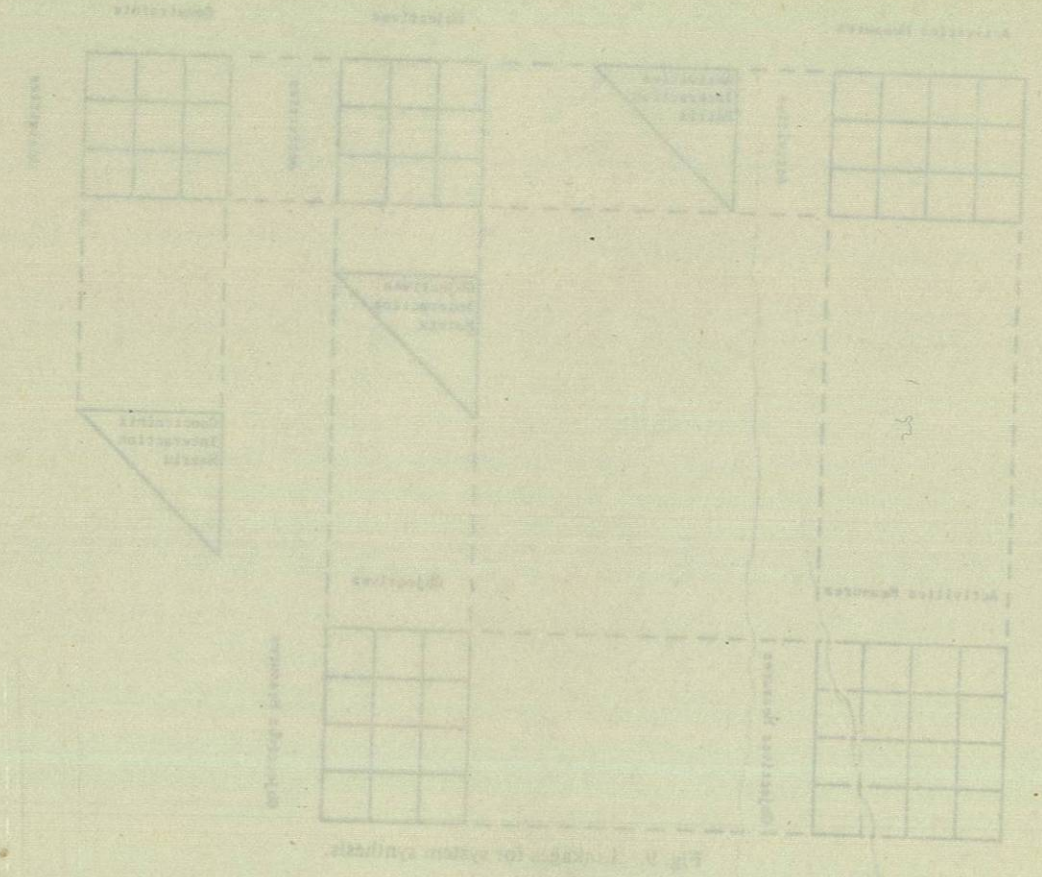
Three major linkages to the preceding steps must be given visibility. 1) The relationship between the planned activities and the program objectives. 2) The interaction between the planned activities and the program constraints. 3) The measurement system required for relating the progress on the activities to the attainment of objectives.

Again, when faced with a linkage problem, the self- and cross-interaction matrices are used as illustrated in Fig. 9. The activities \times objectives cross-interaction matrix is used to relate the proposed activities to specific objectives. Similarly, the interactions of the constraints with the activities are illustrated by the activities \times constraints interaction matrix. Thus the first two of the major linkages

listed in the preceding can be given visibility through cross-interaction matrices.

Next, the measurement of progress on activities is related to progress on attainment of the program objectives. Development of a set of objectives measures was discussed previously. An analogous procedure is followed in measuring the accomplishment of activities. One or more measures of accomplishment are defined for each activity and related to it through the activities \times activities measures interaction matrix shown in Fig. 9. Often, the activities measures are of the form "Percent completion of..." where the three dots represent one of the products of the activity under consideration.

A question which management is likely to ask is "How can you relate the attainment of objectives to the accomplishment of activities?" One method is to examine the relationship between activities measures and objectives measures. The objectives measures \times activities measures cross-interaction matrix can be generated mathematically by Boolean multiplying the objectives measures \times objectives, objectives \times activities, and activities \times activities measures interaction matrices. The resulting matrix must then be carefully examined to ensure that measures of accomplishment of the activities do relate to the objectives measures. If such is not the case, a reexamination of all measures and of the activities \times objectives interaction matrix must be made. Either the matrix must be changed or the measures redefined so the activities measures relate to the attainment of objectives.



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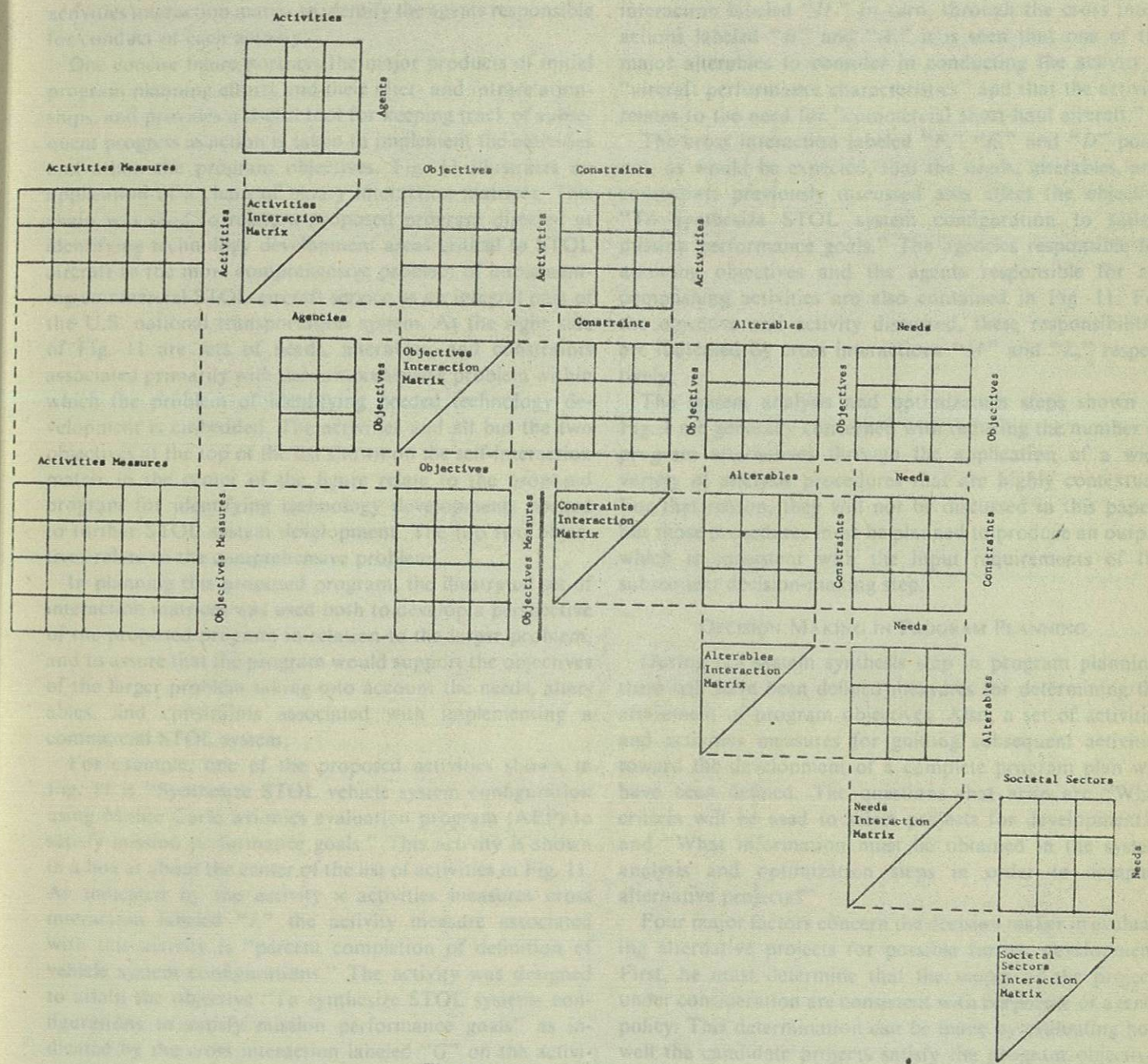


Fig. 10. Program planning linkages.

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To this point, a series of related linkages for the problem definition, value system design, and system synthesis steps of program planning has been discussed. An overall view of a program as planned at the end of the system synthesis step is obtained by combining Figs. 7 and 9 as in Fig. 10. Added to Fig. 10 is an objectives \times agencies interaction matrix to portray which government or industrial groups have an interest in the defined objectives and an agents \times activities interaction matrix to identify the agents responsible for conduct of each activity.

One concise figure portrays the major products of initial program planning efforts and their inter- and intrarelationships, and provides a useful tool for keeping track of subsequent progress as action is taken to implement the activities and attain the program objectives. Fig. 11 illustrates an application of a chain of binary interaction matrices. This chain was used to relate a proposed program directed at identifying technology development areas critical to STOL aircraft to the more comprehensive problem of implementing commercial STOL aircraft service as an integral part of the U.S. national transportation system. At the right side of Fig. 11 are sets of needs, alterables, and constraints associated primarily with the comprehensive problem within which the problem of identifying needed technology development is embedded. The activities and all but the two objectives at the top of the list shown on the self-interaction matrix in the center of the figure relate to the proposed program for identifying technology developments needed to further STOL system development. The top two objectives relate to the comprehensive problem.

In planning this proposed program, the illustrated set of interaction matrices was used both to develop a perspective of the proposed program in relation to the larger problem, and to assure that the program would support the objectives of the larger problem taking into account the needs, alterables, and constraints associated with implementing a commercial STOL system.

For example, one of the proposed activities shown in Fig. 11 is "Synthesize STOL vehicle system configuration using Monte Carlo avionics evaluation program (AEP) to satisfy mission performance goals." This activity is shown in a box at about the center of the list of activities in Fig. 11. As indicated by the activity \times activities measures cross interaction labeled "I," the activity measure associated with this activity is "percent completion of definition of vehicle system configurations." The activity was designed to attain the objective "To synthesize STOL systems configurations to satisfy mission performance goals" as indicated by the cross interaction labeled "G" on the activities \times objectives cross-interaction matrix.

By following around the loop of interaction matrices at the left side of Fig. 11, one sees that the interaction labeled "J" in the objectives measures \times activities measures cross-interaction matrix relates the activity measure to the objective measure "percent completion of mission performance goals definition" which, through interaction K, is related to the objective mentioned above. In this way, the activity

and its measure of accomplishment is tightly connected to the attainment of a corresponding objective or objectives and their measures of attainment.

One can also see from Fig. 11 how the proposed activities relate to the more comprehensive problem. For example, the aforementioned activity must take into account the constraint "system operating costs" since it is directly related to that constraint by the activities \times constraint interaction labeled "H." In turn, through the cross interactions labeled "B" and "A," it is seen that one of the major alterables to consider in conducting the activity is "aircraft performance characteristics" and that the activity relates to the need for "commercial short-haul aircraft."

The cross interaction labeled "F," "E," and "D" point out, as would be expected, that the needs, alterables, and constraints previously discussed also affect the objective "To synthesize STOL system configuration to satisfy mission performance goals." The agencies responsible for attaining objectives and the agents responsible for accomplishing activities are also contained in Fig. 11. For the objective and activity discussed, these responsibilities are indicated by cross interactions "M" and "L," respectively.

The system analysis and optimization steps shown in Fig. 1 are generally concerned with reducing the number of program alternatives through the application of a wide variety of analysis procedures that are highly contextual. For that reason, they will not be discussed in this paper; but those procedures must be planned to produce an output which is consistent with the input requirements of the subsequent decision-making step.

DECISION MAKING IN PROGRAM PLANNING

During the system synthesis step in program planning, there will have been defined measures for determining the attainment of program objectives. Also, a set of activities and activities measures for guiding subsequent activities toward the development of a complete program plan will have been defined. The questions that arise are "What criteria will be used to select projects for development?" and "What information must be obtained in the system analysis and optimization steps in order to compare alternative projects?"

Four major factors concern the decision maker in evaluating alternative projects for possible further development. First, he must determine that the scopes of the projects under consideration are consistent with corporate or agency policy. This determination can be made by evaluating how well the candidate projects satisfy the program objectives which are assumed to be in consonance with corporate or agency policy. (A program whose scope is not consistent with corporate or agency policy would be rejected on the basis of this alone.) Those projects that pass this initial screening are then rated in terms of the remaining three factors discussed below.

The second major factor is the comparative economics of the alternative projects. The analysis should look at the