A New Approach Toward Formulating Research and Development Programs

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This paper discusses concepts and methods for structuring R&D efforts in highway transportation together with techniques for establishing short- and long-range dynamic R&D programs for the purpose of guiding future R&D efforts in a systematic and well-coordinated manner. A new R&D organization structure is proposed based on the concept of "mission-oriented systems approach." A hierarchical structure of 3 levels is developed in terms of strategic, tactical, and action models for the purpose of programming R&D. These structures are used to develop concepts and methods for developing dynamic R&D programs based on R&D needs and resources. These program techniques are helpful in providing systemized procedures that will ultimately help guide, coordinate, and promote positively defined goals.

•THE MAJOR GOVERNMENTAL AGENCIES, universities, industries, and research-oriented organizations with an active interest in highway transportation research are confronted with a complex and long-standing challenge, namely, to solve the many-faceted problems of highway transportation. What logical research and development programs should be formulated to solve these problems? What logical allocation of limited resources should be made to support such R&D programs?

A review of past and current research activities of a number of research organizations indicates that (a) each organization tends to have its own method of formulating its R&D program, which is generally dependent on the nature of the organization, its policies, the internally and externally imposed constraints, and the size and nature of available and future resources; and (b) there has been a great deal of fragmentation, duplication, and lack of correlation and direction in the overall R&D program and some waste of research effort.

One of the consequences of this unstructured approach to R&D in the past has been an absence of tangible benefits commensurate to investment. It is evident that there must be better organized and systemized procedures and structures through which the entire effort of R&D in highway transportation can be guided, coordinated, and promoted toward positively defined goals. This paper is confined to the development of concepts and methods of R&D program formulation. These concepts and methods are especially important from the viewpoint of subsequent detailed development of R&D programs.

The problem of R&D program formulation is conveniently examined within the framework of the following objectives:

1. To develop concepts and methods for structuring R&D efforts toward improvement of highway transportation; and
2. To develop concepts and frameworks for establishing short- and long-range dynamic R&D programs, guiding future R&D efforts in a systematic and well-coordinated manner, and maximizing the benefits resulting from R&D.

While these objectives can be spelled out only in the broadest terms, the criteria that must be met by the resulting R&D programs can be identified more specifically as follows:

Paper sponsored by Special Committee on the Conduct of Research.

1. Provision for both theoretical (new concepts) and applied research (new methods and development);
2. Provision for the translation of theoretical research results into practical use;
3. Use of systems concepts to permit a better understanding of the relationships among many research areas;
4. Capability of development and expansion within the framework of overall programs already established by governmental and industrial agencies;
5. Realism in terms of availability of physical, fiscal, and manpower resources;
6. Realism in terms of priority and scheduling; and
7. Compliance with the research institution's policies.

The overall significance of a framework within which R&D programs can be developed lies in the end product, namely, in a sound base and structure for the orderly expansion and development of both existing and future research and development programs. This is of particular importance when viewed against the complexity and magnitude inherent in future research efforts required to meet the challenges of tomorrow's transportation requirements.

This method of procedure includes 2 phases: (a) development of concepts and methods of formulating R&D structures; and (b) development of concepts and methods of formulating dynamic R&D programs. These phases, while described separately, are not mutually exclusive. On the contrary, they are very much interrelated.

DEVELOPMENT OF CONCEPTS AND METHODS OF FORMULATING R&D STRUCTURES

A prerequisite to developing R&D programs in highway transportation is to establish a number of R&D structures as a guide to the orderly development of such programs. There are basically 2 types of R&D structures that are useful toward this end: (a) the organization structure and (b) the program structure.

Organization Structure

The organization structure is mainly concerned with the arrangement of various, often diverse, R&D functions and activities into an integrated, coherent system with each part working toward the common organizational goal (in this case, improvement of the services provided by the highway transportation system) and each component represented in terms of its ultimate performance within some large system. This type of systems organization or classification is essential for the development of the R&D program structure and, indeed, for successful R&D performance.

The underlying concept of the evolvement of a highway transportation systems research structure (or a dominant requirement of this R&D organization structure) is a mission-oriented systems approach as shown in Figures 1 and 2. This new approach is quite different from the traditional subject-oriented R&D classification (as in the Highway Research Board subject organization) in that the various elements that make up the research effort are structured to accomplish a positive mission. A structure of this nature involves identifying all of the necessary research elements, activities, and their relationships; structuring these activities into a proper hierarchical framework; and sequencing these activities in such a manner as to be useful toward accomplishing a positive mission. Some other characteristics of a mission-oriented structure include clear purpose, clear logic, interrelationship, coordination, logical grouping, coherency, flexibility, and convergency toward a mission or an objective.

Based on this concept, 5 system elements of highway transportation systems research were developed (Figs. 1 and 2). These are administration and management (or systems management), systems planning, systems operations, materials, and structures. (The system elements of materials and structures could have been combined to form "systems physical facilities." The reason for not combining them is that the expertise necessary to develop an R&D program in these system elements is quite unique and often mutually exclusive; i.e., a materials specialist may not be a specialist in pavement structure and vice versa.) These 5 system elements not only constitute the essential

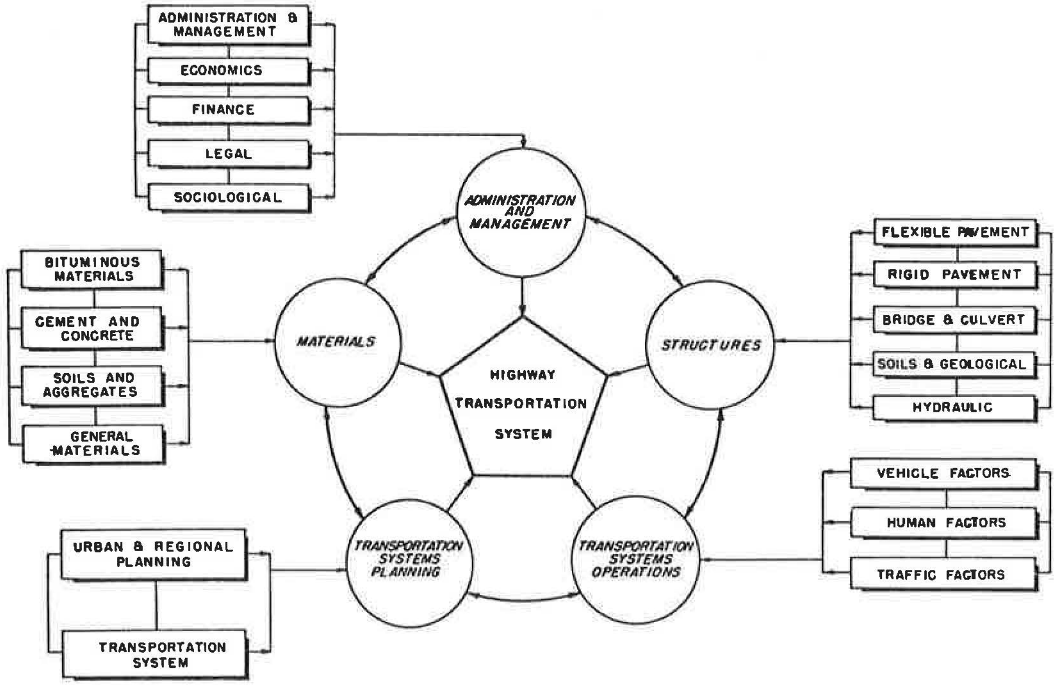

Figure 1. Structure for highway transportation research.

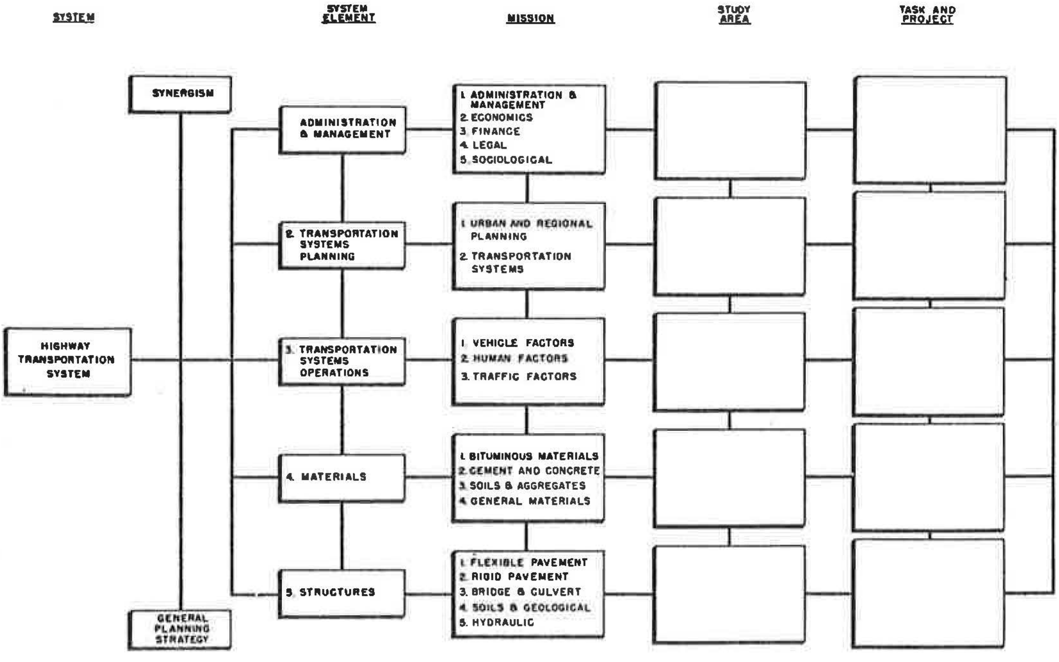

Figure 2. Highway transportation system research model.

core but also cover the entire spectrum of highway transportation R&D as seen today and envisioned for the foreseeable future. These system elements were selected not for the purpose of isolating any of the R&D components but for the purpose of forming viable systems components that demonstrate the distinct characteristics of highway transportation systems research and the need for an integrated synergistic approach to R&D program formulation and R&D performance.

Each system element consists of a number of missions that characterize its vital role in highway transportation systems R&D structure. There are a total of 20 missions under the 5 system elements (Fig. 2). (Actually, each mission should read, for example, "improvement of the performance of flexible pavement," "improvement of traffic factors," and so on. However, for brevity, only the key words are given.) A mission provides a positive research goal to be accomplished. It is an essential hierarchical unit that serves as a basis for establishing R&D orientation goals and systems integration. A mission also represents expertise in the existing R&D discipline structure that could participate in the R&D efforts of its own specialty and capability.

Each mission, then, is comprised of a number of study areas or problem areas. For example, a study area within the traffic factors mission might be improvements in street network operation. This level of the R&D systems hierarchy may be considered as the working unit that specifies the positive objectives to be accomplished. An R&D program is formulated to accomplish these specific objectives. These problem areas may be of an applied or a theoretical nature. They may be short- or long-range R&D activities. They may be given priorities based on some logical priority criteria. Incorporation of the problem areas into the program structure will be described later.

Each study (or problem) area is then broken down to the next lower hierarchy, namely, a number of tasks and projects, and structured in terms of phases and flows of R&D activities that are required to accomplish the stated objectives.

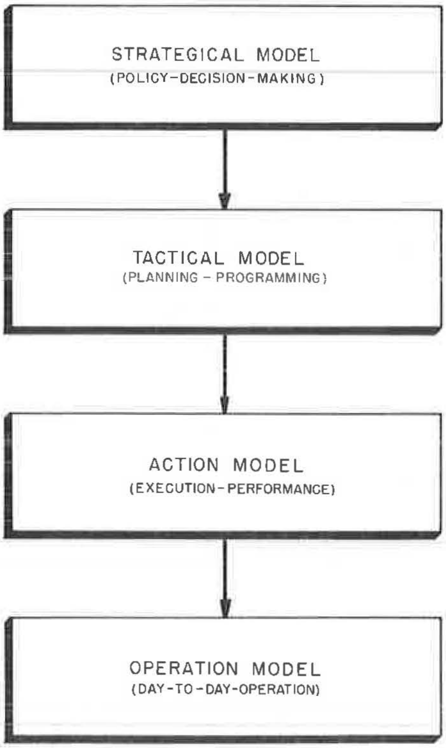

Figure 3. Hierarchy of R&D planning and programming.

In the formulaton of R&D programs on the level of tasks and projects under a given problem area, the project or task selection is not limited to that particular mission area under which the problem area is considered and for which the R&D program is being developed. On the contrary, tasks and project selections for one particular objective or one problem cut across the mission boundaries and thus attain the characteristics of a systems approach. All of the relevant system components that define the problem and the major interactions are integrated into the problem area R&D formulation.

In summary, an organization structure provides a primary framework and basis for a systems approach in both R&D program formulation and R&D performance.

Program Structure

In addition to the R&D organization structure described, there is a need for an R&D program structure to describe and to program various R&D activities that will achieve the stated goals and objectives. An R&D program structure, in essence, provides 3 levels of hierarchy with respect to the orientation, thrust, activities, and structures. The structure that describes this hierarchy consists of strategic, tactical, and action models (Fig. 3). A fourth model (operation model) is not a program model but a day-to-day R&D operation model and is not considered at this time.

The basic concept underlying this program hierarchy is that, if the basic strategy of R&D, either on a national or local level, for a given mission and for highway transportation research as a whole is established properly, then there is a strong probability that present and future R&D efforts programmed in terms of the tactical and action models (which are developed within the framework of the R&D strategy) have at least a fair chance to be sound and effective and also may be expected to maximize the return on R&D investment. If the basic strategy is not properly formulated, however, the tactical and action models would not only be invalid but would also yield the least amount of return.

Thus, it is paramount to develop a series of sound R&D strategies to guide the R&D activities on the national level to promising directions and to successful results. The task of developing these strategies rests on the administrators of federal and state governments and research institutions. These strategies, once established, should be reviewed periodically in the light of new technological development and socioeconomic constraints and demands. For this reason, dynamic R&D programming is needed to revitalize the R&D programs at all 3 levels. The dynamic programming is described later.

The strategic model is developed as follows:

1. Based on the past and present trends and patterns of R&D in a particular area, the state of the art should indicate the status of R&D activities in a given mission or missions. Some of the parameters are R&D gaps, fragmentation, duplication, lack of positive direction, and general trend.
2. Based on this information and socioeconomic requirements and constraints, a general strategy of future R&D in each mission area can be developed. Future R&D strategy may indicate general thrust, orientation, problem areas, goals, priority, consequences, methodology, and interrelationships.
3. The general framework of R&D programs should be an optimal framework for carrying out future R&D programs indicated in 1 and 2.
4. This model will be useful to administrators, sponsors, and researchers in that it provides an overall picture and strategy of a given mission area and a basis for the decision-making process. Thus, basic R&D strategy for a given mission area may be established to serve as a guide for the development of tactical and action models. This model has a general applicability and utility regardless of geographic location or type of organization.

The second level of hierarchy is the tactical model, which is essentially an R&D planning and programming structure. This model is developed within the R&D strategy established in the strategic model and has the following characteristics: (a) establishes and defines positive objectives, study areas, and problem areas; (b) provides well-structured R&D programs for accomplishing objectives and goals established; (c) indicates various R&D flows, interrelationships, phases, and steps to accomplish the stated objectives; (d) serves as an R&D planning and programming tool that is concerned with the intermediate level of the decision-making processes; (e) is useful for R&D management control and for researchers; and (f) has a general applicability and utility regardless of geographic location or type of organization.

The third level of hierarchy is the action model. This defines the tasks indicated in the tactical model in relatively finite terms so that various R&D activities may be clearly programmed and spelled out and actual R&D may be performed based on this program model. This model (a) describes major tasks and projects that are necessary to place the research activities in clear focus; (b) indicates levels and scope of R&D activities of various tasks and projects and interrelationships among them; (c) serves as a test model for the hypotheses and directions established in both strategic and tactical models; (d) describes the R&D resource requirements necessary to reach certain objectives; (e) is useful for R&D management control and researchers; (f) may be developed or tailor-made as an R&D program for a particular institution depending on its policy, constraints, and resources; and (g) is the basis for actual performance (operation model) of R&D.

In summary, for any given mission area or a combination of mission areas, the first task is to establish the basic strategy with respect to the direction of R&D and to determine how the stated goals may be achieved. Then, within the framework of this R&D strategy, the tactical and action models will be developed to achieve the stated goals and objectives in terms of positive R&D programs and resource requirements. The strategic and tactical models have general utility independent of geographic location or type of organization, whereas the action model is a tailor-made program for a particular organization.

DEVELOPMENT OF CONCEPTS AND METHODS OF FORMULATING DYNAMIC R&D PROGRAMS

This phase entails the development and evaluation of possible alternative R&D programs with the eventual emergence of a final, dynamic program set.

Basically, there are 2 approaches in formulating an R&D program. One approach commonly used is based on the R&D needs. The other, which has not been utilized a great deal, is based on available or potential resources. Either approach may be used. Preferably the 2 approaches should be combined depending on a number of variables and constraints. This 2-way approach concept is shown in Figure 4.

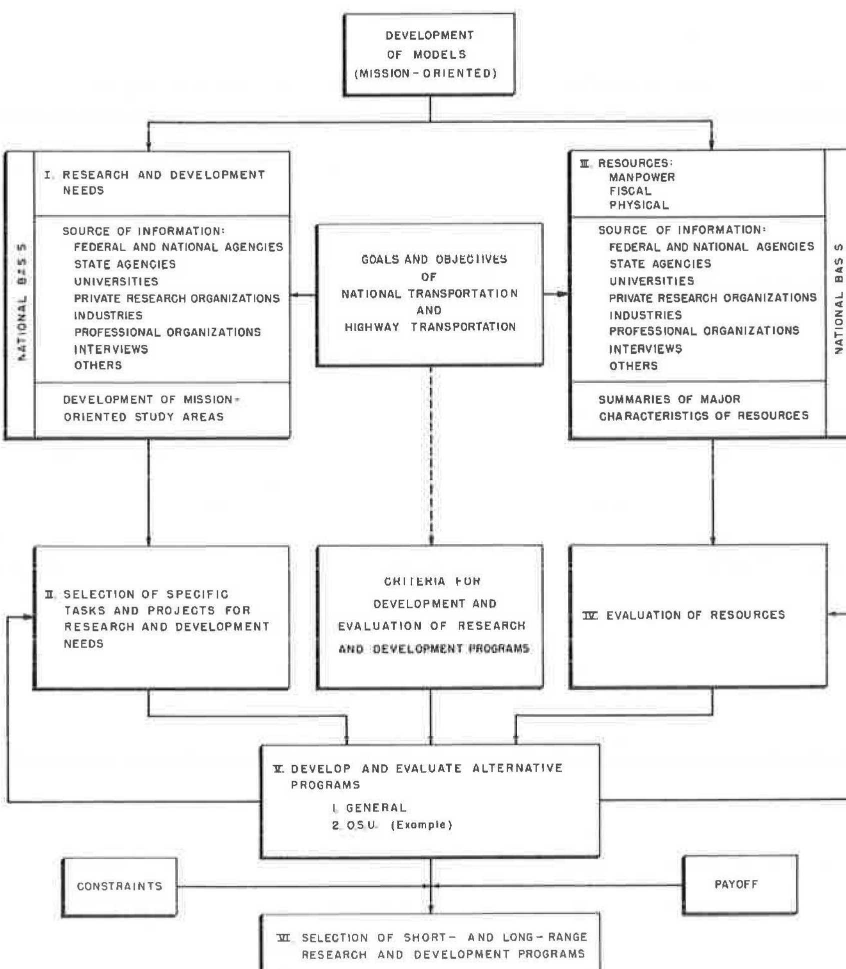

Figure 4. Development of model.

R&D Needs Approach

The first step in this approach is to determine the prevailing R&D needs. These needs are then categorized into 3 levels of R&D programs, namely, strategic, tactical, and action programs (or models), as described in the previous section.

Several studies related to research needs have been completed in recent years (1, 2, 3, 4). The state-of-the-art literature will be helpful in providing a good overview of R&D activities of the present and immediate past. This overview is essential in determining the general trend and pattern, gap fragmentation, duplication, and direction of R&D. It serves as a basis for formulating the strategic model, whose requirements and characteristics were described earlier. R&D needs studies are utilized for determining the future R&D needs. By studying programs, reports, and other socioeconomic requirements and constraints, future direction, thrust, goals, and priority of R&D are established as an integral part of the R&D strategy in each system element and mission area. Information from studies is supplemented by further information secured by interview and discussion with individuals involved in various research activities in highway transportation. Development of R&D strategy is mainly an administrative function.

Based on the R&D goals and priorities established in the strategic model (or program), R&D needs are then formulated into tactical and action programs. The tactical program, whose requirements and characteristics were explained earlier, involves developing well-structured R&D programs for a specific problem or study area. It indicates various R&D flows, interrelationships, phases, and steps to accomplish the stated objectives. General resource requirements (physical, manpower, and fiscal) may be established in this program. Development of the tactical program is an administrative-staff function.

Both strategic and tactical programs are not designed for special usage by any one organization. To the contrary, they have a general applicability and utility to most of the organizations across the country interested in highway transportation R&D.

The action program is then developed for the specific set of objectives within a problem area (or study area) as defined in the tactical program. This program involves judicious and logical selection and structuring of tasks and projects required for accomplishing the stated objectives. Various resource requirements (physical, manpower, and fiscal) necessary for achieving the stated objectives are also indicated in detail. Based on this action program, R&D can proceed. The action program is tailor-made to suit the particular policy, needs, capability, constraints, and resources available to a given organization. Development of the action program is mainly a staff function.

In summary, the R&D needs are first synthesized to form the basic R&D strategy along with other requirements for each system element or mission. Then, tactical and action programs are formulated of R&D strategy to solve specific problems.

Resources Approach

The conventional approach to R&D program development begins with R&D needs and formulates the program on the basis of need priorities within the limits of prevailing constraints. This approach assumes that all types of resources are equally available or that the necessary resources to accomplish certain missions can be planned and obtained. This is often not the case. In some areas of research and development, there exist unique resources (such as impact sleds, high-speed tracks, and specially trained research personnel) that possess very special R&D capabilities and capacities. If and when such unique resources exist, it is logical that a special effort should be made to formulate the R&D program to make the most efficient use possible of them within the confines of the national R&D thrust. This is the underlying principle of the resources approach to R&D program formulation.

Because this approach to program development is built around the special capabilities of specific resources, it is difficult to explain the procedure in general terms. For this reason, the procedure has been illustrated for a specific group of physical resources, namely, research laboratories. A similar procedure can be followed for each of the other types of physical resources (such as field installations or tracks) or manpower resources. The resulting R&D program developed from such an approach will be fully feasible from a resource requirement standpoint and will provide full and efficient resource utilization.

An evaluation of the contribution of laboratories to the total capability of a research facility requires a knowledge of the different types of laboratories available and an understanding as to how these laboratories fit into the operation plan of such a facility. Figure 5 shows an overview of the interactions that take place between physical resources in the support of a set of research projects. The frequency and extent of these interactions are dependent on both the specific character of the research being pursued and the type of resources that are available.

Two general classes of laboratories can be readily identified, namely, primary laboratories and secondary laboratories. Primary laboratories are those directly involved in the performance of basic and applied research relating to highway transportation. Secondary laboratories are essentially support facilities involved along with the workshops in providing services to the primary laboratories and the field

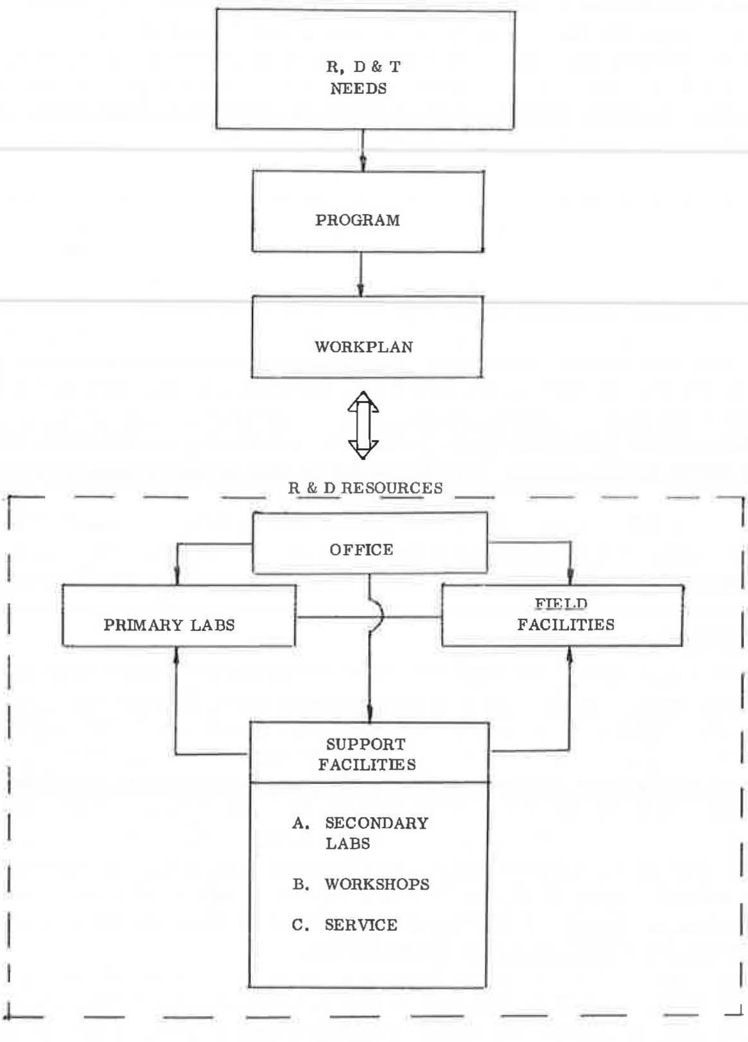

Figure 5. Study overview.

facilities. In general, these laboratories exhibit little or no trade-off with any other physical facilities. The primary laboratories by virtue of the direct highway orientation have the greatest effect on the overall capabilities of a research facility. For this reason they are critical in this approach to R&D program formulation.

Some of the different types of laboratories currently in operation in industry, at universities, and at research institutions in the primary class are highway materials; highway structures; optics and illumination; noise and vibration; corrosion and fatigue; environmental control; hydraulics; signs, markings, and control devices; vehicle guidance; vehicle dynamics and components; traffic dynamics and surveillance; system design and system operation; human behavior; medical analysis; impact; fuels and propulsion; accident reconstruction and analysis; simulation and simulator development; and pollution analysis and control.

Laboratories in the secondary class include communications, data processing and storage, photography, photogrammetry and photo interpretation, instrumentation, chemical, radiology, mechanical, electronics, electrical, and strength of materials.

Each physical resource has a specific capability for meeting different groups of research and development needs. The problem is to match the relevant needs with the appropriate resource. Once this match has been made it will be possible to formulate a set of R&D programs that will make efficient use of all available and potentially available resources.

Many factors combine to determine the research potential of a primary laboratory. Among these are the following: type and amount of specialized equipment available, quantity and quality of available manpower, efficiency of laboratory operation, flexibility of equipment allowing multipurpose usage; and capacity measure (volume of R&D that can be handled in laboratory).

Preliminary study has shown that the first 2 factors listed have the greatest effect on laboratory research potential. Hence, it becomes necessary to determine the major equipment commonly found in each of the primary laboratories. This will allow prevailing research needs (on a study area, project, or task level) to be related to the individual research capabilities of the laboratories with a greater degree of certainty. Once this has been done research programs based on research capabilities can be developed to make efficient use of all laboratory facilities as has been previously suggested. At the same time guidelines may be set for the acquisition of needed facilities in areas where no suitable facilities exist.

The selection of the proper physical resources for inclusion in a research facility is a difficult problem. This problem is complicated in the case of research laboratories because the research potential of such laboratories is a function of the availability of both equipment and manpower. The level of funding available further constrains the laboratory choice.

Figure 6 shows in flow-chart form a general model developed for use in making the laboratory selection. This model combines decision-making processes in 3 different levels of hierarchy: the strategic level, the tactical level, and the action level. The initial input to the model is a set of needs that have been selected from the universe of needs on the basis of similar resource requirements. Once a needs area has been selected for study it must undergo a policy review and a technical review to establish its validity. The purpose of the policy review is to determine whether the selected needs area (a) falls within the scope of interest of the parent research agency, (b) is in line with long-range policies and goals, and (c) offers sufficient potential payoff for inclusion in the R&D program. All needs areas that satisfy these 3 criteria are subjected to technical review. Needs that do not meet the criteria are dropped from consideration.

The purpose of the technical review is (a) to determine whether the selected needs area is still valid in view of present state of the art; (b) to determine whether the research in a selected area is within the technical capabilities of the parent research agency; and (c) to identify special problems involved in selected research that will require special attention and effort from the research staff. After the technical review, all research areas judged satisfactory can be included in the R&D program. Those judged unsatisfactory are dropped from consideration.

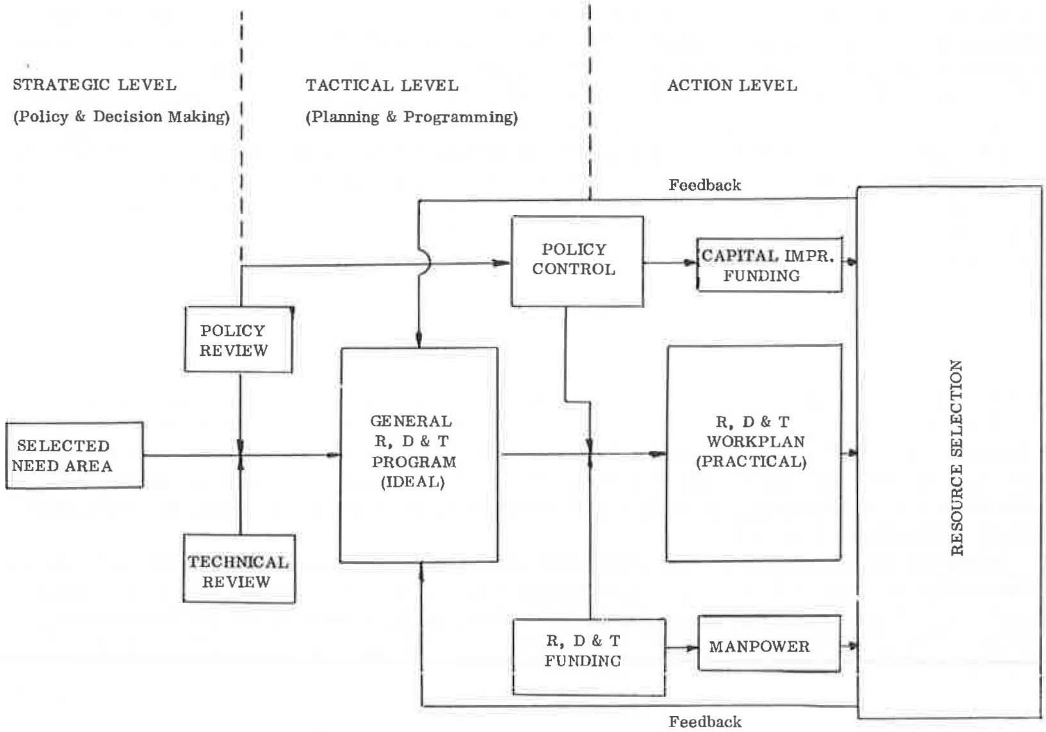

Figure 6. General model for resource selection.

The R&D program derived in this manner represents a compilation of study areas deemed worthwhile from both policy and technical standpoints. It is important to note that simply because a study area is on the program does not mean that it will be implemented in the short run. In order to be implemented, a study area must be moved from the program into the current work plan and defined more specifically in terms of a set of research projects. The impetus for such a move may come from any one of a number of causative factors, which have been termed "initial movers" because they supply the initial push. Prominent among these initial movers are the following: high national priority, promise of high reward, special interest by resident staff, available facilities, work shortages, and special policy decisions.

The exact nature of the initial mover of a particular project is important because it determines the extent to which physical facilities will be allocated to that project. For example, a project with a high national priority that promises high rewards may justify the allocation of large numbers of physical resources to bring about its swift completion, whereas a project generated because of special interests of individual researchers might be allocated lesser resources.

Once the initial impetus has been applied, a project must pass a second policy review, and sufficient funding must be found before it can be included in the work plan. The policy review at this level is primarily concerned with establishing priorities relating the project in question to other projects in the work plan. The priority assigned will determine the level of capital improvement funds that can be released to acquire needed physical resources among which are primary laboratories. The type of laboratory chosen depends on the detailed requirements of the selected project and the nature of other facilities already existing or planned. The concept of trade-off must also be considered. The size of the laboratory depends on the initial mover concept, the quantity of manpower available, the amount of capital improvement funds available, and the size of other existing or planned facilities.

Once the selection has been made, pertinent information on research capability is fed back into the program development process, and the program is modified accordingly. In this manner the resulting R&D program is both dynamic and accomplishable.

In summary, an R&D program may be developed from either R&D needs or resources or from both. The initial concepts and methods are developed. They are to be refined during the course of further study.

Dynamic Programming of R&D

Once the R&D strategy and the tactical and action programs are formulated, R&D can be carried out and useful results obtained. However, any set of R&D programs so established may become partially or totally obsolete in time because of new technological development and varying socioeconomic requirements and constraints. For these reasons any R&D program set must go through a series of revitalization processes, more commonly known as a dynamic programming process. There are basically 3 types of R&D dynamic programming: internal, external, and internal-external.

The internal dynamic programming is applicable to an R&D area where R&D activities are relatively well defined in terms of objectives, activity elements, sequences, and feedback so that the R&D program may be formulated to possess inherent dynamic characteristics. Thus, under a given R&D strategy, the tactical (or tactical-action) program is formulated in terms of a series of R&D objectives, flows, and element interrelationships sequencing with a proper logic and feedback to have internal dynamic programming built in. Administrative control and monitoring, however, are still necessary.

The external dynamic programming, on the other hand, is more applicable to an R&D area where the R&D activities may not be readily defined or programmed with any reasonable certainty. Therefore, there must be some external mechanism that will make a given R&D program dynamic. The general concept and method of an external dynamic programming of R&D in highway transportation are shown in Figure 7. The basic concept is a periodic feedback and review of 3 programming models. It is recalled that the first task is to establish a sound R&D strategy. Then, within the framework of this strategy, tactical and action programs are developed. Thus, it is necessary to make a systematic reappraisal and review of the basic R&D strategy in the light of various dynamic requirements and constraints. For the purpose of this study, a 6-year review by administrative action is proposed. Detailed functions and

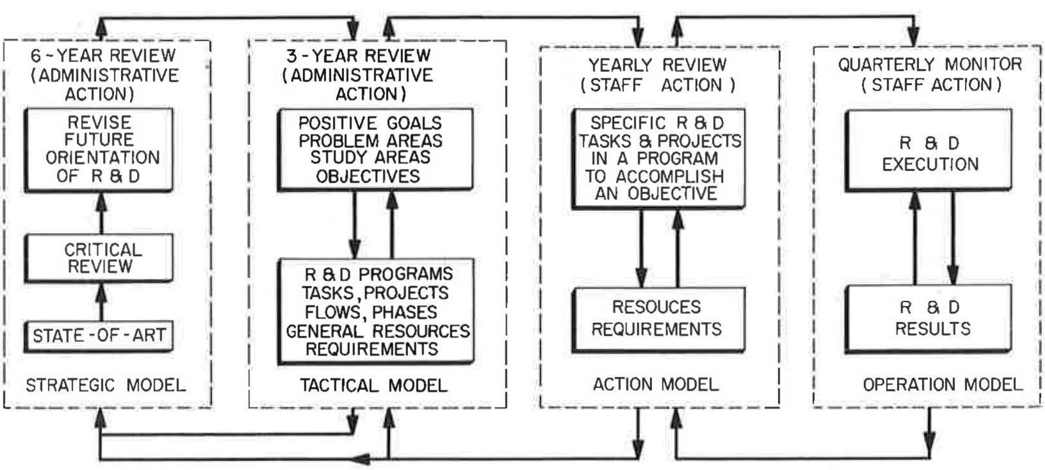

Figure 7. Dynamic programming of R&D in highway transportation.

activities are described in the diagrams. Then, within the framework of a revised R&D strategy, the tactical and action programs are reviewed and revised. The tactical program is revised every 3 years and the action program every year. The results of evaluation, reappraisal, and revision of these 2 programs are then fed into the strategic program to verify whether the strategy requirements and constraints are satisfied. Thus, an R&D program may be reoriented and revitalized to solve the stated problems.

The internal-external dynamic programming is a hybrid of the 2 previous methods. This method is useful for formulating a short-range R&D program by utilizing the internal dynamic programming method and for formulating a long-range R&D program by utilizing the external programming method when a large R&D program consists of both short- and long-range activities.

SUMMARY

In essence, this paper attempts to provide some guidance and direction to R&D program formulation. Emphasis is placed on the concepts and methods of formulating and developing R&D programs. The new concepts and methods are based on a mission-oriented systems approach. Based on this concept, various R&D program structure methods are developed. These concepts and methods provide a basis for better organized and systemized procedures and structures through which the entire effort of R&D in highway transportation may be guided, coordinated, and promoted toward positively defined goals.

ACKNOWLEDGMENTS

The material for this paper was developed in a research project sponsored by the Ohio Department of Highways in cooperation with the Federal Highway Administration. The support of this research is gratefully acknowledged. The statements in this paper are those of the authors and not of the sponsors.

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