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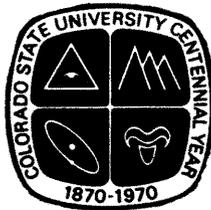
"TRANSPORTATION RESEARCH NEEDS RELATED  
TO CIVIL ENGINEERING"

by

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## ABSTRACT

This report sets forth the civil engineering research needs in the field of transportation. The program is drawn looking to the future needs of the profession for the type of engineering information, data, and findings best developed through purposeful research. The report has been prepared as a means to declare publicly the present and immediate future needs for research in the civil engineering aspects of transportation. Needed research in associated fields is indicated but not detailed.

This is one of a series of reports prepared as a means to declare publically the present and immediate future needs for research in civil engineering. This series of reports are the results of a joint effort of the American Society of Civil Engineers, the Civil Engineering Department of Colorado State University and a number of agencies and organizations providing partial funding. Other reports in the series give results of research needs studies in environmental, structural, and water resources engineering and in activities supporting and closely related to civil engineering.

Transportation is considered as a system made up of a grouping of parts, or sub-systems, of social and economic programs. The report is divided into two parts. The first deals with establishing the role of transportation in society, and the interest that the civil engineer has in transportation. The second deals with research needs as viewed from the perspective developed.

A program of research is presented in considerable detail with estimates of the level of funding considered to be necessary if the profession is to improve and enlarge its capabilities to meet the future needs for transportation of the society. Many subjects, such as, soil

mechanics and foundations, structures, and environmental considerations, which are vital to overall development of a transportation system, may seem to have been treated rather lightly. The reason for this is that research in these subject areas will be covered in depth in other reports in the series. Research in fields other than civil engineering are mentioned but not detailed. It is hoped by doing this that the report should make the case for multi-disciplinary research to link together science, engineering, economics, law, management, public administration, and foreign affairs.

Requirements to sustain the research program developed are:

(1) Funding of a level of \$1 billion per year; (2) manpower to include 20,000 professionals; and (3) \$200 million per year in expenditures for research facilities.

Eighty-two references are included.

#### KEY WORDS

Descriptors -- transportation, highway transportation, railroads, pipelines, waterway transportation, air transportation, research, systems, systems engineering, social aspects, political aspects, personnel, costs, research facilities, professional personnel, economics, social mobility, environment, land use, freight transportation, passenger transportation, terminals, transportation models, aesthetics.

Identifiers -- research needs, transport systems, U.S. Department of Transportation.

## FOREWORD

A business leader once said, "Everyone is interested in the future, in what lies ahead, and particularly is this true in business. Peering into the crystal ball to discuss the future can be interesting, frustrating, tedious, sometimes even humorous, but at all times it is an important phase of business leadership. Forecasting has been described as an educated guess."

In a like manner, the development and progress of the joint ASCE--Colorado State University study on Research Needs and Requirements has been interesting, frustrating, tedious, and humorous, but it has and continues to prove itself a useful and profitable preoccupation of ASCE research activities. The results of the studies as they are produced lead the way not only to new areas and needs for research in civil engineering fields, but they also lead the way in new fields of adventure and practice by the civil engineer. Failure to look ahead, and not only accept change but promote it, can only lead to obsolescence and eventual dissolution of a profession or any other group charged with public responsibility in today's world.

Recognizing the need to look ahead and plan for increased research efforts in civil engineering, the ASCE Committee on Research conducted an ASCE Research Conference at Skokie, Illinois in April 1962. The objectives of the conference were to develop plans for research and to propose implementation of these plans. A major recommendation of this conference was that a major study be made to evaluate the overall effort of civil engineering research in relation to present and future requirements; and that such a study must include the determination of

the level of research needed by the United States in each field of civil engineering over the next 15 to 20 years.

Based on this recommendation, a plan for such a study was developed as a joint effort between ASCE and the Civil Engineering Department at Colorado State University. Essentially the project called for the production of research needs studies by each of the ASCE Technical Divisions and Research Councils and eventual assembly and correlation of this information by the staff at Colorado State University. All of this work was coordinated and guided by the Task Committee on the Study of National Requirements of Civil Engineering Research of the ASCE Committee on Research. The initiation of the portion of the project involving staff work at Colorado State University was funded by the National Science Foundation in 1965.

As proposed to the National Science Foundation, objectives of the study were to evaluate:

1. Needs of the nation for research in civil engineering fields.
2. The status of research related to civil engineering.
3. Requirements necessary to implement recommended research programs.

Reasons for justification of the study were: No real data exist to establish, on a rational basis, the needs for development and support of programs of research related to civil engineering. In addition, there is a growing concern among professional leaders that a significant amount of engineering research, which is conducted and supported by various agencies, seems to be of questionable value.

An initial study on a broad basis will be a very valuable reference for planning and organizing meaningful research when areas of specific need are being considered.

Many reports and surveys have been published on the amount and distribution of research funds. Few of these are of real value for civil engineering purposes and many results are subject to easy misinterpretation. A review of present reporting practices by various groups, and development of a technique for collecting and presenting the information in usable form as it relates to an engineering profession, would be extremely valuable.

By its very nature, civil engineering is concerned primarily with nondefense type activities, activities not given the publicity and glamour provided programs such as the national space program. Most activities are in some fashion concerned with various aspects which deal, to a great extent, with development of the urban environment. Funds for research on these problems are not as readily available as they are for programs such as those oriented toward defense or space technology. Yet, each year, a major portion of the nation's budget is used for construction of works related to civil engineering projects.

Emphasis in the past years on special and crash programs has also seriously affected the balance of research needed to develop well-rounded programs for high-quality professional education. Increased support is needed by civil engineering departments at educational institutions. One estimate showed that more than 4 million additional dollars in research support were needed by Civil Engineering Departments in 1961-62 and more than 10 million dollars additional per year would be needed in the near future if present trends continued.

The assembly of the necessary information and compilation of reports by the Technical Division Research Committees were monumental tasks all done by voluntary work. The reports represented all levels of

sophistication of research and each Division reported its work in a manner that represented its best approach to future needs.

The amount of information accumulated was of such a magnitude that a decision was reached to divide the final reporting into a series of documents rather than one major document with a summary as originally planned. Included in the series are research needs studies on the four major civil engineering subject areas of Environmental Engineering, Structural Engineering, Transportation Engineering, and Water Resources Engineering. Included in other parts of the series is an overall summary and coverage of such matters as research needs on activities supporting civil engineering, research needs in related fields, and educational institution requirements.

Each report in the series will be suitable for publication separately, but will include adequate preface material and cross-referencing to identify each as a part of the whole. An overall report is intended to combine the separate reports into a presentation as a whole.

Additional funds from the National Science Foundation and others were obtained to help assemble and present the material accumulated in the various categories listed above.

As the project developed further justification was cited as follows:

"A major portion of the nation's annual budget is used for construction of works related to civil engineering projects. In 1969, for instance, a total predicted construction budget of over 91 billion dollars was reported by Engineering News-Record based in Department of Commerce reports. This does not include estimates on cost for planning, engineering, operation and maintenance of civil engineering works. Expenditures for research in the field of civil engineering are small, however, when compared with expenditures in other areas.

In civil engineering educational institutions alone, where a substantial portion of civil engineering research is conducted, it was indicated by a survey in 1965 that only 20 million dollars of research was in progress. This is expected to be closer to 30 million dollars in 1970. Civil engineering department heads have indicated that they wish that this amount would be closer to 35-40 million dollars."

Preliminary results of work done to date on the ASCE - CSU joint project indicate that there are at least 1/2 billion, and possibly 1 billion dollars of worthwhile research that could be done at this time in all fields of civil engineering. There are neither the funds nor the talent available to undertake this amount of work.

The entire project has taken much longer to complete than was originally intended, but it has involved a large number of professionals who are leaders in current thinking in their own areas. By helping crystallize their thinking and showing how their interests related to the whole picture, the project has more than justified itself. If nothing else, it has pointed out many areas that are unwittingly researched to death while major problem areas of our society or unrecognized opportunities for progress beg for attention.

It is hoped that this study provides the basis for even more careful investigations of new areas of needed research as well as the basis for self-appraisal by those engaged in research. It is also not intended that these reports are final in themselves. Continuing studies of this nature in civil engineering are needed if the profession is to progress and meet the challenges of our day.

The American Society of Civil Engineers gratefully acknowledges the efforts of its technical divisions and research councils, the staff

at Colorado State University, and its various consultants, the various organizations who contributed to the financing of various parts of the study series, and in particular, the staff of the National Science Foundation without whose encouragement, support, and patience this entire effort would not have been possible.

At Colorado State University the study is indebted to the work of Dr. Maurice L. Albertson and Professor Charles W. Thomas who were co-principal investigators. Their chore to assemble and report the work in detail has been a difficult assignment.

Overall responsibility for the study from the point of view of ASCE was under the direction of the Task Committee on the Study of National Requirements of Civil Engineering Research. This was a Task Committee of the ASCE Committee on Research. While the membership of the Committee on Research changed substantially over the years, the Task Committee membership remained intact except for the liaison member to the Committee on Research. This Task Committee was under the direction of the chairman, Joseph M. Caldwell. Other members were: Theodore M. Schad, Maurice L. Albertson, Gene M. Nordby, Donald S. Berry, Edward Wenk, Jr., and John F. McLaughlin. This Committee is to be commended for their vision and courage in initiating and fostering the project.

William H. Wisely  
Executive Secretary, ASCE

Donald C. Taylor  
Research Manager, ASCE

## PREFACE

The purpose of this report is to set forth the civil engineering research needs in the field of transportation. The program is drawn looking to the future needs of the profession for the type of engineering information, data, and findings best developed through purposeful research. The report has been prepared as a means to declare publicly the present and immediate future needs for research in the civil engineering aspects of transportation. Needed research in associated fields is indicated but not detailed.

The report is presented to insure that the American public and its institutions of learning, its legislators and administrators, and its other agencies--public and private--will have available to them this guide to assist them in meeting their responsibilities for programming, funding, and guiding civil engineering research in the field of transportation.

The report presents a program of research in considerable detail with estimates of the level of funding considered to be necessary if the profession is to improve and enlarge its capabilities to meet the future national needs for transportation. The program is, in a sense, a minimum program: failure to carry through with at least this level of research can only mean that the profession will not, in the coming years, keep pace with the other technical advances in society and will meet its obligation with decreasing effectiveness.

Transportation has different meanings to different people. In this report the meaning is within the general context of a subset of civil engineering. Thus, transportation research must have relevance

within the context of civil engineering. For civil engineering itself to be relevant, it must view the problems of society. That is, modern engineering must be directed toward a system approach which integrates all the technical disciplines along with the social sciences to provide a socially useful objective that is technically optimized.

Transportation affects, and is affected by, many economic, social, and institutional factors. The competence of those engaged in the engineering and the physical sciences can be brought to bear on only a few of the aspects that are involved in the functioning of transportation. Adequate appraisal of the transportation situation requires the insights not only of the engineers and physical scientists, but also social scientists, economists, urban planners, lawyers, and others intimately familiar with the practical aspects of providing transport facilities and operating the services. The position taken throughout the study reflects the "interdisciplinary" approach. It is hoped that further efforts to pursue broad studies of transportation that may ensue from this initial step will draw upon all disciplines that can contribute insights into this pervasive activity.

If science and its accompanying technology continue to advance at an accelerating pace, any new transportation planning should take account of scientific investigation in anticipating future needs and solutions, and to forge new solutions using technological capacity. Yet, research in the field of transportation has been the tool most conspicuously neglected in the whole kit of instruments available.

Charles F. Kettering, the late leader of General Motors, once defined research as the business of figuring out what you are going

to do when you have to stop doing what you are doing now. There has never been a time when we needed more to apply his advice.

A larger portion of transportation research should be motivated by goals, policies, or current research pertinent to the engineering of joint systems of technology and society.

It is quite understandable that no single report can express adequately or accurately the many opinions and conclusions of individuals and groups who contributed the information. The material presented herein is frequently a compromise of the ideas presented. Further, it is not intended that the ideas are final. It is expected that need for changes will be apparent from year to year as new information and opportunities become available.

Many subjects, such as, soil mechanics and foundations, structures, and environmental considerations, which are vital to overall development of a transportation system, may seem to have been treated rather lightly in this report. The reason for this is that research in these subject areas will be covered in depth in other reports in the series. An effort has been made to reduce overlap in coverage but not elimination. To do so would reduce the value of this report and others in the series. Similarly, research in fields other than civil engineering has been detailed. It is hoped by doing this that the report should make the case for multi-disciplinary research to link together science, engineering, economics, law, management, public administration, and foreign affairs.

#### Acknowledgments

This project which is a part of a larger undertaking, has involved the joint efforts of the American Society of Civil Engineers (ASCE), the

Department of Civil Engineering of Colorado State University (CSU), the U.S. Department of Transportation (DOT), the National Science Foundation (NSF), and the Consultant, Mr. Robert F. Baker.

The continuing contribution in time and funds by the ASCE, particularly the time spent by the Headquarters Staff, was conducive to the success of the project. The financial assistance and provision of supporting facilities by CSU also aided greatly in the successful conclusion. A monetary grant by the DOT with administration of the funds by the NSF made the project possible.

The report was authored by Robert F. Baker acting in the capacity of consultant to the project. Charles W. Thomas, Professor of Civil Engineering, CSU, was the principal investigator with Maurice L. Albertson, Centennial Professor of Engineering, CSU, as co-principal investigator.

The initial source material for the report was assembled and evaluated by the principal investigator. The author assembled and analyzed considerable additional material for incorporation into the report.

The material contained in the report is the result of efforts of many individual members of ASCE and others both within the civil engineering profession and in other disciplines. Major contributions toward assessing transportation research needs were made by groups organized by the ASCE. Notable among these were: The Technical Council on Urban Transportation; The Research Committees of the Aero-Space Transport, Highway, Pipeline, and Waterways and Harbors Divisions. Information generated by the research committees of several of the ten other technical divisions of the Society with overlapping interests was also used.

However, the major portion of the information provided by these latter committees will appear in other reports of the series.

The voluntary contribution of time and effort by members of the ASCE Task Committee on the study of National Requirements of Civil Engineering Research has kept the project moving and coordinated with the other reports.

A Task Committee on Transportation Research Needs was organized by ASCE in 1968 to provide expert guidance in the preparation of the report. Members of the committee were: Donald S. Berry, Chairman, William N. Carey, Jr., Robert Horonjeff, Paul W. Shuldiner, Wilbur S. Smith, and John F. McLaughlin, liaison member to the Task Committee on Research Needs. This Committee was especially helpful in providing comments and advice throughout the period of preparation and the members made diligent reviews of drafts of the report and contributed many constructive remarks.

The assistance rendered by the many individuals and groups not specifically mentioned is gratefully acknowledged.

Charles W. Thomas,  
Principal Investigator  
Ft. Collins, Colorado  
June 1970

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## INTRODUCTION

Transportation is in the middle of a heated debate. There are those who deplore the adverse effects on the environment of the rapidly increasing transport system, and there are those who expound on the essential need for adequate transportation to serve society.

One side holds a view that the transport systems, which are being provided, show too little concern for human resources and are too permissive in the destruction of environmental values -- that too much energy is being expended in pursuit of physical resources. The other side believes that transport systems must be economically efficient and that society cannot afford expenditures that may be non-productive from a transport service point of view.

Debate was in full swing before many transport officials, officials who supported economically efficient systems, realized that those on the opposing side were dead serious and were competent and effectively organized. One of the early targets of the backlash was the highway program in urban areas. Several freeway facilities were rejected or at least delayed. Soon to follow were air transport programs. Close proximity of airports to central cities was no longer generally accepted as an optimum location. Aircraft noise was a source of serious complaint. This led to rejection of improved jet aircraft at some airports.

These sudden attacks seriously challenged established techniques for advancing transportation. Suddenly there was no universally acceptable basis for designing and locating transportation facilities. The economic-return approach was being rejected, the trend was toward a social-return approach. Not only did the new basis lead to lower economic return, but they called attention to conflicting social values

that could not be clearly identified or measured. Even where such values were fairly specific they had not been assigned priorities by the very society that was concerned with them. For example, society demanded more safety and improved esthetics, esthetic treatments that often produced less safety. Air pollution was deplored at the same time street improvements, which reduced pollution, were being rejected.

These conflicts among values were paralleled by increasing need for funds for many costly programs in the health, welfare and cultural fields. This of course led to greater competition for financial resources, and increased resistance to improvements in transportation, particularly highways because of their ubiquitous effects on all segments of society.

On the research side, frustration had been building for years. Little funding was available and many areas of transportation were locked into outmoded practices. Advances in transportation technology were not finding their way into practice as rapidly as they should have. Many of the questions raised in the transportation debate called for major research efforts.

The decision by the American Society of Civil Engineers to explore research needs in civil engineering provided for focusing attention on transportation problems and the research needed for their solution. The decision led eventually to this report, but only after several years of effort by national committees of that Society, financial support from the U. S. Department of Transportation through the National Science Foundation, and coordination by faculty of Colorado State University.

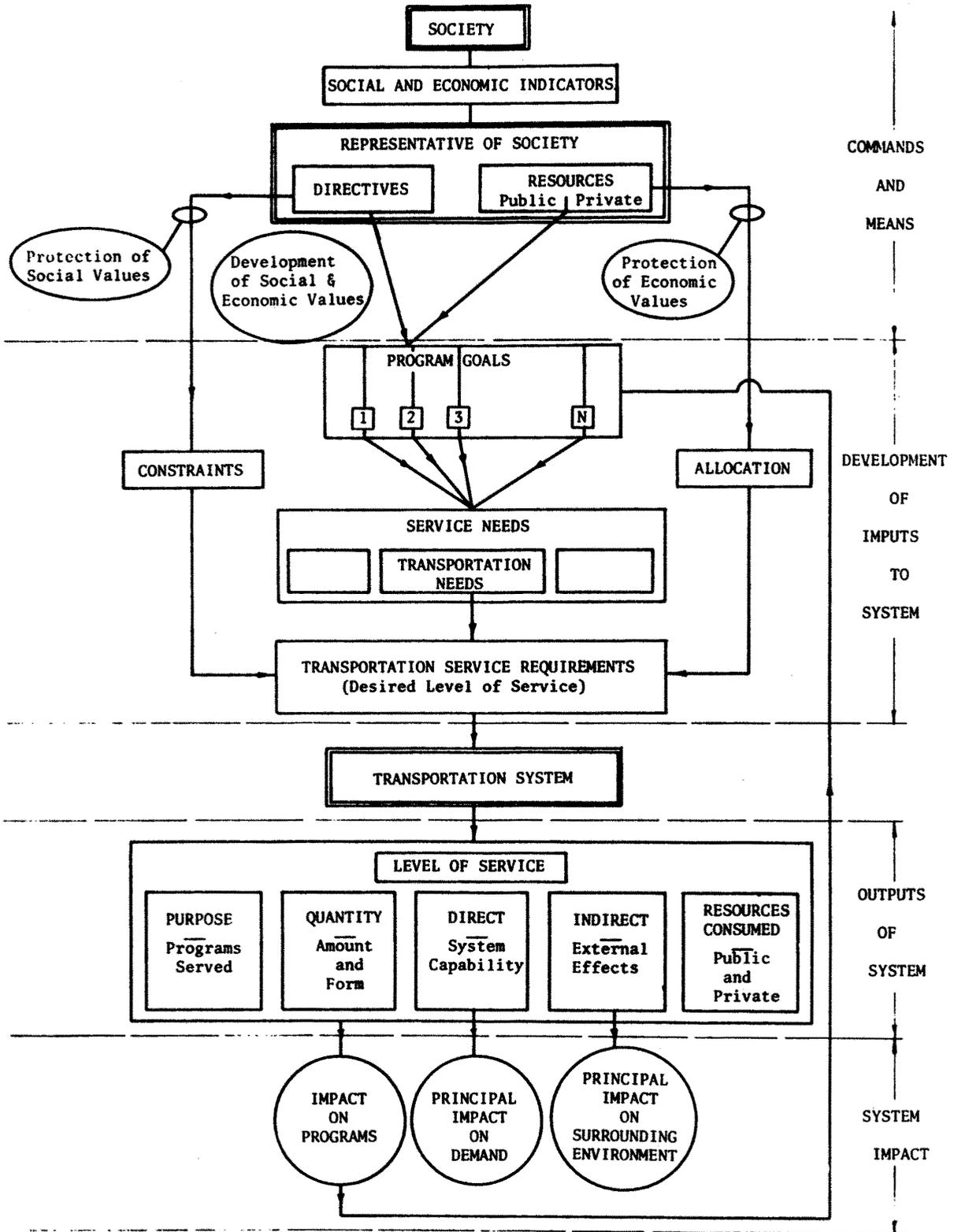
At the start of this study on transportation research, it was concluded that the conflicts arising from different views on the relevancy of social and economic values needed to be fully explored and understood.

Transport progress, it was believed, would continue to be surrounded by needless delays until the fundamental nature of the debate could be comprehended. Therefore, the approach taken was to review at the outset the basic role of transportation in order to clarify confusion related to criteria and objectives. An analysis of research needs in a field so heavily involved in transition could not be effectively pursued without a careful examination of the functions transportation will play in the future as well as in the present.

Such reviews revealed alternative ways for viewing transportation, and as a corollary several different ways research could proceed. A diagram that represents transport in relation to society is contained in Figure 1.

First, transportation emerges as a massive cluster or grouping of parts, or sub-systems, of social and economic programs. The objectives of these programs have nothing to do with transportation, being basically concerned with the development of human resources. The greatest impact of this view is that transportation should be related to the character of the service needed to advance the quality of life of society rather than to the development of a mode (or modes).

Second, due to competition for public funds, transportation investments should be based on benefits to social and economic programs that will be advanced. To assume the public interest is best served by the use of public funds to improve transport in response to a growing demand for facilities is no longer adequate. Before funds are allocated in the future, the increasing demand for transportation should be traced to the needs of the most urgent problems of society - at least insofar as public funds are involved. The focus will be increasingly directed to the priorities of programs, rather than to the extension of what individual users of transportation most desire under the present alternatives.



To simplify the diagram all feed-back loops have been omitted except the principal one from impact to program goals.

Figure 1 Basic Flow Diagram (17)

Third, technology can not contribute as effectively as it should to advance transportation (and the attendant goals of society) until problems and goals are defined more precisely. Present techniques involving intuitive selection and evaluation of existing or proposed facilities or vehicles will need to be replaced. Analytic methods, based on the quality characteristics (or level of service) of transport required to assist in the solution of the most urgent problems of society, are needed.

Fourth, transportation policy, should be derived from ultimate social and economic desires of individual elements of society rather than from modal requirements. If transportation is a collection of sub-systems of society, the programs that require transportation (the senior systems of society) should produce realistic requirements and statements of the quality of service that is needed. In systems language, the transportation sub-system should not specify its own requirements and performance. Service characteristics will need to be developed through an iterative process that considers the needs of programs that use transport and transport technology.

Fifth, there is a need for improved standards or bases for comparing alternate transport solutions. No really adequate standard exists. Meaningful comparisons between the relative effectiveness of two solutions to a specific social or economic problem are not now possible. Furthermore, the needed characteristics of transport cannot be intelligently discussed, and this of course leads to intuitive and subjective treatment of the problems.

Sixth, research in any field should be programmed in support of top management goals; that is, if top management identifies the types of advances that are needed, research can provide vital contributions. A

continuous long-term research program, however, must also be supported if future short-term problems are to be solved.

The report is divided into two parts. The first deals with establishing the role of transportation in society and the interest the civil engineer has in transportation. The second deals with research needs as viewed from the perspective of transportation that is developed in Part I.

PART I  
TRANSPORTATION'S ROLE IN SOCIETY

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Chapter 1

A DESCRIPTION OF TRANSPORTATION

Transportation is taken for granted by most individuals. Transportation's role in developing our present culture is either little understood or of only academic interest. Even those involved with transportation may not comprehend the dependence that individuals and groups have always had on the movement of persons and goods. The following description is a good place to start re-examining transport's role and its place in history: (1)

"There may have been a day when transportation was unimportant to mankind, but if there was, society then was vastly different than it is today. Even the most primitive man we know of found transportation important. Finding a wild animal or a patch of berries was but slightly more important to him than transporting his find to a place where it could be safely stored and where it might be more conveniently consumed. For primitive man the most important factors of transportation were the distance his quarry had to be transported, the amount of time required to travel that distance, and the amount of physical energy required for the job. Since primitive man provided his own transportation, he was little concerned with some of the complicated questions that modern man faces.

As time passed, transportation made possible the fabled exploits of Marco Polo, the commercial ventures of the Phoenicians, and world domination by various great powers, each in its turn. Some of these powers used their transport capabilities and military power to dominate the civilized world. Others exploited what economists sometimes term "place utility." They located products worth relatively little where they were found and moved them to other parts of the world where they were valuable. They transported spices from the Indies, where they could be had for the picking, to temperate zones where they could not be grown. They transported surplus manufactured goods from industrial areas where they had little value to remote areas where they were worth small fortunes. They recognized that control of transportation represented control over markets and the supply of many goods. They also discovered

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(1) Underscored numbers refer to List of References in Appendix A.

that transportation might often be equated with military might and that control over the instruments of transportation meant effective control of the commerce of the world. It is not by accident that the British were able to defeat Napoleon at Waterloo. Indeed, had Britain not been the leading maritime power of that day, exercising virtual control over the sea lanes of the world, her encounter with Napoleon might well have ended on a different key.

Transportation was important in the days of mercantilism and in the early colonial period. Control over transportation made it possible for small geographical areas of the world to dominate larger, remote areas. It enabled successful trading companies to amass large fortunes by transporting products from one area of the world to places where their value was much greater.

But it might be said that transportation did not really come into its own until the Industrial Revolution. Reasonably adequate transportation made it possible for raw materials to be moved into a factory and for finished products to be sold in lucrative world markets. Without adequate transportation, the industrial revolution would not have been possible. Indeed, the most restrictive factor of that day probably lay in the technology of transportation. Virtually all of the industry of that era was located adjacent to natural waterways, since they provided the only feasible means of transporting large quantities of goods.

Today no facet of the economy is more important than transportation. The transportation industry is important as an employer, as a customer, as a vehicle for investment, and as an industry which provides vital services to every segment of the economy. In the United States today, more men are employed in the transportation industry than in any other industry except agriculture. It is the largest single user of aluminum, rubber, petroleum, concrete, and steel. It purchases tremendous quantities of products such as nylon, copper, plastic, and glass. It provides opportunity for the investment of hundreds of millions of dollars in debentures, bonds, mortgages, warrants, equipment trust certificates, and common stocks, thus indirectly providing employment for many people in banks, brokerage houses, and other investment institutions.

For more than a century, transportation securities have been the backbone of many investment portfolios. If the nation's transportation system were to deteriorate, the effect on the investing community would be profound. If it were to collapse, it would deal a sharp blow to many institutional investors. Indeed, such a collapse would be a severe shock to some foundations and a major catastrophe for many individual investors.

But the greatest importance of the transportation industry lies in the fact that it is vital to its millions of users. If

a major segment of the nation's transport facilities suddenly stopped operations, this might deal a body blow to agriculture; it could cripple much of the nation's industrial capacity; it certainly would immobilize much of the nation's defense capability. While reasonably adequate substitutes can, in time, be developed for virtually every useful product, there is no substitute for transportation!"

The relevance of transportation to the economy of the United States is shown in Figure 1.1. Its pervasiveness is further described: (3)

"In a nation that spans a continent, transportation is the web of union.

Twenty years ago there were 31 million motor vehicles in the U.S. Today there are 90 million. By 1975 there will be nearly 120 million.

Twenty years ago there were 1.5 million miles of paved roads and streets in the U.S. Today this figure has almost doubled.

Twenty years ago there were 38,000 private and commercial aircraft. Today there are more than 97,000.

Twenty years ago commercial airlines flew 209 million miles. Last year (1965) they flew one billion miles.

Twenty-five years ago American transportation moved 619 billion ton miles of cargo. In 1964, 1.5 trillion ton miles were moved.

The manufacturing of transportation equipment has kept pace. It had tripled since 1947. Last year \$4.5 billion was spent for new transportation plant and equipment.

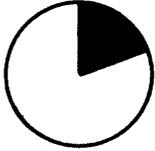
Transportation is one of America's largest employers. There are 737,000 railroad employees, 270,000 local and inter-urban workers, 230,000 in air transport, almost a million men and women in motor transport and storage.

Together with pipeline and water transportation employees, the total number of men and women who earn their livelihood by moving people and goods is well over 2.5 million.

The Federal Government supports or regulates almost every means of transportation. Last year alone more than \$5 billion in federal funds were invested in transportation--in highway construction, in river and harbor development, in airway operation and airport construction, in maritime subsidies. The government owns 1,500 of the nation's 2,500 ocean-going cargo vessels."

IMPORTANCE OF TRANSPORTATION\* TO U.S. ECONOMY

NATIONAL EXPENDITURES

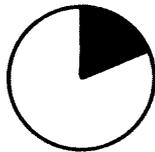


Approximately 20% of our total annual expenditures for goods and services, or our Gross National Product, is made either directly or indirectly for transportation of one kind or another. This percentage relationship has held true throughout the period 1958-1963. In 1963, this amounted to \$118.5 billion.

A breakdown of this \$118.5 billion by major classification is as follows:

Private Auto - \$56.0 billion, or 47.2%	
Non-ICC Regulated Truck - \$28.0 billion, or 23.6%	
ICC-CAB Regulated Carriers - \$24.0 billion, or 20.3%	
Other Transportation Media - \$10.5 billion, or 8.9%	

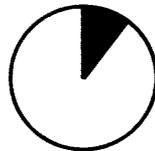
TAXES



18% of our total federal taxes come from transportation sources. In 1963, this amounted to \$19.1 billion.

Corporate Income Taxes - \$3.5 billion or 16%	
Excise Taxes - \$6.8 billion or 43%	
Individual income and Employment Taxes - \$8.8 billion or 13%	

INVESTMENT

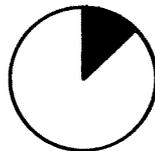


About 10% of our total net civilian investment in privately owned reproducible assets is for transportation facilities. In 1961, this amounted to over \$126 billion.

A breakdown of this \$126 billion by major classification is as follows:

Auto \$60 billion or 47%	
Rail \$30 billion or 24%	
Truck \$11 billion or 9%	
Other \$25 billion or 20%	

EMPLOYMENT



13% of our total civilian employment is in transportation or transportation related industries. In 1964, this amounted to about 9.1 million employees.

TRANSPORTATION IS A HEAVY USER OF OTHER INDUSTRIES' PRODUCTS, CONSUMING:

62% of Rubber	50% of Petroleum
50% of Lead	33% of Zinc
29% of Steel	24% of Cement
23% of Aluminum	19% of Copper

\* Including for-hire and private services and private and public facilities.

Figure 1.1 Importance of Transportation to U.S. Economy (2)

It is inevitable that the character or capability of a nation's transport would have sweeping influences on its way of life. Just as transportation improved conditions for the earliest civilizations, today it is possible to find extreme differences that can be attributed to transportation. Wilfred Owen suggests: (4)

"The nations of the world may be classified into two groups-- the mobile and the immobile. The present degrees of mobility and immobility are shown in Table 1-1. The freight mobility index for France expressed as 100. All countries with mobility indexes above 40 have relative high per capita income. The relation between wealth and mobility is striking. It is believed that the wealth is determined by the transportation available rather than vice versa."

The need for transportation for enhancing economic resources is also critical for the future. As has been suggested, inadequate transport influences the entire economy. The prediction of transport requirements is a problem that is receiving serious attention. One relationship that has been advanced is based on a comparison between GNP and freight traffic. From Table 1-2, one could anticipate that the ton-miles of intercity freight would equal 3 per dollar (1954 basis) of GNP. Through 1965, the relation has remained constant. With more than a 5 percent per year increase, it means that the intercity freight will double in less than 15 years.

Another picture of the growth pattern can be obtained from highway vehicle-miles of travel. For passenger cars alone, approximately the same rate of increase (5 percent) is involved which means that this type of transport would also double in less than 15 years.

Even more phenomenal is the growth rate of freight and passengers in air transportation. It is estimated that passenger traffic will have doubled between 1965 and 1970, and will have doubled again by 1975. For

TABLE 1-1. Index of Per Capita GNP and the Mobility of Nations, 1961<sup>a</sup>  
(France = 100)

Country	GNP	Freight Mobility <sup>b</sup>	Passenger Mobility
<b>Immobile Nations</b>			
Ethiopia	3.2	1.7	1.7
Nigeria	6.0	4.0	3.5
Indonesia	6.1	4.5	5.5
Iran	15.5	4.7	4.3
Burma	4.3	5.3	5.5
Philippines	8.6	5.8	5.2
Pakistan	5.5	6.7	8.3
Syria	11.2	6.8	5.7
Thailand	7.1	7.2	5.6
Egypt	8.8	7.5	9.3
Sudan	6.9	8.8	---
India	5.9	10.0	11.5
Ghana	14.6	10.1	9.5
Ecuador	13.4	10.2	8.7
Colombia	20.8	11.3	9.2
Guatemala	12.9	12.5	---
Peru	13.3	12.7	10.8
Turkey	14.2	13.7	---
Paraguay	9.6	15.7	14.7
Malaya	20.6	15.8	17.0
Algeria	20.6	17.3	16.0
Greece	31.7	17.8	18.7
Ceylon	10.1	18.2	21.5
Taiwan	10.7	18.8	---
Brazil	13.7	19.7	19.8
Bolivia	8.3	20.0	18.2
Portugal	20.8	24.5	27.7
Israel	59.8	25.2	21.7
Mexico	23.0	27.8	22.8
<b>Mobile Nations</b>			
Japan	37.2	30.5	46.3
Spain	27.5	33.2	34.8
Chile	33.3	38.2	36.2
Lebanon	30.2	39.2	40.3
Yugoslavia	24.2	39.5	38.8
Italy	51.8	45.3	53.2
Netherlands	77.3	58.2	69.3
Argentina	27.8	63.8	68.0
Norway	98.1	64.0	61.8
Finland	81.4	65.2	61.7
Austria	64.5	66.8	71.8
South Africa, Republic of	31.3	70.5	---
United Kingdom	104.0	86.0	94.5
Sweden	130.8	93.0	104.5

a. See next page  
b. See next page

(continued)

TABLE 1-1. Index of Per Capita GNP and the Mobility of Nations, 1961<sup>a</sup>  
 (continued)  
 (France = 100)

Country	GNP	Freight Mobility <sup>b</sup>	Passenger Mobility
Ireland	50.9	93.8	---
West Germany	105.4	99.3	91.0
France	100.0	100.0	100.0
Belgium	101.1	103.2	116.7
New Zealand	114.3	106.5	---
Denmark	102.6	110.0	119.0
Luxembourg	109.5	136.5	---
United States	207.3	189.0	147.2
Australia	112.3	216.7	---
Canada	147.9	223.1	148.9

Sources: United Nations, Statistical Yearbook, 1958, and Statistical Yearbook, 1959; Highway data from the International Road Federation, "World Highway Statistics," Staff Report (1957 and 1958); per capita GNP computed from Amendment to the Constitution of the International Labor Organization, S. Rep. No. 179, 83 Cong. 1 sess. (1962), Tables pp. 24-25.

a. Reproduced from Reference (4)

b. Freight Index = Average index for rail lines per 100 sq. miles, rail lines per 10,000 population, surfaced highways per 100 sq. miles, ton-miles per capita; and commercial vehicles per capita. Transport data based on 1957-58 figures. Passenger Index = Average index of the following: passenger miles per capita, passenger cars per capita, and rail lines per 100 sq. miles, rail lines per 10,000 population, surfaced highways per 100 sq. miles, and surfaced highways per 10,000 population.

TABLE 1-2. Relation of Freight Traffic to GNP in the United States and Canada, 1940-60 (4)

Year	United States		Canada	
	Ton-Miles of Intercity Freight (In billions)	Ton-Miles per Dollar of GNP <sup>a</sup>	Ton-Miles of Intercity Freight (In billions)	Ton-Miles per Dollar of GNP <sup>b</sup>
1940	618.6	3.0	58.9	5.4
1941	772.1	3.2	71.9	5.8
1942	929.0	3.5	76.1	5.1
1943	1,031.3	3.5	84.4	5.5
1944	1,088.4	3.4	85.9	5.4
1945	1,027.1	3.3	85.1	5.5
1946	903.9	3.2	74.5	4.9
1947	1,018.7	3.6	82.5	5.3
1948	1,045.1	3.6	84.1	5.3
1949	915.8	3.1	82.7	5.1
1950	1,062.6	3.3	87.7	5.0
1951	1,178.1	3.5	100.7	5.4
1952	1,144.3	3.2	108.5	5.4
1953	1,204.1	3.3	110.1	5.3
1954	1,123.1	3.1	102.1	5.1
1955	1,274.9	3.3	118.7	5.4
1956	1,355.4	3.4	141.2	5.9
1957	1,335.5	3.3	132.2	5.5
1958	1,215.1	3.0	126.6	5.2
1959	1,295.3	3.0	133.7	5.3
1960	1,330.9	3.0	128.7	5.0

Sources: U.S. ton-miles of intercity freight from Interstate Commerce Commission, Bureau of Transport Economics and Statistics, "Intercity Ton-Miles 1939-1959," Statement 6103 (April 1961), pp. 4-5 (for 1940-58); Interstate Commerce Commission, Annual Report, 1961, p. 15 (for 1959-60). Canadian ton-miles of intercity freight from George A. Wagdin, "The Role of a Central Statistical Organization in the Field of Transportation," presented at the IV World Meeting of International Road Federation, Madrid, Oct. 14-20, 1962, Appendix V. U.S. GNP figures from Economic Report of the President, 1961, and 1963; Canadian GNP figures from National Accounts Income and Expenditure, 1950-61, Research and Development Division, Dominion Bureau of Statistics, Ottawa.

a Calculated from U.S. GNP in 1954 prices.

b Calculated from Canadian GNP in 1949 prices.

freight traffic, the increase between 1965 and 1980 has been estimated at 1,500 percent.

That transportation will continue to grow appears evident. But the need for transportation for enhancing social values is also critical.

There are only limited data on the non-economic impacts of transportation, except those that adversely affect the environment. While some data are available on noise and air pollution from transportation services, for example, there is no systematic assembly of information on what human values are being advanced. Certainly transport services for medicine, doctors, nurses, and emergency vehicles are significant. Food, clothing, and such extras as television sets, are influenced by transport which in turn influences an individual's way of life. Capabilities or limitations of the system to transport individuals and families to various recreational and cultural activities, and for short-and long-distant vacations have an impact on life styles. The positive and negative influences of transport in crime and its prevention affect individuals. Both the positive and negative social values of transportation are necessary for comprehending future requirements. The values are particularly necessary for discussions relative to alternate solutions to most of the urgent social problems of society.

For more than twenty years, the official policy of the Federal Government has been one of "user pay" for transport services, which does not usually take into account values to society. Management of finances and operations of transport systems, however, has varied from mode to mode. For highways and air transportation, ground facilities are normally provided by the government. For air and waterways, government goes so far as to operate the medium through or over which the vehicle travels.

Railroads and pipelines have been essentially free enterprise operations, although government regulations control all or parts of the activities. Practically all vehicle operation, regardless of the mode, is conducted by the private sector under some form of government regulation.

Up until the early part of the 20th century, transportation was considered a "local" problem--something for individual communities to work out. Highways were controlled by local governments, and frequently not even states were financially involved. This local concept has continued into the present with specific exceptions, such as broad standards for numerous facilities (Interstate and other federally-aided highways, runway and other airport safety features, etc.). This has led to the difficult problem of integrating transport systems. For example, more than 33,000 government agencies have jurisdiction over a portion of the 3.7 million miles of highway.

Historically, the Federal Government has attempted to keep out of transportation, leaving as much of the task as possible to the private sector. For waterways and highways and subsequently airports, however, it was concluded that investments required in the public interest would not be forthcoming from the private sector, and the provision of the facility became a public responsibility.

Part of the present debate on transportation centers around how financial support from governments is viewed. If user taxes are seen as transportation "billings" then the user taxes are seen as payments for a given service. Parallel arrangements would be those for sanitary services, water supply, telephone, electric power, etc. But if user taxes are seen as just one method the government uses for raising revenue for public programs, then there is no relation between user taxes and the

amount to be expended in the interest of the user. The debate between the two views is one of the major sources of disagreement in the controversy over priorities in social and economic goals.

Until the establishment of the Department of Transportation, federal interest in transportation was sporadic and fragmented. The orientation of the activity was modal in character, and widely different fiscal and legal policies prevailed. To a great extent, this situation has not changed.

The modal orientation is a natural outgrowth of transport evolution. The differences in technology, fiscal and operational policies, and the character of the services provided are great. There has been little interchange, and considerable competition. These conditions are not likely to change, certainly not in the near future. There is little necessity that they do so, since each mode is performing a significant function for specific programs.

A major role of non-modal interests in transportation is a re-examination of how well transportation is serving society and to look at the future in a way that is difficult for a single mode to do. Inherent values and limitations exist for each mode. The non-modal concerns can be more "society-oriented," and keyed to the type of transport capability that will be required or can be eliminated. Modal interests are likely to continue to be efficiency oriented, and concerned with enhancing their inherent values, reducing their limitations to a practical extent, and maintaining or improving their position in the transport field. Non-modal interests will need to concentrate on realistic and objective justification of transport programs, while modal interests will focus more on achieving operational advances.

Historical records reveal strong indications that the economic advance of a society is dominated or controlled by its transport system. The same records will indicate the strong influence of transportation on society's way of life, apart from the economic effects. There is no reason to believe the importance of transport on the social and economic well-being of society will not continue in the future. Therefore, how transport evolves will dramatically influence the character of tomorrow's society.

## Chapter 2

## PRINCIPLES OF TRANSPORTATION

In today's society, small protests are heard. Because of these protests, economic justification of transportation is not sufficient in itself. Furthermore, technology can build almost anything, almost anywhere and therefore it has lost the power it once had to dictate a solution. As a result of these conditions, there is no firm basis for developing a unique solution. There are an infinite number of solutions for practically every problem. This has led to a continuing series of debates, conflicts and compromises.

For transportation, it has meant an effort to continue to provide services, compromising when necessary to achieve certain objectives. Those working in different modes have viewed travel in terms of their own specific requirements, or as a response to user demands, or as an opportunity to use new technological advances. The inevitability of compromise has been recognized, and adjustments that are required to obtain new facilities have been made. There is no basis, however, for considering how compromises should be made. Just as it is possible to provide too much transportation, it is possible to provide too little.

An example of a complex problem to compromise is the case wherein a highway facility for 100,000 vehicles per day would need to be lengthened one-quarter mile to achieve a social or cultural gain. The extra length adds 25,000 vehicle-miles of travel per day and for every three-years of its operation, one fatality can be expected due to the additional travel. This does not begin to discuss all of the benefits and losses that are related to such decisions.

What is needed, then, is a re-examination of what transport is and how it fits into society. Its contributions and its negative effects must be understood and measured in a way as to permit intelligent compromises. The best interests of society require a process of resolving conflicts that are based on comprehensive and factual views of the consequences of alternate actions, not narrow and emotional perspectives of what is "good" and "bad".

The purpose of this chapter is to answer fundamental questions about what transportation really is, and how it must operate to fulfill non-economic and economic goals.

#### What Is Transportation?

The following definitions are advanced:

Transportation is the means of conveyance or purposeful movement of persons and goods from one place to another.

A transportation system is a group of elements (components or sub-systems) that provide assistance in the purposeful movement of persons and goods from one place to another.

The second definition of the latter also could be stated:

A transportation system is a group of sub-systems of the social and economic programs (systems) of a society.

The requirement that the movement be "purposeful" means that transport is a service. It is not the end-point, but is a means to some end. Presumably, the "end" is related to why the movement is desired, but it is certain that the reason is not solely for the sake of movement (5, 6, 7, 8, 9). Consideration of transport as a means rather than the end is not at all uncommon.

Various kinds of person movement for pleasure come to mind, for example, walking, boating, flying, driving and bicycling. Are these properly termed transportation? Or, what about patrol activities of law enforcement and defense personnel? Or emergency medical transport where the victim is treated enroute to a hospital?

Obviously, some of these activities accomplish a purpose in the process of movement, rather than simply completing the movement. Consistent in all of these cases, however, is that transportation is always the means and not the end - it is a service to an individual or to an activity.

The preceding noted that most transport is a service for a purpose that is met when the transport is completed. It follows, therefore, that the service has no inherent value, that it is a waste of resources, that its reason for existence is in what it makes possible. Transport, then, is an impediment, one that should be minimized to every extent possible. Once again, the purpose of the trip will control the extent that the minimization can be achieved.

This perspective is academic in that complete elimination of the transport service is not even remotely attainable. The primary significance of the view is that the benefits of transport to human resource development cannot be understood except through knowledge of the ultimate purpose of the transport.

#### Why Transportation?

The following definition is advanced:

The performance of a system is the output for a given input.

The following general principles are advanced for establishing transport systems that fulfill transport's purposes:

1. The purposes or functions of transportation are inputs (requirements) to transport systems and should be derived from the objectives of the social and economic programs for which services are required.

2. The performance of any social or economic system is a function of the performance of the transport system it uses.

3. The performance of any complete transport system has no intrinsic social nor economic value, other than for those components for which transportation is an end in itself.

Periodically transportation is the primary means whereby major human progress has been achieved. Military requirements have frequently dictated such advances. In modern times, the construction of the Autobahn in pre-World War II Germany is a classic example of this. Early in the 1920's in this country, the farm-to-market movement also produced a transport advance that was accomplished solely for the ultimate reason for the transport. The Interstate Highway System in this country was planned as more than an increase in service to highway users. The plan was developed prior to World War II as part of a defense system, in addition to its value in connecting major population centers.

Most generally, however, transportation has grown due to economic reaction to a technological advance. Economic return has been the criterion that industry, and subsequently, governments used to analyze the wisdom of proceeding. This process characterized the development of shipment by waterways, railroads, highways and, most recently, the airways. Transportation has been generally accepted as a prerequisite for economic advance in a nation or region (10).

The justification of government-funded transportation on the basis of economic return, can lead to oversimplification and can be misleading.

For example, human values are frequently converted to dollar values. Safety savings of life, suffering, and injury, time savings of non-business trips, and esthetic improvements have been expressed in dollars. Such analyses provided quantitative comparisons of alternate ways to improve transportation. This approach can be easily misunderstood, however, as saying that transportation is expected to generate economic resources, and the results misunderstood to mean that a community would enjoy a certain increase in resources. Dollar values assigned to safety, non-productive time savings, and esthetics are an approximation of how much the community is expending, or is willing to expend, for these benefits; they do not increase the physical resources available to the community.

The services of transportation are certainly economic, in part, but, equally important, transportation provides benefits in non-economic values, values which cannot be adequately represented by a dollar sign. The following is a statement by Harvard University's Arthur Smithies (11):

"Many government activities are designed to yield both economic and non-economic returns. Education is a good example. One of its objectives undoubtedly is to produce an enterprising and skilled labor force that will contribute to economic prosperity. Another is to preserve and enlarge the cultural heritage of the country, and, hopefully, to sustain its capacity to govern itself, despite technological advance. Another example is public health. Reduction of working time lost by sickness is one of its benefits. But measures to reduce suffering in old age are not undertaken for economic reasons. The idea of economic measurement has great attractiveness because of the analytic possibilities that it offers, especially to economists. But it is a perversion of human values to push it into areas where it does not belong." (Underlining provided.) (11)

It is important to take account of transportation's contribution to both the development of economic resources and the enrichment of human life. Social benefits derived from transport by such activities as law enforcement, health, education, sanitation, trips to work, and recreation

cannot be adequately evaluated when expressed in dollars. The need for a transport investment can be more readily seen when the direct benefits are derived by the activities that require transportation. It is impossible to develop the significance of transportation to a community, region or society without studying specific functions of which transport is a component. It is equally impossible to design transport systems, which can assist in optimizing performance of social systems, without understanding the role transport is expected to play in all activities of which it is a part.

A look at the pervasiveness of transportation services is helpful in understanding the distinction between transportation for economic return and for benefits to other human requirements. Practically all human activity requires some transportation. From law enforcement to religious services, from education to defense, from health and medical services to recreation, there is an ever-present need for transport. Employees' travel to work and freight shipments of paper clips, textbooks, medical supplies, TV sets, clothing, and groceries suggest the dependence society has on transportation. In Figure 2.1, the nature of the dependence of society on transportation is shown.

Transportation is not alone in this all-inclusive characteristic, the social and economic structure of society creates unlimited interdependencies. For example, education, law enforcement, health, recreation, and cultural activities are not inseparable entities. Many activities, other than transportation, could be placed in a focal point of society. An important consideration, however, is the dependence of the performance, or quality of life, of the society on the performance of transportation.

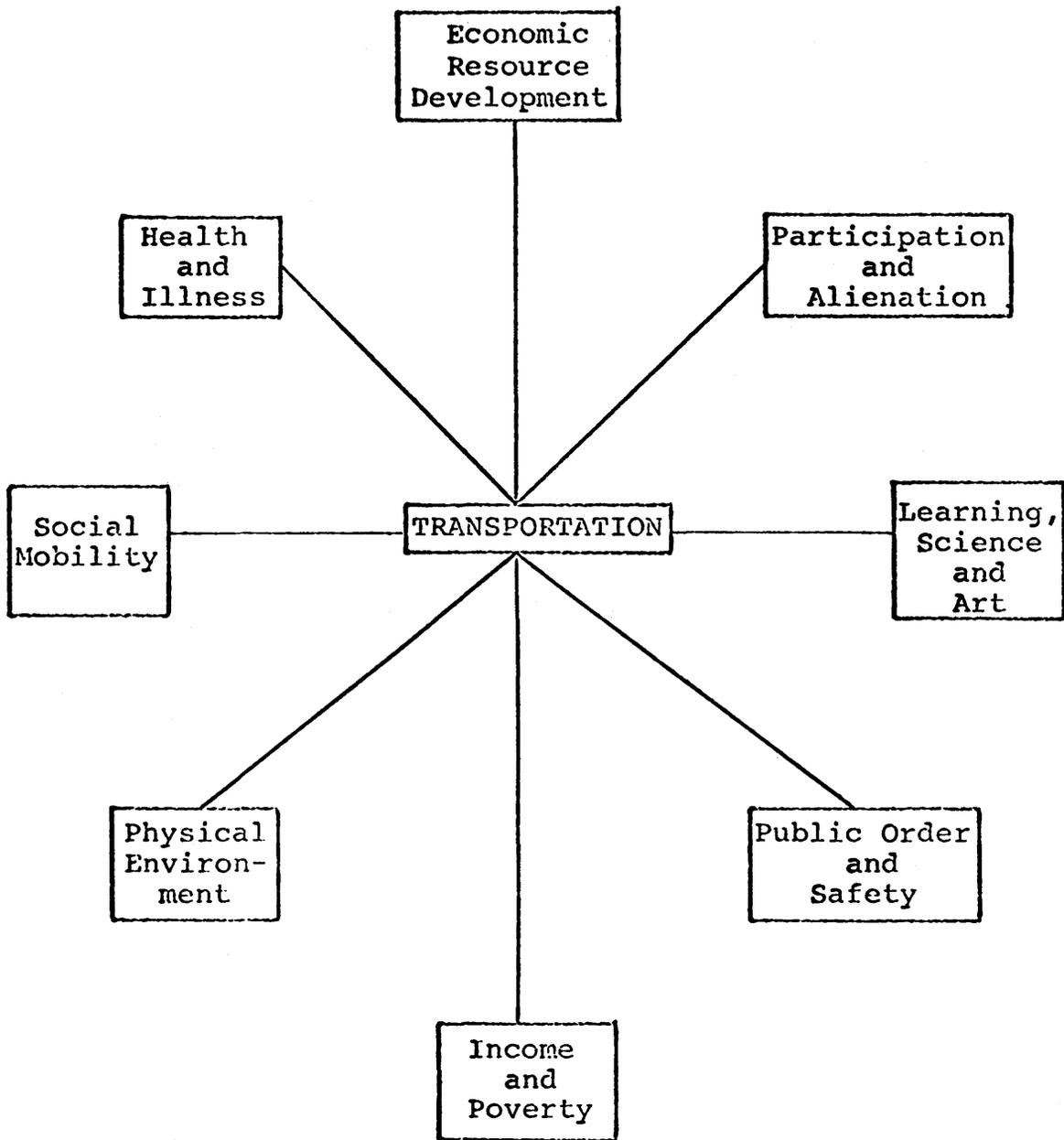


Figure 2.1 The Pervasiveness of Transportation

(Note: Social indicators suggested in "Toward a Social Report" (12))

### How Should Transportation Be Provided?

The following definitions are advanced for use in this study:

Economic efficiency is a measure of the adequacy of the economic return produced by an investment.

Social efficiency is a measure of the adequacy of the non-economic return produced by an investment.

The following principles will guide the analyses of how transport should be provided:

1. Optimization of performance of any social or economic program is functionally related to the performance of that part of the transportation system that it utilizes.
2. Changes in transportation performance, or of the performance of any mode of transportation, should be selected in such a manner as to optimize the total programs that are being served.
3. Performance of social and economic programs are limited by the performance of the transport systems which they utilize.
4. Compromises in economic efficiency of transportation will be required when social efficiency is judged more critical.
5. Probability that public funds will be allocated to improve performance of transportation is functionally related to:
  - a. The priorities assigned to social and economic programs, and the sensitivity of those high-priority programs to the performance of the transportation system.
  - b. To the level and type of improvement in performance.
  - c. To legal and fiscal policies controlling the use of public funds.

Interest in the economic and social value of transportation is far from academic. The interest stems from governments' concern for the utilization of public funds. In industry, profit and competitive requirements, and government regulations define the extent to which human values are considered. This is not true with government. Their responsibility is to the welfare of the society, and this concern for individual welfare transcends solely economic considerations. This distinction is well stated by Premier Ernest C. Manning of Alberta, Canada (13):

"The Government believes that the time has come to view the development of the physical resources of Alberta in a new and different light than heretofore. The time has come to realize and declare explicitly that the physical resources and economy of the province are means to an end, and not ends in themselves. The overall purpose and objective in physical resources development must henceforth be to facilitate human resources development--to facilitate the development of free and creative individuals.

"Because physical resources development is absolutely essential to human resources development, the necessity of establishing and maintaining a strong provincial economy cannot be overemphasized. The development of the physical resources of Alberta to their maximum extent must remain an explicit objective of both government and people. The new orientation and emphasis outlined in this paper, however, calls for both government and citizens to recognize that the overall purpose of such physical resources development is not simply to utilize, but rather to maintain and to facilitate the development of Alberta's human resources.

"In a free enterprise economy, physical resources development is primarily the responsibility and function of the private sector. A new orientation, bringing human resources development into better perspective, therefore calls for more explicit social concern and action on the part of those who believe in private ownership and freedom of economic activity. It is the Government's intention, in proposing this broader purpose and objective for physical resources development, to do everything within its power to facilitate the harnessing of an economy based on the principles of freedom of economic activity and private ownership, to the task of achieving objectives stemming from humanitarian values and a social concern based on the concept that the individual human being is the supremely important unit of consideration." (13)

Certain expenditures of government are directed, therefore, to advancing human resources. Such expenditures will be limited by the availability of physical resources from taxation or regulation. For example, a developing region or nation cannot support programs directed to improving non-economic values until there are sufficient physical resources. Services such as hospitals, law enforcement, and stream pollution are functions of both funding and ethical judgments. But, the greater the physical resources, the greater the potential for improving various phases of human resources.

It is equally apparent that certain qualities of life must be sacrificed if resources are to be generated. Stream and air pollution and desecration of wilderness areas are typical values that were sacrificed in this country when necessary to the development of economic resources. This is not to say they should or should not have, but only that one was sacrificed to obtain the other. The way such compromises are treated play an important part in the rate of economic development.

The debate extends into the present. Certain activities are relied on to generate necessary resources to produce a higher quality of life. Although individual differences in what constitutes such qualities confuse the answer, they do not change the fundamental requirement that resources are needed before one can provide for non-economic values.

Transportation is expected to produce both social and economic benefits, but since it also produces negative impacts upon the environment, it is increasingly more important to know which values are to be compromised. For example, the reduction of air pollution by improving highway vehicles may produce a non-productive expenditure--one which will increase costs to programs using transport and reduce the resources

generated by highway transportation. Freight costs would increase as would the costs of products that are shipped. The ultimate effect would be a change in the quality of life. This change in quality would be positive for those areas where air pollution is critical, but it would also be negative for the low-income group, affected by the price changes.

While the changes in the foregoing example seem nominal, a cost of \$100 per vehicle is an annual expense of \$1 billion (a loss of resources to the nation's economy). The same price extended to the 100 million existing vehicles would cost \$10 billion. The question is how do the benefits from this use of \$1 or \$10 billion compare with the benefits to be derived by using the resources in other ways? What constitutes a "good" decision, depends on more than the undesirable characteristics of air pollution, unless the latter transcends all other economic and human values.

Compromises are also necessary within the transport system. The modal nature of transport and the legal and financial bases on which the various modes operate, produce requirements that the mode serve an "average" user of the transport. To a modal interest, the user is seen as the individual who "pays for the service" and not the program for which the expenditure is made. For personal travel, this appears to be one and the same. But for all travel, some basic program controls the quality of the service desired. For example, the highway system must provide for home-to-work movement, recreation and cultural travel, trips to the supermarket, deliveries to educational institutions, emergency services, freight transport and business trips.

The end result of the service-to-user approach is a modal system that is geared to provide the best assistance possible to numerous, varied programs. It is inevitable that some programs are constrained, and their

ultimate contributions reduced because the transport service must restrict its performance capability to stay within available funds and to meet social restraints.

Urban transportation is a good example of how compromises have been necessary. Emergency services for law enforcement, medical purposes, and fire protection are limited by the capability of ground-based systems. It is obvious that superior emergency services could be provided by using the airways, although it is not equally obvious that there are resources to do so.

The preceding is not an abstract, impractical point-of-view. For example, if transportation costs were traced and charged to the programs for which that service is provided, it is probable that the transport system would look a great deal different. Consider what could happen if home-to-work travel costs were to be charged to the employer (rather than his reimbursing the employee who then takes care of his own travel). Numerous alternatives would become available that are not apparent under the existing system.

### Practical Implications

The following summary provides some practical implications of the preceding review of the function of transportation in society.

1. For transportation to serve society most effectively, it must be viewed as a "cluster" of sub-systems that are serving various social and economic programs.

2. To qualify for a high priority on public funds, it will become increasingly more important for improvements in transportation to be directed to solutions to the most urgent social problems of society and not to economic efficiency of modes.

3. Economic efficiency of a mode will be of continuing interest, but will not be sufficient in itself to justify investments. Social efficiency may prevail.

4. It is more likely that imaginative new solutions with real impact will come from a study of performance requirements of social and economic programs than from studies of sophisticated changes in modes.

5. Use of the scientific method requires optimizing the performance of social systems. To avoid unnecessary sub-optimization, performance of transport systems must be specified by the social systems. While transport interest can and should assist in the derivation of transport performance requirements, the latter should not be specified by transport interests.

## Chapter 3

PRINCIPLES FOR DEVELOPING  
TRANSPORTATION GOALS

An existing transport system will always be in need of improved capabilities and efficiencies. The size, distribution, and the long life of transportation systems preclude a situation where no improvement could be made.

Studies of the condition of a transport system, then, will always lead to lists of inadequacies or will show that significant problems exist. The question is when and what type of change can be justified. Or stated in another way, how can decisions be made to decide when an improvement is essential?

In this chapter, principles for conducting analysis of these questions are examined:

1. Transport goals should consist first of specific service characteristics required of the transport system, not equipment and facility needs.

2. Long range goals for service characteristics of transportation are a necessary input from society for the evolution of the most optimum system.

3. The rate of change of service characteristics of the transport system, or any part of it, is input by society, derived from an evaluation of the needs to achieve the ultimate goals of social and economic programs.

4. Short-range targets, which should be set for each increment of improvement in service characteristics of the transport system, are a function of:

- a. Long range goals
- b. Performances of the existing system
- c. Rates of growth of transport requirements
- d. Resource requirements for transport change, relative to other resource needs in the social and economic programs they support.

The projections of transport requirements in a burgeoning population, and the shifting of even larger percentages of the population to urban areas, suggest an increasing rather than a decreasing pressure to improve modes. Other crises, particularly in urban areas, also are producing pressures for resources and for progress in goals that are not always in agreement with transport solutions.

Transport goals of the future will be reviewed in light of the increase in need for transportation and the parallel increase in need for other improvements in society. Analyses directed to justifying a program solely on the basis of the growth in demand will become increasingly less adequate. A more complete projection is needed - an analysis that not only recognizes the continuing nature of the transport improvement problem, but the shifting nature of who and what in society has the greatest need. A new approach is required primarily because of the shift from purely economic efficiency to the controlling nature of social efficiency. Key questions for developing transport goals under non-economic criteria are:

1. Are the economic and social gains of the program worth the non-economic costs?
2. Is the non-economic gain from the transport improvement a good use of the limited physical resources available for developing human resources?

It should be noted these questions apply equally to all programs involving public funds or government regulation. The shift toward a social efficiency scale is across-the-board and the new basis for justifying the use of public funds is equally demanding for program justifications.

### Economic and Social Accounting

Progress in economic and social programs can be measured by changes in economic and social indicators. These indicators provide insight into the rate of growth (or loss) of physical resources and into the rate of change of the qualities of life that are important to individuals. How these indicators are likely to change if a specific action is taken can be analyzed by economic and social accounting.

The economic accounting system has become a useful tool over the past twenty years. The economic indicators are the behavior characteristics of economic programs; the performance of an economic system is described by the change in the indicators. These indicators consist of such measures as Industrial Production, Gross National Product, Personal Income, Personal Outlay, Employment and Unemployment, International Accounts, and Prices and Earnings.

The highly sophisticated advances in economic accounting permit analyses of the impact on the economy of various kinds of investments and regulations. One looks to such a system for an answer about how a transport investment would influence the physical resources of society.

For relatively small investments at local levels, the national indicators are not sensitive to change, however. Economic impact analyses are frequently made, therefore, on limited regions affected by small improvements.

A more frequently used economic measure is economic return or cost/benefit analyses, based on savings that can be made by users of a system. For example, a better highway or other change may reduce costs to users more than it costs to provide the change. Such an analysis indicates whether a release of funds should occur, but does not provide information as to whether an increase in physical resources will be achieved; (i.e., if a system is already being subsidized, a savings would reduce the subsidy, but it would not generate physical resources). Capability is limited for determining, in quantitative terms, the net economic effect of a transport investment. Research and data are required to produce analytic techniques that can indicate whether a specific transport investment 1) increases resources, 2) has no effect, or 3) utilizes resources. If it is the latter, it means the improvement will need to be subsidized.

While economic accounting has progressed as a barometer of the economy, social accounting is a much more recent development (12, 14). Primary efforts are being directed to establishing the social indicators - or measures of social health. A social accounting system, capable of predicting the effect of an investment on social indicators, will be several years in evolution.

The most recent report by the Federal Government suggested the following major categories of social indicators: (12)

1. Health and Illness
2. Social Mobility
3. Physical Environment
4. Income and Poverty
5. Public Order and Safety

6. Learning, Science and Art
7. Participation and Alienation.

There has been debate about the necessity for a sophisticated social accounting system. It is argued that the free enterprise system is a competent method for allocating resources. Those who favor social accounting believe a system is needed that can deal more effectively with non-economic requirements, and more specifically with measurement of the quality of life of individuals.

Regardless of the measurement system, various levels of government face urgent social problems (15). These problems range from relatively universal concerns for safety, clean air and a lower crime rate, to highly focused problems of low income, race inequalities, and esthetics. The trend has been to provide greater and greater financial assistance to these high priority social problems. Future requests for public funds for transport improvements will be evaluated in light of these priorities.

#### Level of Service

Goals of many programs of society are directly addressed to achieving human resource development, for example, health, education, law enforcement and poverty. For these programs, the "ends" are quite visible. Other programs like transportation are means to an end--that is, a means for developing human resources. Examples of these programs are communication, industry, national defense, land use planning, and postal service.

Programs that are a means to the development of human resources (ends) will need to be clearly distinguished from those programs that produce ultimate objectives. The former programs are "services" and their capabilities are measured by the character of the service provided. For

example, transportation can provide only the means whereby a quality of life can be achieved. Its contributions are not directly measurable in terms of life qualities. Its success in influencing human resource development must be estimated from the character of service that is provided.

The importance of distinguishing between means and end-oriented programs is traced to the desire to make most effective use of resources to further specific "ends". There are many means to achieve the same end, and powerful forces are directed to improving various means. To retain objectivity, and to produce the greatest gain in human resource development, a measure of the extent and type of benefit to be derived is essential.

In Chapter 2, performance was defined as the output of a system for a given input. The desired output of a service activity is the best service, nothing else. Accordingly, the level of service can be defined as the performance of a service system. To comprehend the ultimate effect of a service activity, it will be necessary to measure its level of service.

Standards for the level of service of transport systems have not been fully developed. While cost, safety, comfort, and time (or convenience) have been frequently used, there is no generally accepted classification of the elements of service. Within each of the preceding four groups, for example, there are a large number of significant variables. One study identified over 400 features that could be included under transport capability (16).

Not having an accepted standard for measuring transport service is a serious problem when comparisons between transport systems are to be

formulated. In addition, programs that require transport need a measure that would permit their evaluation of service.

Three perspectives are important in the classification of level of service: (1) the program that requires the transport, (2) the operators and users of the transport system, and (3) the society in which the activity and the transport exist. The classification should permit analyses by each of these three interests.

The reason that the transport is needed is the source of the quality and quantity measures that represent the functional requirements. The capabilities the transport system can provide are the direct effects. Society imposes various types of constraints that take the form of (1) physical or technological limitations, and (2) protection of human values that would be reduced or destroyed by uncontrolled efforts to achieve transport efficiency. These constraints evolve from indirect effects on the environs. Control of resources is exercised by society in order to enhance the possibility of achieving the most urgent objectives, and so the resources consumed are of interest.

In Figure 1, the relationship of level of service to transport systems is indicated. Figure 3.1 is the classification of level of service produced in a recent study (17).

The development of transport goals should start from an analysis of the existing level of service. The impact on social and economic goals of changing the level of service can then be estimated.

The preceding three perspectives of transport are becoming increasingly important to the development of transportation systems. Under existing conditions, only limited data and theory are available for approaching transportation in this manner. The level of service of

LEVEL OF SERVICE  
OF  
TRANSPORTATION

Purpose	Quantity	Direct Effects	Indirect Effects	Resources Consumed
Programs Requiring Transport Services	Amount, Amount/Time Special Characteristics	System Capability Time (and time related) Cost to User Safety Comfort (Physical and Psychological)	Physical Esthetics, Topography, Noise (Vibration, Shock) Air Pollution Barriers (Land Separation) Psychological Transportation Availability Presence of Facility	Financial, Manpower, Space, etc.
	Q <sub>1</sub> Q <sub>2</sub> Q <sub>3</sub> Q <sub>4</sub>	D <sub>1</sub> D <sub>2</sub> D <sub>3</sub> D <sub>4</sub>	I <sub>1</sub> I <sub>2</sub> I <sub>3</sub> I <sub>4</sub>	Public Private
A. B. C. D.				

Figure 3.1 Level of service of transportation

From Reference (17)

individual modes has been the primary basis for improving systems, along with an extrapolation of past demand for predicting total modal requirements. Functional (social and economic) needs have rarely been considered outside the military establishment. In recent years, more and more constraints have been imposed.

Even greater resistance to funding transport systems can be expected unless the three views of transports are used to develop requirements and the attendant benefits. If transport efficiency (or improvements in system capability) remains the primary basis for expanding transport services, difficulties in increasing transport capability can be anticipated.

For the advancement of transport, the importance of determining the social benefits of transport services will need to be emphasized. It is important to know what programs would be handicapped by the imposition of a non-productive constraint. The adverse features of transportation are contained in the external effects, that is, the effects on the environs. Some external effects are inevitably negative. Efforts to minimize them should be diligently attacked. However, decreasing the service capabilities of transportation by imposing non-productive constraints must ultimately reduce the effectiveness of programs that use transportation. The ultimate decision in this regard is not with transport interests, but with political leaders who can weight the alternatives.

This is not an argument for improving transportation at the expense of other social or economic interests. But it does suggest self-imposed constraints by transportation are illogical. By so doing, transport officials are placed in the role of judging the relative importance of programs for which they are not responsible.

As long as vague notions and intuition are required for evaluation of social values, political controversies and vacillation will characterize attempts to modify transportation systems. As soon as priorities on community problems have been determined by responsible officials, however, the requirements for and the responsiveness of modification of levels of service can avoid a purely intuitive approach based on selecting new facilities or equipment.

### Problems in Developing Transport Goals

Three practical problems that must be considered in setting transport goals are:

1. Competition for funds
2. Strategy for change
3. Availability of technology.

Expenditures of public funds normally involve competition between programs for some part of the limited resources. With the increase in priority for programs directed to human resource development, the competition has broadened; programs are being evaluated for both social and economic efficiency. This competition leads to the question of whether public funds should be expended for transportation, or which mode of transportation, as opposed to such uses as education, health, etc. Accordingly, it is of practical significance to determine impacts of transport on social programs in order to comprehend the ultimate benefits of transport improvement, and to provide decision-makers with a comprehensive view of the consequences of a transport investment.

The second consideration, strategy for change, refers to the practical problems of introducing a major change in a system that is as massive

and pervasive as transportation. Changes of value to one program may produce adverse effects on another. Large investments are almost always required.

The more revolutionary the change, the more critical the need for a strategy that can accomplish the change. No matter what type of improvement is envisioned, modification of the existing system, rather than its replacement, will be a necessary first step.

A strategy is also a practical necessity if the time for full implementation is more than five years. Both industry and government leaders are geared to two- to five-year objectives, partly because the leadership is evaluated on the basis of results produced, and partly because of uncertainties of predicting conditions more than five years in the future. Improvement should be scheduled in measurable targets, preferably in two-year increments. This will be difficult, again because of the massiveness and pervasiveness of transportation.

The role of technology is a third area of practical concern. The unavailability of a standard performance measure, and the change from an economic to a social-economic efficiency scale, has led to a waste or non-use of science and technology. The tendency has been to search for readily available hardware and to try to insert it into the transport system. This trial-and-error approach is no longer effective. In the absence of accepted measures of performance, and with the inability to predict the effect of the investment on social and economic values, little action has been initiated.

Attempts to short-cut implementation time by studying an intuitively selected hardware solution is rarely successful. Estimating the social and economic benefits to be derived may be possible, but the major question

still remains, is the selected solution the best among reasonable alternatives?

Technology can be utilized best by specifying the desired change in level of service. Such an approach permits optimization analyses, and can provide consideration of a much wider spectrum of solutions for the same service requirements.

### Tailored Transportation Systems

Development of the most productive program for improving the transport system will need to consider the following principles:

1. The role of transport systems is to provide a service capability that will ultimately produce better performance of individual social and economic programs.

2. Social and economic accounting have not yet developed to the point where the consequences of a massive investment can be accurately predicted.

3. Transport systems are so large and long-lived that rapid change is not practical, and long-term goals need to be accomplished in small steps.

4. Competition for public funds requires that transport programs be responsive to urgent problems.

Based on such considerations, an available technique is to tailor transport changes to improvement in service for specific, urgent problems of the community or nation. Three approaches are possible.

1. Analyze education, health, law enforcement, etc. to determine how transport changes can improve performance of specific end-oriented programs.

2. Analyze the highest priority social problems, particularly in urban areas (i.e., poverty, racism, law enforcement, education, health),

to determine how transport change can improve performance of such programs.

3. Analyze and identify specific programs that would produce a significant improvement in performance if there were a transport change; specific programs such as law enforcement, emergency services, home-to-work, urban postal service, etc.

The emphasis of this procedure is society's needs or on problems that can be stated explicitly. The following are examples of such transport goals:

1. Government activities

- a. Emergency services, providing faster and more reliable assistance to law enforcement, fire protection, and medical programs.
- b. Postal services, providing faster and more efficient distribution of mail.
- c. Education, studying influence of centralized versus decentralized school system on transport requirements.
- d. Effect of concentrated employment centers on transport requirements.
- e. Refuse collection and transport.

2. Industrial activities

- a. Solution for the home-to-work problem.
  - 1) Parking cost vs. bus service
  - 2) Location vs. employee residences.
- b. Special requirements for transport of executives or for emergency supplies and equipment.

3. Mode problems

- a. Grade crossing accidents
- b. Weather visibility problems
- c. Protection of dangerous cargoes
- d. Air traffic control.

The success of such efforts will depend on how specifically the desired service characteristics can be stated.

## Chapter 4

## CIVIL ENGINEERING AND TRANSPORTATION

A definition of engineering as proposed by the Engineers' Council for Professional Development is: (18)

"Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize economically the materials and forces of nature for the progressive well-being of mankind." (Underlining provided).

A major feature of this definition is the reference to the responsibility of the engineer to mankind. The desirability for economic solutions is just one of the goals of the engineering profession.

Traditionally, concern for public welfare has been an important part of civil engineering. Some of the early engineering use of scientific advances for the welfare of individuals and for society are a well known part of the history of civilization. The usefulness of engineering works, in bringing about "contentment" and satisfaction even to people governed by a foreign power, is documented by Alexander Gest in his book, Engineering (19). Professor Gest says of the expansion of the Roman Empire:

"It was a distinguishing characteristic of the Romans that they carried their civilization with them to the countries that they conquered; though often unjust and oppressive in the administration of their provincial governments, they were wise enough to see that the permanence of their dominion depended upon the loyalty and contentment of their subjects, and consequently, after they had reduced a nation to subjection, they devoted their energies to the development of the country and to the promotion of the welfare of the people."

For centuries, some of the most advanced cultures have relied heavily on the engineer for the maximum comfort and convenience that society could afford and technology could provide.

The modern era, significantly different from the past, is characterized by space travel, nuclear energy, laser beams, and other seemingly unbelievable technological advances. But in another and rather special way this new era is more than just different. People in other generations, the Victorian era for instance, marveled at the technologic advances of their age, but there is no parallel to the growth and general affluence that today's society has for the full exploitation of technology for the comfort and convenience of individuals within our society.

We emerged from the industrial revolution, which was a continuation of the basic drive for survival, with only a few individuals obtaining some level of "luxury". Today in America the vast majority of families are spending part of their incomes for what would have been considered "foolish" or "extravagant" luxuries thirty to forty years ago.

Just as economic conditions have changed in the past, so has the civil engineering profession. Civil engineering interest in transportation has been broadened extensively since the original function of locating, designing, construction and maintaining travel ways over which persons, and vehicles move. Highways, railroads, bridges, runways and taxiways, harbor improvements, pipelines, power generation and transmission towers, tunnels and drainage systems cover only the obvious interests of the civil engineer. Underlying the technical aspects of such engineering are specialized areas of engineering mechanics, soil and rock mechanics, hydraulics and hydrology, surveying and mapping, and photogrammetry.

The specialized areas are related to the unique nature of civil engineering and its requirement to provide facilities constructed

primarily of local materials that can withstand climatic attack for 20 to 100 years. Civil engineering also can be characterized by the relatively high percent of its activities that are provided by governments in the public interest.

As civil engineering and society has advanced, the complex nature of location and design has led to an increasing need for planning, operating, and administering the programs. Due to the controlling nature of the most difficult technical area of transport - effective utilization of low cost materials for providing engineering works with unusually long-life characteristics.

The civil engineer can provide highly proficient skills in perhaps the most difficult technical area of transport - difficult at least in the sense of effective utilization of low cost materials for providing engineering works with unusually long-life characteristics.

While steeped in the tradition of economic efficiency and technical analysis, civil engineers in transportation have not been insensitive to social concerns. For highways, Francis C. Turner has stated, relative to the Federal Government's interests:

"...in determining route locations we require a study of all feasible alternate alignments, and this involves identification of all significant differences among them. Each comparison of route location alternates includes consideration of many determinants including:

- National defense
- Economic activity
- Employment
- Recreation
- Fire protection
- Esthetics
- Public utilities
- Safety
- Residential character and location
- Religious institutions and practices
- Rights and freedoms of individuals

Conduct and financing of government  
 Conservation  
 Property values  
 Replacement housing  
 Education, and disruption of school district  
 operations  
 Specific number of families and businesses  
 displaced  
 Engineering, right-of-way and construction  
 costs for proposed highway facilities and  
 other transportation facilities  
 Use of highways and other transportation  
 facilities during construction and following  
 completion

The extent of the consideration of each determinate varies with the nature and magnitude of the proposed highway project and with the characteristics of the area in which it is located.

In the area of social values there is currently the largest difference of opinion as to the range of numerical values to assign to various factors. But we are engaged in considerable research which seeks to quantify these values also..." (20)

Civil engineering has been and is vitally interested in the public welfare (21, 22, 76, 77, 78). It might be noted that many other disciplines are also involved. In fact, it is doubtful that civil engineers have any greater concern or responsibility for public welfare than several other professional groups.

It also is doubtful that any single discipline is capable of providing complete expertise when it comes to public welfare, since the entire range of science and technology is involved. Even within the technical phases of transportation, civil engineering is not alone. Aircraft, airways control systems, vehicles, vehicle control systems, safety, economics, and many others are within the scope of some other discipline.

The civil engineer's area of technical competency is reasonably well understood in the profession and within the transportation field. In the same manner, other technical fields can be identified with their

particular areas of proficiency. Undoubtedly, the basic technical alliances will remain, and civil engineering cannot nor should not expect to become the technical experts in a host of new areas.

On the basis of the analysis of transportation that appears in Chapters 2 and 3, the idea of transportation engineering as a unique field also appears irrelevant, since it still would not be possible to provide a transportation engineer with all of the technical competency required.

It would appear, then, that the technical interest of the civil engineer in transportation will remain much the same. This is not to say his technical background, education, and techniques will not change; only that the area of primary technological proficiency will remain constant.

The major shift of interest of the civil engineer in transportation will be at the analytic level of providing alternate solutions for public welfare problems. Such a shift of interest will require that he be capable and sufficiently knowledgeable to work with other disciplines in developing the goals and criteria upon which advances in transportation will be based.

The evolution of goals and criteria will require two contributions from the civil engineer. One is related to the continuing need for technical skills to design, construct and operate systems. The other is related to multi-discipline studies required for establishing transport goals. The control of public works will rest with government officials who have a non-partisan view of public welfare. The decision-level echelon of transportation will require a diverse set of technological backgrounds, and technical skills of the civil engineers as well as those from other disciplines will be needed to assist in analyses related to policy development.

The policy development activity greatly broadens the perspective required of the civil engineer. High technical proficiency will not be the only requisite. Ability to understand and to deal analytically with interactions and interrelationships will also be important.

Civil engineering must be interested in the way that broad transportation problems are stated and defined because of the insight its own technology can bring to this problem definition. The same can be said for the other disciplines involved.

In essence, then, at the policy level civil engineers are concerned with any phase of transportation, and at the technical level with those phases for which their special fields of technology are required.

**PART II**  
**TRANSPORTATION RESEARCH NEEDS**

PART II  
TRANSPORTATION RESEARCH NEEDS

In Part I, the role of transportation in society was examined from a fundamental perspective - the what, why, how, and when of the purposeful movement of persons and goods. From this, it is possible to derive the principles upon which transportation development must be based in order to fulfill its contributions to the social and economic programs of society.

In Part II, the emphasis will be on how research can be designed to further goals of transportation. More to the point, how can transport provide the greatest contribution to society? Just as it was important to understand the role of transportation, it is of critical importance to understand what research is and what it is not.

Research has existed in the past as an academic pursuit, a search for knowledge. In the era of science and technology, however, it has assumed a more dominant role in practical affairs. From being a search for new insight, research has become a vital tool of management - a major way top management achieves organizational goals.

This practical function has neither changed nor de-emphasized the function of research in society. To the contrary, if research is to continue to be one way of assisting society in achieving goals, it is of critical importance to continue "academic" pursuit of elusive knowledge (79).

A modern view is developed in Part II. Conventional approaches for justifying research that have depended entirely on "need to know" can be enhanced by focusing on why it is desirable to know. With limited funds it is more and more important that this "why" be understood so both short-term and long-term objectives can be attained.

A modern view of research leads to much greater levels of funding, but not because of idealistic desires to accelerate availability of knowledge. Rather, because it provides the improved capability for achieving goals. Larger funding of research is justified because of its contributions to specific missions.

Transportation research needs are developed for three distinctly different purposes: (1) development of systems to further specific goals of social and economic programs of society (Chapter 6), (2) advances or increased efficiency, in a specific mode, serving a group of programs (Chapter 7), and (3) advances in scientific disciplines that contribute to transportation (Chapter 8).

The contribution to social and economic programs of research for each of the three purposes can be evaluated. The results, however, will influence society in different ways. For example, the systems that are derived directly from the needs of social and economic programs will produce a much more rapid and direct result on a troublesome problem.

The second purpose - improving a given mode - assumes that a continuing need for the mode has been established, and that more efficient service is adequate justification for the research. The third purpose - improving the technology - assumes that advances in technical capability will lead to better transport service.

The latter two purposes are directed to improving a much broader set of social and economic programs than is the first, and their benefits to social and economic programs will be less direct and less susceptible to measurement.

For modern research programs, then, specificity of objectives and realistic appraisals of anticipated benefits are required. The complexity of modern social problems can well utilize the added capability of research.

## Chapter 5

## DEVELOPING RESEARCH NEEDS FOR TRANSPORTATION

Research, basic research, applied research, development, policy development, planning, engineering, professional activities and administration are difficult terms to define precisely, or at least, precisely enough to delineate borderline cases. For the present study, precise definitions of the terms are not of great consequence.

Research and development can be categorized as studies to produce new knowledge or new applications of existing knowledge for the general solution of a set of problems. Professional activities can be described as studies based on existing knowledge which require judgment to produce a solution to a specific problem. Mission-oriented research and development will frequently phase into professional work as the implementation of a general solution is achieved.

There is a long-standing argument in the scientific world about the meaning of basic research in engineering and other fields of applied science. This question is not as relevant to the present study, as is a distinction between research with a long-term and short-term requirements for completion. Studies requiring five to ten years to complete, or studies for which it is impossible to predict the "pay-off" day, may or may not be "basic research" in any classical sense. Such efforts are unquestionably basic to the progress of civil engineering (and transportation), however, and it is in this sense that research projects are viewed in this study as being basic. The term "research" will be used to refer to all classes of research and development.

### Research as a Management Tool

In industry, research has become a major tool of top management. This is particularly evident in chemistry, applied physics, and mathematics. The chemical business, electronics industry, space-related hardware manufacturing, communications field, computer firms, and Department of Defense contractors are typical of industries wherein research often has a controlling voice in a company's management decisions. In these fields, failure to produce research results, which can be profitably exploited, is tantamount to going out of business.

In simple terms, research is highly relevant to these organizations, relevant to economic profit. Management is using its investment capital for research instead of more traditional money-making activities, with research evolving as a profit-making operation, not just an academic or philanthropic pursuit.

This new perspective of research has led to a much higher level of fiscal support. It has also led to a more objective appraisal of probabilities of success and of completion on rigid time-tables.

The newer view of research has not been generally adopted by the transportation field; aircraft and air traffic control systems, however, are notable exceptions. In both of these cases industrial profit was present as a strong motivating factor, along with the experience of these companies in other areas of industrial research.

The orientation of top management to research needs is highly important. For an organization, whose future requires a policy commitment to achieving rapid progress, research becomes a key mechanism for reaching its objectives. For an organization where production or operation does not appear to require such progress, research is less essential.

The nature of transportation and of civil engineering in the public works field has not encouraged rapid change. Massiveness of the transport systems, huge investments required for research and any significant modification, complexities of designing systems to last 50 years or more, division of responsibility between government and the private sector, and absence of an economic motive have discouraged research programs that would have produced major innovations in transportation.

In light of the constant increase in demand for transport services, and in view of safety, congestion, noise, air pollution and other problems facing the existing transport system, the position is assumed in this analysis that it is highly critical that significant progress be made--that a policy commitment for rapid progress in transportation is required.

It should be recognized that both the private and the public sector are involved. There are obviously private interests in such areas as construction materials, construction equipment, vehicles and electronic hardware for many phases of transportation. But in the public sector, the objectives of transportation, as seen in Part I, transcend the conventional view of user-satisfaction to a broader concern for the social and economic goals of society. Rapid progress for such a broad spectrum of goals will require analyses that produce the type of specific advances in transportation that social and economic goals require.

Research needs, when viewed as a management tool, produce the type of activity that is required to maximize the organization's goals. Furthermore, as progress in achieving goals becomes more urgent, research requirements will become greater.

### Discipline-Oriented Research

Much of the research conducted in transportation has been generated by professionals and academicians who were concerned with the inadequacies of existing technology. Such studies have been largely oriented toward the disciplines of those making the studies as contrasted to the preceding discussion of research as a management tool. Research has been viewed as a technical activity that can and should be supported primarily because of a "need to know."

Progress, made over the years, has been achieved because of the dedication of these above mentioned professionals, who often worked under serious handicaps of financial, equipment, and manpower shortages. Such research will continue to be vital to long-term progress. It is the basic wisdom of these creative professionals that provides the storehouse of knowledge needed for making relatively rapid advances.

At times, these efforts are considered to be "basic research". At other times, they are recognized as applied, short-term studies, not necessarily producing major changes nor major benefits. However, the inquisitive drive for progress is a major resource that should be supported.

Generally speaking, one of the curious characteristics of discipline-oriented research is its lack of appeal to top management. Highly technical efforts are hard to translate into terms relevant to the urgent problems of the organization. Generally, too, the research objective is more likely to be a technical refinement with little evident organizational value.

In short, much of the discipline-oriented research produces long-term rather than short-term benefits. It is an investment in the future and immediate value is not necessarily achieved. This type of work

must be carried on, however, for it provides a vital "storehouse of knowledge". If all of the research were to be oriented to the urgent needs of the organization, eventually all research would have to build its own base, and the timetables for results would necessarily be longer.

Organizations have limited capability, however, for investments for the future. Always short of funds for worthwhile activities that would produce benefits now, even the most progressive management can only risk a limited amount on the future.

Research needs from a discipline perspective, then, are derived differently from those that are developed in direct response to organizational goals. The basis for assigning priority, the level of funds to be allocated, and the timetables are all different. In the case of the discipline-oriented research, the level of effort will be a subjective decision, greatly influenced by the general policy of top management and its willingness to invest resources in programs for the future. Failure of management to allocate some level of continuing support, however, is to either risk obsolescence or to pass along to a future generation the responsibility for developing new knowledge.

#### The Meaning of "Research Needs"

A complete inventory of the "unknowns" or "research needs" of transportation engineering would consist of a systematic listing of all related physical components and processes, and an estimate made of how much effort would be required to perfect each of them. The preparation of the list would be a time-consuming task but not too complex. To develop an understanding of "perfection", however, is impossible.

No such listing was envisioned for this study. The term "research needs" has conventionally implied a priority system or judgment that a potential or desirable change is or should be possible. The priority can be viewed either (1) as a technical decision, (2) as an administrative action based on an organizational need or goal, or (3) as dependent on the value of the results or payoff.

For this report, "research needs" have been defined as the most critical problems to be faced in developing a greater responsiveness of civil engineering works to critical organizational or societal needs for transportation. Criticality will be a judgment of (1) relative importance of the human values that can be improved, (2) level of improvement that can be anticipated, and (3) short-term and long-term requirements.

The judgment required for specifying research needs is quite different depending on whether a management or a discipline-oriented perspective is assumed. As a management tool, research needs will be based on the organization's goals. In industry, an economic advance is the primary criterion, while for governments, both economic and social gains are logical objectives. In discipline-oriented efforts, the criticality of the solution to a set of technical problems may well be a dominant factor.

Regardless of the perspective from which research needs are viewed, specific goals or objectives are required. Vague statements are useful to obtain maneuverability, but specific objectives are a prerequisite for using the scientific approach.

For management or mission-oriented efforts, the objective must be stated in terms of the organization's ultimate performance criteria,

that is, in terms of improving the output. For transportation, both social and economic efficiency are involved. At the highest policy level of management, transportation must be viewed as a means to advance social and economic programs. In a positive sense, this means in what way can the cost, safety, comfort or time characteristics of transportation be changed to produce a given return for a social or economic activity. In a constraining sense, the government may also require that in order to advance human values, external effects (noise, air pollution, space usage, etc.) must be reduced to a specific level.

Goals derived at policy levels will be directed to improving performance of non-transport activities through a change in level of service of transportation. To accomplish the desired specificity, an iterative process is needed -- a process that explores ways and costs to improve specific activities of society by changes in the level of service of transport.

At other echelons of the transport system, increased efficiency is a logical objective. This efficiency can be economic or it can be in terms of human values. Economic efficiency is concerned with cost reduction through improved system operations, in savings of productive time, or in reduction of economic losses through accidents. Changes in safety (lives lost, injuries, suffering, etc.) comfort and nonproductive time-savings can produce "social efficiency" or improvement in non-economic human values.

A discipline-oriented research goal is developed on different bases. Within the total transport system, many important relationships have not been solved. Some of these constitute significant blocks to advances in both economic and social efficiency. Many will require

extensive effort before a significant advance can be expected. For many, a highly accurate cost effectiveness analysis is not possible because of the inadequacies to which the research is addressed. Nonetheless, specific objectives can be identified, and estimates of resources that are required can be developed. The basis for approving the use of resources, however, lacks the positive nature of the mission-oriented studies.

Finally, the practical nature of what constitutes a research need must be considered. It makes no difference how worthy the advance, nor how favorable the cost effectiveness or benefit/cost estimate is, resources are required. Both fiscal and manpower limitations exist. Accordingly, there is a built-in understanding that in the broad spectrum of criticality of need, there is the practical problem of limited resources.

For all organizations, limited resources is a real, not imaginary, problem. It is a management concern, related to budgeting funds for many needed requirements. Making decisions for research funding is a top-level policy problem--an ultimate decision about how resources are to be used. This will require "political" judgment regardless of whether the private or the public sector is involved. It is a decision that rises above the technical level because the choice of how the resources are used controls the ultimate character of the organization.

No effort is made in this study to pre-judge the influence of available or potential funding on the definition of research needs. Some, but not all of the most significant problems which might have solutions and thus merit attention, are identified. No effort is made

to provide a "practical" answer, since to do so would be to propose resource allocations that could not begin to account for the many demands on an organization's funding.

#### A Framework for Research Needs

Given specific goals for research activity, there are several approaches to developing programs. These include:

1. Derive the plan of attack directly from the statement of the goal (BPR National Program) (23).
2. Derive the plan of attack from a systematic examination of established deficiencies. (Tallamy-Smith Report) (24).
3. Derive the plan of attack from a systematic examination of the elements of the transport system. (Ohio State University) (25).

The first is applicable to all levels of problems. The second and third are particularly useful for discipline-oriented efforts and for coordinating autonomous, separate research activities in the solution of large complex research problems. The third approach provides the type of framework needed to structure and to examine the needs of the entire transport process.

The large number of scientific disciplines involved with the civil engineering phases of transportation, and the many different organizations participating in transportation research has led to a number of efforts to classify research activities. These classification systems have tended to combine the studies along discipline lines, since specific research activity is accomplished at the discipline level. With the advent of the systems approach, however, and because most transport

goals have a multi-disciplinary interest, other systems that combine goals have been suggested (26). The following is typical of this type:

1. Performance requirements for transportation
2. Traffic operation requirements
3. Physical plant requirements
4. Techniques or processes.

Even this classification is essentially discipline-oriented, and many significant problems require joint efforts. Particularly for efficiency-oriented, modal efforts, however, the preceding grouping permits focusing on relatively severe problems of the system.

For this report, no extensive repetition of published documents was considered necessary. Resources recommended in the documents, however, are relevant and were included when available.

Finally, the extent that civil engineering is involved was resolved on the previous grounds of historical, technical competency. Within each mode, the civil engineering interests are fairly well established. Changes in modal interests and non-modal problems have tended to broaden interactions. Therefore, the types of problems included are those that the technical role of the civil engineer is one of the necessary inputs.

## Chapter 6

RESEARCH NEEDS FOR  
TRANSPORTATION SYSTEMS

In this chapter, transport research needs are viewed and those that are required for human resource development are emphasized. A systematic evaluation defining specific goals and priorities was considered outside the scope of this specific study. The nature of the transport service needs that are advanced, however, are responsive to the objective of improving the environment and the quality of life of individuals.

The Decision Problem

Transportation research needs can be viewed from various levels of government and the private sector. No matter what level of government or what part of industry is involved, the need for research will exceed the resources available. As a result, the choice between research programs will inevitably be made by top management.

To develop the most effective programs, the following steps are required:

1. Identification and specification of the ultimate goals and criteria for the organization.
2. Establishment of priorities for achieving the goals.
3. Establishment of the transport service characteristics required to achieve the goals.
4. Establishment of the plan for providing the necessary transport systems.
5. Research to implement the plan.

Transportation research in support of physical resource development will normally be based on economic return. The private sector will capitalize on successful research in this area, but occasionally the risks

are too great, the delay until payoff is excessive, and so government funding is required.

Examples of this type of research can be seen in railroad systems and pipelines, for the development of natural resource, and specialized transport systems for large manufacturing plants.

For human resource development, the profit motive is frequently not present, and responsibilities for the development or modification of transport systems rest with government. Analyses of this type require a systematic examination and evaluation of the non-economic requirements of society.

Programs directed to human resource development have not had a generally accepted set of values from which to work. "Quality of life" has been difficult to define and even more difficult to measure. Assignments of priorities to elements of human resource development have been correspondingly handicapped.

The study of transport needs for these programs cannot avoid the fundamental problems of definitions, criteria and goals. Some guidance is available, however, from the progress in defining social indicators (12, 14).

The problem of priorities is much more complex. Past and present priorities of governments can be partially understood by a study of how resources are allocated, and what regulations are applied.

Former President Johnson's Budget Message to Congress, submitted on January 15, 1969, stated: "The overall size of the Federal budget reflects the needs and demands for public services as a whole. The composition of the budget reveals much about the nation's priorities" (27).

An examination of that budget reveals that of the \$195.3 billion requested, \$81.5 billion (42%) were for national defense and \$67.8 billion (35%) were for major social programs. Of the remaining \$56 billion (23%), \$16 billion (8%) were for interest payments and \$24.9 billion (13%) were for programs that had shown little or no increase over the five-year period of 1964-1970. Major social programs accounted for a \$37.4 billion increase over this same period, paralleled by a \$28 billion increase in national defense. For the five-year period, major social programs were increased by 123%.

A special analysis of the budget (28) for the major social programs provided the following (in millions of dollars):

	Civilian Agencies	Dept. of Defense	All Agencies
Special analysis:			
J. Education - - - - -	8,804	998	9,802
K. Manpower- - - - -	2,819	675	3,494
L. Health - - - - -	16,269	2,008	18,277
M. Income security - - - - -	45,842	2,725	48,567
N. Reduction of crime- - - - -	868	-----	868
Deduction for duplications included above- - - - -	<u>-2,162</u>	<u>-----</u>	<u>-2,162</u>
Totals	72,440	6,406	78,864

Additional information on these programs is provided in Table 6-1.

Based on these data the priority assigned by the Federal Government to major social programs was:

- . Income Security
- . Health
- . Education
- . Manpower
- . Reduction of Crime.

TABLE 6-1 Federal Social Programs Proposed for 1970\*

Program	Budget (\$ in Millions)
<b>EDUCATION:</b>	
Elementary and secondary - - - - -	3,358
Higher - - - - -	5,030
Adult and continuing - - - - -	357
Training of public employees - - - - -	494
Foreign- - - - -	292
Other- - - - -	271
TOTAL - - - - -	<u>9,802</u>
<b>MANPOWER:</b>	
Job Opportunities in the Business Sector (JOBS)- - - -	239
Concentrated Employment Program (CEP)- - - - -	193
Work Incentive Program (WIN) - - - - -	163
Vocational Rehabilitation- - - - -	509
MDTA Institutional and OJT Training- - - - -	330
Job Corps- - - - -	283
Neighborhood Youth Corps (NYC) - - - - -	321
U.S. Employment Service (ES) - - - - -	378
Other Programs - - - - -	448
SUBTOTAL - - - - -	<u>2,864</u>
Civilian Skill Training - Defense- - - - -	630
TOTAL - - - - -	<u>3,494</u>
<b>HEALTH:</b>	
Development of health resources, total - - - - -	3,496
Health research- - - - -	1,639
Training and education - - - - -	932
Construction of hospitals and health facilities- - -	728
Improving the organization and delivery of health services - - - - -	<u>197</u>
Provision of hospital and medical services, total- - -	<u>13,977</u>
Direct Federal hospital and medical services - - - -	2,996
Hospital and medical services, indirect- - - - -	<u>10,981</u>
Prevention and control of health problems, total - - -	<u>804</u>
Disease prevention and control - - - - -	522
Environmental control- - - - -	102
Consumer protection- - - - -	180
TOTAL - - - - -	<u>18,277</u>

(Continued)

TABLE 6-1 Federal Social Programs Proposed for 1970\* - Continued

Program	Budget (\$ in Millions)
<b>INCOME SECURITY:</b>	
Federal outlays, cash benefit programs (millions):	
Income replacement programs:	
Social security and railroad retirement - - - - -	29,469
Federal employee retirement systems - - - - -	5,201
Unemployment insurance programs - - - - -	2,818
Veterans compensation - - - - -	2,796
Other programs- - - - -	684
Proposed legislation- - - - -	<u>1,519</u>
Subtotal, income replacement- - - - -	<u>42,487</u>
Income support programs:	
Public assistance - - - - -	3,863
Veterans pensions - - - - -	2,242
Other programs- - - - -	62
Proposed legislation- - - - -	<u>-87</u>
Subtotal, income support- - - - -	<u>6,080</u>
TOTAL- - - - -	<u>48,567</u>
<b>REDUCTION OF CRIME:</b>	
	(\$ in Thousands)
Assessment of crime:	
Statistics on criminal justice- - - - -	6,729
Research and information- - - - -	<u>8,153</u>
Sub- - - - -	14,882
Reform of criminal laws - - - - -	2,634
Services for prevention of crime:	
Development of community resources for crime prevention- - - - -	21,766
Alcoholic and addict rehabilitation - - - - -	20,866
Public education- - - - -	<u>4,929</u>
Sub- - - - -	46,929
Federal criminal law enforcement:	
General Federal enforcement - - - - -	152,583
Enforcement in support of Federal systems (e.g., tax, postal, customs, and immigration enforcement)-	172,706
Federal police activities - - - - -	15,203
Special enforcement against organized crime - - - - -	<u>35,858</u>
Sub- - - - -	376,350

(Continued)

TABLE 6-1 Federal Social Programs Proposed for 1970\* - Continued

Program	Budget (\$ in Thousands)
REDUCTION OF CRIME: (Cont'd)	
Law enforcement assistance:	
Support of State and local law enforcement - - - - -	153,107
Support of Federal law enforcement - - - - -	<u>21,432</u>
Sub - - - - -	174,539
Administration of criminal justice:	
Conduct of criminal prosecutions - - - - -	30,390
Operation of Federal court systems - - - - -	23,409
Other supporting programs- - - - -	<u>30,967</u>
Sub - - - - -	84,766
Rehabilitation of offenders:	
Operation of correctional institutions - - - - -	72,080
Probation, parole, and community treatment - - - - -	15,395
Inmate education and training- - - - -	17,811
Other rehabilitation programs- - - - -	<u>39,275</u>
Sub - - - - -	144,561
Planning and coordination of crime reduction programs-	<u>23,537</u>
TOTAL - - - - -	868,198
<hr/>	
Deductions for duplications- - - - -	2,162
TOTAL - - - - -	<u>78,846</u>

\* From "Special Analyses", Budget of the United States, Fiscal Year 1970, U.S. Government Printing Office, 1969 (28).

As to goals, the budget analysis (28) provides the following description of the program objectives:

Income Security - to "provide individuals and families greater financial security through the replacement of lost income or by supplementing inadequate incomes". Approximately 70 percent of this effort is included with the Social Security program. The technique used is essentially one of direct distribution of funds or the provision of food, health care and housing assistance.

Health - to enlarge health resources of the nation, to provide financial assistance for hospital and medical care, and to prevent and control health problems. This wide category of health-related matters includes research, education, construction of facilities, disease prevention, environmental control, and consumer protection. Safety is not explicitly identified within the above listed funds.

Education - to provide "an opportunity for the best education which the Nation can offer to each individual, suited to his abilities and interests and without regard to his family income, race or place of residence"; and to provide "an improvement in the quality of education through experimentation with new materials and methods, new ways of using and training personnel, and new organizations designed to ensure regeneration and renewal of schools and colleges".

A wide range of programs are included in this area for all levels of education and research. A major technique employed is the provision of financial assistance.

Manpower - to provide an improvement in the work force "by increasing the skills and employment opportunities of persons who are in the work force or who desire to be in the work force but are unprepared".

An increasing emphasis is being placed on "increasing the employability of the disadvantaged". Job training is the major technique being used.

Reduction in Crime - to "identify the underlying causes of criminal behavior, gain a better understanding of the magnitude and nature of the crime problems, and prevent and reduce crime through effective law enforcement, public education, and rehabilitation of criminals and juvenile delinquents". The objective is "to reverse the trend of rising crime so that the economic loss and loss of human resources associated with crime are substantially reduced, and the fear of criminal abuse or exploitation in our communities is alleviated".

Programs range from education and research through enforcement, criminal justice, and rehabilitation.

Interpreting a budget for its implicit priorities is complex, and can lead to disagreement. For example, the transportation budget request (27) for 1970 was \$6.9 billion and for the Post Office Department, \$7.8 billion. Within the transportation budget, \$4.8 billion was for the provision of highways. Two significant observations can be made. First, the government's responsibilities for providing highway facilities and for the postal service are quite different from their responsibilities in providing services, such as railroads, telephones, power supply, water supply, etc. If, for example, free enterprise instead of government were responsible for collecting a "toll" at the gas pumps, or for selling the stamps at the Post Office, the support (or priority) provided by the government would be more comprehensible. Extending the example to the provision of airports and the operation of the airways by free enterprise would further reduce the government's "allocation" of funds to transportation. The conclusion, then, is that since governments provide (and

do not provide) all or parts of some services (and not others), the priority assigned to various goals cannot be directly inferred from a budget.

Second, transportation and postal activities are typical services that are means to some end. A change in the quality of these services would produce a change in the way the development of human resources could be achieved. For example, within each of the five listed major social programs, a requirement for transportation of persons and goods is implicit. The character of the required transport service is not given, but the quality of the service will have a bearing on the success or failure of the social programs. Other services are also implicit. Insofar as human resource development is concerned, the decision as to the quality of various services depends on the relative effectiveness of a service in contributing to the goals of the social programs.

The priorities, budget levels and approved programs that are directed to human resource development are matters of political philosophy and judgment, and are subject to change with a new administration or management, and with public sentiment. The preceding data are not presented for the purpose of proposing priorities. They do provide, however, one important perspective on the importance of social programs.

Keeping this in mind, the development of an effective transport research program requires a systematic evaluation of alternatives. A clear distinction must be recognized between the formulation of policy decisions and the planning process. The latter consists of professional activity concerned with effective implementation of policy, and should be accomplished by skilled technologists in various fields; for example, transportation, medical education, housing, sanitation, public safety, welfare, etc.

Policy formulation, on the other hand, requires a non-partisan view of the means whereby goals, criteria, and priorities of the community are achieved or established. While requiring technological support, the activity is primarily political because of the judgments required concerning importance of various programs directed to both physical and human resource development. While the ends may not be readily separable from the means, policy formulation should be primarily concerned with ultimate goals rather than methods, if effective programs are to be developed.

In the past, the development of transport solutions from social objectives has been frequently proposed (29, 30, 31, 32, 33). Specific techniques for dealing with transport problems in such a manner have centered around systems analysis methods (8, 16, 34, 35, 36).

In a recent study sponsored by the Engineering Foundation, a technique was proposed for developing airport access requirements directly from the objectives of social programs (17). A study, which approached the urban transport problem from social objectives on an intuitive basis, was completed by the Department of Housing and Urban Development (37).

A problem must be comprehended in numerical terms if a unique solution is to be obtained (38). A benefit to a social program cannot be computed until the existing condition is represented in a statistically reliable manner, and an effect is estimated of a change in some characteristic of the level of service of transportation. Much of the data needed is available and need only be assembled and analyzed. Other data needs to be collected, not just for transport studies, but for the evaluation of any proposed social action.

A major problem is how to introduce major innovations. There is no difficulty in producing long-term goals, although there can be considerable differences in opinion as to the "greatest good". The major stumbling block is the strategy for change - the rate and character of the step-by-step improvements. Shortage of resources and the urgency to deal directly with social problems often obscures and prevents necessary changes that will be required in basic services, such as transportation, communication, power supply, sanitary facilities, and water supply.

Lack of a technique for relating transportation to non-economic objectives has led to research needs being proposed on an intuitive basis. This subjective approach has resulted in a host of "solutions" from eminent physical scientists, engineers, architects, planners, economists, sociologists, and political scientists. Many of these claim to be the "answer". None of them are able to provide a satisfactory, quantitative justification for their solution (as compared to another). Each of them contains an inherent ethical judgment about the most urgent need. The differences are not so much in the relative technological feasibility, but in the assumptions that each contribute to the "greatest good".

This diversity in views is predictable, as is the enthusiastic support of a specific solution. For the ultimate decision-maker, however, the question of which solution is "right" is a difficult one. None of the solutions need be "wrong", since different assumptions and judgments will produce different solutions.

The existing decision process has been described as a process of reaching agreement. Frequently, agreement is sought on means rather than on the ultimate ends and priorities. Lack of concurrence on means is inescapable, particularly if the goals for human resource development

are not clear. Conflicts are inevitable if every action requires review and debate, not only on the ultimate goals, but the priorities to be assigned to them. If a consensus is impossible on the goals and their priorities, then consensus on an action program will be even more difficult. Action programs will disrupt and interfere with some qualities of life for some individuals, and one basis for resolving these issues is a set of goals on which agreement exists.

The separation of transportation from other programs and activities of society is difficult and undesirable since transport is a service function to these programs. On the other hand, to include all of these programs in transportation is to encompass the entire social system and all fields of technology. Accordingly, the problems and research of the non-transport systems are not included herein. The problems of integrating the many sub-systems are no more within the activity of transportation than they are of any single system or discipline.

The following discussion of research needs, summarized in Table 6-2, does not attempt to arrive at decisions as to priorities on human resource goals, but rather, that the research is typical and responsive to how transport systems can be specified to correlate with both social and economic goals.

TABLE 6-2 Summary of Research Needs for Transportation Systems

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A. Research Needs for Methodology

1. Develop procedures for establishing priorities on social values and the criteria by which social values will be measured.
2. Develop a process for obtaining policy decisions on how extensively non-productive changes are to be introduced in the form of requirements and constraints.
3. Develop an analytic process for estimating the level of service of transportation systems.
4. Develop the analytic capability (model) to predict the effect on the level of service produced by a change in the input to a transportation system.
5. Develop procedures for examining benefits to various social objectives of alternative levels of service.
6. Develop procedures for studying how rapidly the level of service can be changed.
7. Develop an information system for collecting and storing data requirements for quantitative analyses of transport for human resource development.
8. Develop the interrelations between transportation and land use, communications, power and water supply, and sanitation systems in achieving human resource development.

B. Research Needs for Requirements and Constraints

1. Establish specific statements of the constraints that will be imposed on transportation during the next twenty years, in five-year increments.
2. Develop minimum levels of service for transportation for the most urgent social objectives.
3. Develop and implement a process for monitoring and adjusting the level of service provided by transport modes for various community activities.
4. Develop and implement guidelines for specifying level of service in order to facilitate reduction and replacement of transportation in a manner that will improve human resources development.

(Continued)

TABLE 6-2 Summary of Research Needs for Transportation Systems - Continued

C. Research Needs for New Systems

1. Develop an urban home-to-work transport system that will provide a better level of service for 90 percent of the work force.
  - a. Develop a home-to-work transport system that provides 30 minute, or better, service to most employment areas in the urban community from a region of low-income residents, at a daily user charge of no more than one percent of the minimum daily wage.
  - b. Develop and implement an employer incentive plan for improving the level of service of the transport of his employees for the home-to-work trip.
2. Develop and implement an emergency response system that can reach any point at any time in the community within ten minutes with the equipment and personnel needed to cope with the problem.
3. Develop and implement a training program to accommodate a reasonable percentage of the low-income group for jobs in the design, construction, maintenance, and operation of transport systems.
4. Develop and implement a transport system that provides a satisfactory level of service to cultural, recreational, educational, and hospital facilities of the community for the low-income group.
5. Develop limits and implement a new level of service for collecting and transporting trash and for waste disposal.
6. Develop and implement an improved level of transport service for law enforcement, shore and beach surveillance of waterways, and other patrol activities.
7. Develop an improved level of service for neighborhood mobility and accessibility.
8. Develop an improved level of service for freight distribution.
9. Develop improved level of service of transport for postal services.

D. Research Needs for Transport Facilities

1. Develop analytic techniques and establish level of safety requirements for various modes in five-year increments.

(Continued)

TABLE 6-2 Summary of Research Needs for Transportation Systems - Continued

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Research Needs for Transport Facilities - (Cont'd.)

2. Develop and implement measures of the behavior or performance of ground facilities.
  3. Develop analytic capability to incorporate the probability concept into measurements of level of service and social values.
  4. Develop methods for reducing construction costs of transport facilities without lowering the existing quality of construction.
  5. Develop a cost-effectiveness approach to the maintenance and operation of facilities, and implement.
  6. Develop and implement the capability of tunneling at an increased rate both for driving and lining of tunnel and excavating and supporting the cavity.
  7. Develop levels of service requirements that are possible through use of control systems to replace human operators throughout the transport system.
  8. Develop level of service requirements that will produce new materials and new applications of existing materials for transport facilities.
  9. Develop mode interchange systems.
-

## Research Needs for Methodology

A major need exists for analytic techniques and a sound data base for the study of how transportation can be more responsive to the development or preservation of human resources. Existing technology is designed to be responsive to economic efficiency (development of physical resources and to precise statements of objectives), but at present methods do not exist for a comprehensive analysis of the distributional or disaggregated effects of the results achieved. Changes that are classed as non-productive (of physical resources) or are not stated in measurable terms are rejected or resisted. There is no objective basis for comparison or evaluation of new transport systems to serve the indigent, the young, and the elderly, or for social values such as esthetics, clean air, less noise, and safety. Transportation, for the most part has been viewed as an economic system (39), and economic return has been the ultimate criterion. Until capability is developed to conduct comprehensive analyses of non-economic improvements, conflicts and debates on the wrong issues are likely.

The following are major research needs in the area of methodology:

1. Develop procedures for establishing priorities on social values and the criteria by which social values will be measured.

These studies are of concern to more than just transportation interests. While the ultimate answers will require years to develop, at any given instant, and for any given community (or for the nation), priorities can be obtained. The basis for measuring the values and the necessary statistical representation of social scaling will be more troublesome. The benefits of a change in transportation (or of any other change) cannot be measured, however, without quantitative datum for the quality or sets of qualities that are to be influenced.

2. Develop a process for obtaining policy decisions on how extensively non-productive changes are to be introduced in the form of requirements and constraints.

The ability to improve "quality of life" depends on the availability of physical resources. Some activity must produce these resources or the desired qualities cannot be achieved. There is a limit to the availability of resources for non-productive advances. The analytic capability for obtaining both social and economic impact of constraints and for obtaining information to elicit the prevailing policy on the need for a minimum level of economic return must be developed. In these analyses, it will be essential to isolate and identify non-economic gains in addition to physical resources that are generated (or used).

3. Develop an analytic process for estimating the level of service of transportation systems.

The level of service of transportation should be measured and disaggregated in order to estimate the ultimate impact on various social and other objectives. Aggregations of the level of service can be accomplished when the purpose of the transport calls for practically identical levels of service. Due to inherent variability of the service levels of different transport systems, statistical representations are essential to comprehending the manner in which a change in level of service can be helpful.

4. Develop the analytic capability (model) to predict the effect on the level of service produced by a change in the input to a transportation system.

The prediction of the effect of a change in input on the level of service of a transport system is required to estimate benefits. The need for the model is technological, and is not related to how the input is

obtained--provided the model can handle the necessary types of inputs. The purpose of the model is not for directly determining what the level of service should be, nor what effect the output will have on the input. The model is needed to formulate systems or to select among alternatives to meet a specified level of service. The specification of the input and the desired output are policy requirements, and cannot be developed by technologists unless relationships between social and economic values are also specified. Three major systems analyses in recent years have attempted to develop a predictive model, (16, 34, 36), but none is available for practical use. The study for the Bureau of Public Roads was directed explicitly to "system capability" (or the direct effects of the level of service) with which social impacts could be related. Analyses to provide a practical application are continuing under the Office of Research and Development, Bureau of Public Roads, U.S. Department of Transportation.

5. Develop procedures for examining benefits to various social objectives of alternative levels of service.

Programs with both economic and non-economic objectives require transport services. Many of these programs will have different levels of service needs. The provision of all of the individual requirements will not be feasible for the major transport sub-systems (modes) since their objectives will continue to be that of providing "optimum" service. If social objectives are to receive priority, however, consideration will need to be given to specifying the service requirements for a given mode, or parts of a mode. For reasons of operational efficiency, the maximum permissible latitude should be given to how the service is achieved. These service requirements will include the social objectives to which the service is directed. Furthermore, quantity measures of transport,

for which the system should be designed, will need to be specified as a part of the level of service of the several programs. Where free enterprise is involved, financial support of non-economic objectives will need to be assured.

6. Develop procedures for studying how rapidly the level of service can be changed.

There are many active and reactive forces that will resist changes in level of service. The large mass of the transportation requirement precludes revolutionary changes. Investments are frequently for facilities that will last from 20 to 50 years. Plans for new investments often require 5 to 10 years to implement. To produce the most rapid and desirable change in service, a well-conceived plan for short-term periods is essential. The relatively slow change of transportation in the past has not posed this type of problem. Capability does not exist for making realistic estimates of the rate of change of level of service, with or without the introduction of an innovative change.

7. Develop an information system for collecting and storing data requirements for quantitative analyses of transport for human resource development.

The necessary information will be of two types: inventory and analytic. Under the former, complete census-type data are required for broad management questions concerned with the ultimate size of the problem. For analysis, much more specific and detailed information will be needed, but only a sufficient sample to obtain a desired confidence level will need to be collected. Information on the purposes (social) of transportation and on the direct and indirect effects of the level of service are not available in statistically reliable form. There is

some information available, but it needs to be analyzed and presented in a different form. The use of a predictive model, and the derivation of transport quantities from program needs would eliminate the requirement for the type of inventory needed for projecting the trends of existing alternatives.

8. Develop the interrelations between transportation and land use, communications, power and water supply, and sanitation systems in achieving human resource development.

The achievement of the quality of life desired by individuals and groups of individuals can be accomplished through appropriate combinations of levels of service of massive systems. The development of those systems can be most effectively accomplished by coordinated efforts. Another consideration, furthermore, is that large long-term investments are normally required, which leads to committing future generations to the type of answer that is proposed. The interrelationships between these major services in the development of human resources will need to be established in order that a more complete set of alternatives will be available.

#### Research Needs for Requirements and Constraints

In the preceding section, the need for new methodology was reviewed. These needs are extensive, complex, and will require several years to develop. In the meantime immediate action will require the development of interim procedures and the attendant requirements and constraints. The following needs exist in this area.

1. Establish specific statements of the constraints that will be imposed on transportation during the next twenty years, in five-year increments.

Due to mobility of transportation, local action has limited capability for constraining the adverse effects of transportation. Nonetheless, during the past five years, local efforts have tried to control the noise levels of SST's, air pollution from jet aircraft, the noise level of jet aircraft, air pollution from automobiles, and hazards from highway-railroad grade crossings. To the extent that these controls have only local impact, the local jurisdictions should have complete autonomy. If these actions affect other communities, however, uni-lateral regulations pose problems. Setting realistic constraints on local control may be all but impossible because of special interests. To achieve the ultimate in human resources development, constraints should be established for the nation, with maximum possible flexibility for local control. To accomplish the needed specificity, statistically reliable data must be developed so that benefits of the constraints can be predicted and ultimately measured. These analyses will need to incorporate the negative effects of the constraints on social and economic programs, due to the lower quality of service (direct effects).

Constraints on allowable air and noise pollution, disruption of neighborhoods, and use of space is primarily the concern of the policy-makers with responsibility for the entire social system. For transport interests, however, a systematic review of the benefits and the attendant losses in direct effects should be conducted in order that both the gains and losses will be understood. Much more objective and factual bases for actions are needed. For example, the variability, in statistical measures, of air and noise pollution is needed so that an approximation of the effect of a proposed action can be understood.

2. Develop minimum levels of service for transportation for the most urgent social objectives.

Program objectives with the highest priority for the community and nation need to be identified and the minimum levels of service for transportation need to be specified by the appropriate jurisdiction. For greatest effectiveness, local jurisdictions need some autonomy in the setting of these levels, subject to minimum levels for systems providing regional service. The techniques for analysis, and programs requiring funding may very well involve both the state and the Federal Governments. For community, state, regional and national transportation systems, minimum levels for the system should be developed immediately for entire systems.

3. Develop and implement a process for monitoring and adjusting the level of service provided by transport modes for various community activities.

Each mode should provide the optimum level of service to the user within the scope of the funds available. In the process, problems of concern to the community may not be provided with the necessary priorities or funding to achieve the special level of service that is required. Periodic review of the level of service to specific programs will permit necessary adjustments.

4. Develop and implement guidelines for specifying level of service in order to facilitate reduction and replacement of transportation in a manner that will improve human resources development.

The necessity for moving persons and goods should be minimized as much as possible. By a study of the ultimate purposes of social and economic programs, and by re-examining the means whereby individuals and programs achieve their objectives, reduction in an undesirable reliance

on transportation can be obtained. These results can only be accomplished through a systematic analysis of non-transport goals. Authoritarian or capricious actions, which reduce transportation's level of service, will be resisted, particularly if individual goals concerned with accessibility and mobility are threatened.

#### Research Needs for New Systems

The transport level of service required for developing human resources should be studied, and specifications developed for level of service, including resources available, constraints to be applied, and timetable for achievement. Given these specifications, alternative systems can be considered and policy decisions can be made as to how to proceed. The following are typical research needs for new systems that would provide direct benefits to human resource development.

1. Develop an urban home-to-work transport system that will provide a better level of service for 90 percent of the work force.

The movement of persons to and from work is creating most of the urban transport concern. Existing facilities are more than adequate in most urban areas to cope with traffic outside of the home-to-work and work-to-home timetable. Failure to identify the purpose of the transport may have led to proposed solutions which are not particularly suited to solving the basic problem, and a failure to consider some alternatives. When viewed as a home-to-work problem, the basic interest of the employer as well as that of the employee is more evident. Increasing taxation to provide home-to-work transport, costs for providing parking facilities, the requirement to pay the employee a sufficient amount to make the two trips daily, the fact that time of travel to work is not "free

time" insofar as individuals are concerned, and the absolute necessity of the trip to the employer suggests considerations leading to solutions in which the employer could participate. For example, the location of the Pentagon in an area of Washington, D.C. that was removed from the center of good public transportation produced a major requirement on the community for transport service, and a major requirement on the Department of Defense for parking space. There are no known analyses of whether the location of the Pentagon, or of the solution for transportation is optimum or the most desirable from either the Department of Defense or the employees' point of view or on the land use at possible alternative locations for the Pentagon. There is also no clear responsibility for conducting this type of analysis.

Most solutions to the urban transport problems are still treating transport as an "end". Estimates are made of transport (or mode) growth rather than estimating the needs of social objectives. In the example of the Pentagon, many alternatives exist if the nature of the requirement of the employer for employees is taken into consideration. Concern as to whether this would lead to specifying where an individual could live and work is not of serious consequence since this type of authoritarian approach does not exist under our government. Tax incentives, company-owned buses, transit costs paid by employer, and numerous similar solutions could lead to superior service to individuals in the work force, and at a lower cost to the employer.

The requirement that each social and economic program considers all of its sub-systems is not irrational. Moves in this direction have occurred in the Washington, D.C. area in 1968 and 1969, when the General Services Administration started requiring analyses of the housing accommodations in a proposed relocation of a Federal office. During the same period, a

major Federal building was authorized for construction in a Montgomery County, Maryland suburb along an already over-crowded highway facility. The possibility of the government providing special transport services is being discussed. The provision of parking facilities is now a requirement for new construction. Conceivably, an alternative would be an employer-sponsored transit system.

The following are additional research needs directed to specific home-to-work problems:

a. Develop a home-to-work transport system that provides 30 minute, or better, service to most employment areas in the urban community from a region of low-income residents, at a daily user charge of no more than one percent of the minimum daily wage.

Increasing the income for the lowest income group is a major objective of social programs at both the national and local levels. More adequate transport should assist in achieving this objective.

b. Develop and implement an employer incentive plan for improving the level of service of the transport of his employees for the home-to-work trip.

2. Develop and implement an emergency response system that can reach any point at any time in the community within ten minutes with the equipment and personnel needed to cope with the problem.

Medical, fire, and law enforcement emergencies arise which threaten the life and well-being of individuals in the community. Ground-based systems cannot respond as rapidly as needed during peak periods of usage or in congested areas. Furthermore, ground-based systems require more personnel and equipment for the same response time. An analysis of a given community can provide an integrated system of various modes to achieve the desired response.

3. Develop and implement a training program to accommodate a reasonable percentage of the low-income group for jobs in the design, construction, maintenance and operation of transport systems.

A wide range of skills is needed in support of the transport system. In some areas of construction, particularly in materials testing and construction control, a shortage of skilled employees exists. An increasing number of those with electronic skills will be needed. Extensive technical training is not available at the present time for low-income groups.

4. Develop and implement a transport system that provides a satisfactory level of service to cultural, recreational, educational, and hospital facilities of the community for the low-income group.

Problems of social mobility, racism, education, and medical assistance can be alleviated by the provision of transport to the many activities that improve the quality of life for individuals.

5. Develop limits and implement a new level of service for collecting and transporting trash and for waste disposal.

The character of the service required is partially understood, and the adverse effects of the present system can be readily identified. The solution will depend on an integrated plan for the ultimate disposal of the waste.

6. Develop and implement an improved level of transport service for law enforcement, shore and beach surveillance of waterways, and other patrol activities.

In addition to crime reduction, patrols for traffic flow and safety, and other surveillance activity can be improved by a well-conceived

inter-modal system. By incorporating improved communications, particularly from ground to air, a much more effective program can be developed.

7. Develop an improved level of service for neighborhood mobility and accessibility.

For new communities, better utilization of space can reduce the need for transportation. For many existing communities, few alternatives exist beyond the conventional highway-automobile system. The improvement of service must be sufficiently great to offset the availability of the necessary system for longer trips. Pedestrian-vehicle conflicts should be minimized.

8. Develop an improved level of service for freight distribution.

The existing system and pattern of distribution through shopping centers needs re-examining with a view to designing new transport systems and the optimum approach to retail outlets. The advantages to individuals of ready accessibility cannot be separated from the ultimate transport requirements. Failure to include the adverse indirect effects of the transport sub-system obscures the nature of the decision; that is, roads and streets are required in urban areas for freight distribution, as well as for person movements. Off-peak deliveries and new types of transport can be evolved from new requirements for level of service.

9. Develop improved level of service of transport for postal services.

While essentially a postal concern, the use of existing transport facilities and equipment provides an opportunity for an integrated attack to advance the goals of the postal service. Present plans for the use of telecommunications to reduce the amount of transport required is a desirable step toward replacing transportation. Distribution and collection can be enhanced by a combination of transportation and postal

services technologies. The desired level of service is controlled by policy and requirements of the postal service.

#### Research Needs for Transport Facilities

The following is a summary of the research needs that are non-modal in character, in the design, construction, maintenance and operations of transport facilities.

1. Develop analytic techniques and establish level of safety requirements for various modes in five-year increments.

The safety level achieved in transportation is a function of the resources available for this purpose. Safety measures are normally non-productive (that is, they do not generate physical resources) and expended funds from the public or private sector for safety, can be classified as expenditures for non-economic gain. The problem is not one involving the value of human life, but is a question of which resources can best maximize non-economic benefits. The minimum level of safety and the total public and private resources that are available should be established, in five-year increments, toward a twenty-year objective. Individual modes should then be given great flexibility in achieving the required level of safety.

2. Develop and implement measures of the behavior or performance of ground facilities.

Existing technology does not provide a basis for measuring the behavior or performance of ground-based facilities. In the absence of such measurements, there is no rational way to study the effectiveness of introducing innovative technology. Performance measures for structural characteristics and operational features do not exist. Problems

related to traffic flow, snow and ice, inclement weather, etc., are not being measured in objective terms that permit analyses of the transport system's over-all performance.

3. Develop analytic capability to incorporate the probability concept into measurements of level of service and social values.

Statistical theory and the application of frequency distributions and probability concepts have not been incorporated into transportation analyses as effectively as is needed. Data sampling and analyses (except for market research) are frequently based on over-simplified assumptions about the meaning of the data. Designing transportation advances will normally require studies of how to change frequency distribution patterns in one way or another. This applies to both the social values and to the level of service of transportation.

4. Develop methods for reducing construction costs of transport facilities without lowering the existing quality of construction.

Construction specifications for transport facilities call for economical construction and a concurrent effort to improve quality. The present measures of quality are inadequate insofar as it is possible to relate the quality to the behavior or performance of the facility. A statistically reliable reference should be obtained, and efforts directed to lowering the cost of the existing quality of construction. At such time as a quality improvement can be shown to produce a measurable improvement in performance, the question of higher quality can be effectively addressed.

5. Develop a cost-effectiveness approach to maintenance and operation of facilities, and implement.

The existing basis for measuring the priority for use of maintenance and operations funds for ground facilities is intuitive. This is because there are no standards for measuring the behavior or performance of facilities, and because of inability to predict the effect of maintenance expenditures on performance. Establishing levels of funding and allocating available funds to various functions are, therefore, based solely on judgment. A procedure that permits the evaluation of alternative ways to use funds would greatly increase the performance of the ground facilities for a given level of resources.

6. Develop and implement the capability of tunneling at an increased rate both for driving and lining of tunnel and excavating and supporting the cavity.

Major advances in tunneling and underground excavation will increase the alternatives which are available for transport facilities. A five-fold increase in rate is the first of a series of targets that can lead to a large reduction in costs of underground facilities. In addition to improving existing modes, improvement of tunneling would greatly increase the feasibility of pipelines.

7. Develop levels of service requirements that are possible through use of control systems to replace human operators throughout the transport system.

With rare exception, the use of automation has not progressed rapidly in the transport field. Throughout the construction, maintenance, and operation fields many activities could be improved through less reliance

on a human control system. Economy, as well as safety, reliability, and comfort could be achieved. Broad principles and minimum levels of service should be established so that the benefits can be derived from use of available technology.

8. Develop level of service requirements that will produce new materials and new applications of existing materials for transport facilities.

Imaginative levels of service and an adequate system of measuring behavior or performance of facilities will permit the application of modern technology to the development of materials and their application. These new levels of service can best be developed from a mode-independent approach, with each mode given autonomy as to the manner that the advance is achieved.

9. Develop mode interchange systems.

These transportation centers should provide for continuity of movement of people and goods regardless of mode, i.e., rail, rapid transit, bus, etc. Center city distribution and parking would be a necessary part of these centers.

## Chapter 7

## RESEARCH NEEDS OF TRANSPORT MODES

Research needs in the civil engineering phases of the several transportation modes have been studied by committees of ASCE over the past four years. Their efforts were a part of the over-all review of civil engineering research needs that was initiated by ASCE, the National Science Foundation, and Colorado State University in 1965. This chapter summarizes these committee efforts and additional available statements of research needs.

This review of modal needs is restricted to the major concerns of civil engineering technology. The needs are directed primarily to the planning, design, construction, maintenance of ground facilities, and to some phases of the operation of ground-based systems. This division creates the possibilities of inefficiencies and sub-optimization, but these problems can be avoided with increased cooperation between disciplines and continued efforts to integrate transport systems.

Transport modes have developed over the years as economic systems (39); that is, they are expected to produce economic returns. Social values have been viewed either as luxuries (beautification) or as services to society when economically feasible (safety, emergency services, park roads, etc.). Operated as utilities, the modes served those who bought their services, and special privileges or actions, which increased the cost to general users, were resisted. The development of modes that serve unique needs of individuals will require analyses of the type advanced in Chapter 6, and a means of financing some part or all of these special systems will need to be developed.

Changes in transport modes have come with dramatic suddenness, as well as with painful deliberateness. Garrison (29) has described two processes for "innovation" or change. One is finding a new way to do an old task, and the second is to describe a problem and find a way to solve the problem. The use of computers is a typical procedure of the first process, whereas landing a man on the moon was noted as typical of the second. Chapter 6 suggests the design of new systems by use of the second process.

The past studies of modal research needs, with the exception of the aircraft industry, have been dominated by the search for new ways to do existing tasks. These searches for increased efficiency have led to major economic gains in the past and attendant benefits to society.

In this chapter, these modes are discussed:

Air

Highways

Pipelines

Railroads

Waterways.

Included in Chapter 6 was a discussion of mode-independent research needs. A coordinated program between modes would be also highly desirable. Three of these are interrelated and fundamental to an efficient advance of individual modes:

1. Develop and implement measures of behavior (or performance) of ground facilities.
2. Develop methods for reducing construction costs of transport facilities without lowering the existing quality of construction.

3. Develop a cost effectiveness approach to the maintenance and operation of facilities and implement

With reference to the first of these, the behavior of some components can be numerically expressed, for example, portland cement concrete, steel, asphalt, and soil.

For the second and third studies, the development and implementation procedures for reducing construction costs and allocating resources for maintenance and operations requires the preceding measure of performance. In addition, construction, maintenance, and operation processes must incorporate probability concepts into sampling, testing, and evaluation. New construction specifications including probabilistic concepts are essential to achieving substantial cost reductions.

Present specifications for construction of facilities are outdated, being primarily guidelines for construction. They are not specifications in that they do not provide, in precise terms, the common intent of the purchaser and the seller. Advances introduced thirty years ago in the manufacturing industry have not yet been adapted. The existing sampling and testing programs (except in a limited number of applications in a few states) have been shown to provide little quantitative information on the character of the completed construction (40). Research in this area has been actively pursued for the past five to ten years (41, 42, 43, 44, 45, 46), and significant progress can be achieved if the results are implemented.

### Air Transportation\*

The civil engineer's interest in air transportation is primarily in the provision of ground facilities. These include terminals, large and small service buildings, airport drainage, roadways and parking, pavements for runways, taxiways and aprons, structures for communication systems, and access to the airport. Maintenance and operation of many of these facilities are also a part of the civil engineer's role. Inevitably, the planning of many phases, including the airport location and layout, requires close cooperation and liaison with other disciplines.

The possibilities of sub-optimization are perhaps more acute in air transportation than in any other mode. This is due, in part, to the dynamic and progressive attitudes of the aircraft and electronic industries which results in faster and larger planes, aircraft, and more sophisticated control systems for the airways. On the other hand, there is a much lower capability for producing rapid changes of the ground facilities. The future of air transportation will be greatly influenced by the effectiveness of the over-all analysis of the air system.

Air transportation is a broad and diverse field involving technologists from many sciences and professions. The broad problems in air transportation are new ones and do not fall conveniently within the scope of any one existing skill or profession. Thus, in identifying those research needs of relevance to the civil engineer, principal attention has been focused on determining what could and should the civil engineer

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\* Based on "Research Needs in Air Transportation", Report of the Research Committee, Aero-Space Transport Division ASCE, April 1969 (47).

contribute to this field rather than simply reviewing what he has been and is doing in it.

The following research needs will not repeat nor necessarily directly include many phases of research of a supporting nature included in Chapters 6 and 8. Many basic structural and material problems, for example, will be applicable to airport pavements and buildings.

Research needs were solicited and obtained from a wide segment of the air transport industry, including the following:

1. 1964 report of the Research Committee of the Aero-Space Division, ASCE (47).
2. Technical divisions of ASCE.
3. Questionnaire responses from airline and airport facilities planners and engineers.
4. Engineering Foundation Research Conference on Access to Airports (38).
5. Committee member solicitations from individuals in government, industry, and universities.
6. Review of the literature on air transport, including publications of ASCE, AIAA, SAE, ASME, HRB, FAA, and DOT.
7. Review of the Schreiver-Seifert report (48).
8. Review of 1968 ASEB report (49).

Table 7-1 contains a summary of the research needs reported by the Research Committee of the Aero-Space Division, ASCE. Detailed descriptions are included in the published version of that report. The following is a brief resume of the five major areas.

TABLE 7-1 Summary of Research Needs in Air Transportation.\*

- 
1. Planning for Desired Change (5)
    - . Planning Horizon
    - . Demand Forecasting
    - . Planning for Technological Change
    - . Air Transport Network Dynamics
    - . General Aviation Assistance Program.
  
  2. "Terminal System" Concepts (7)
    - . Regional and Metropolitan Airport Systems
    - . Airport Expansion versus New Airport
    - . Functional Airports
    - . Satellite Terminal Buildings
    - . Air Cargo Industrial Complex
    - . V/STOL Facilities
    - . Airport/Airspace Simulation Models.
  
  3. Air Transport Ground Traffic (7)
    - . Impact of Airport Traffic on Urban Freeways
    - . "Transit" for Airport Traffic
    - . Passenger and Baggage Flows: Functional Standards and Design Guidelines
    - . Analysis of Air Cargo Ground Movement
    - . Intra-Airport/Terminal Transport Systems
    - . Ground Movement of Aircraft
    - . Design for and Operational Control of Apron/Taxiway Traffic.
  
  4. Air Transport Ground Facilities: Analysis and Design (5)
    - . Space Allocation at Terminals
    - . Baggage Claim Area Design
    - . Air Cargo Facilities and Ground Systems Planning
    - . Fixed Facilities for Aircraft Servicing
    - . Control of and Protection from Pollution--Noise, Jet Blast, Fumes.
  
  5. Aircraft-Ground Interface (5)
    - . Runway/Taxiway Designs for Increased Capacity
    - . New Concepts of Aircraft-Ground Interfacing and Structures
    - . Economics of Pavement Structures versus Aircraft Interfacing Systems
    - . Runway/Taxiway Strength Assurance
    - . Runway/Taxiway Construction and Maintenance.
- 

\* From "Research Needs in Air Transportation", Report of the Research Committee, Aero-Space Transport Division, ASCE, April 1969, (47).

1. The first of the problem areas, Planning for Desired Change, has timely significance in that it is the result of efforts in this area - or the lack of effort - that determine, to a large degree, the range of options open in the other problem areas. The absence of air transport system development planning is a major cause of many present day problems in this field. Increasingly, much of the responsibility for system planning rests with the civil engineer. To be sure, there are broad social, economic, and political questions that range far beyond his professional scope. Nevertheless, the proven capabilities of civil engineers in system analysis, design, programming, construction and maintenance are an essential ingredient in the process of establishing system development programs. The research needs relating to Planning for Desired Change, point to the need for substantially increased activity in the area of system engineering and planning.

2. The second major problem area Terminal System Concepts is to be broadly interpreted to include the entire ground network of air transport-related facilities in an urbanized region and the interplay between this system and the region and its economy. A great deal of publicity has dealt with the problems of airport expansion, location, community impacts, access, etc., and there has been much talk of a wide range of possible cures for these various problems. The research needs singled out in this area relate to some of the more promising "cures" for these problems, and to the need for more rational bases for generating, analyzing, and evaluating such proposals. The focus must be on seeking causes and finding appropriate cures rather than the somewhat more

costly "expedient" of symptomatic fixes. Underlying most of these research needs is a broad deficiency in basic knowledge of the elemental processes and relationships of the "ground" portion of the air transport complex and its impacts. This inadequacy coupled with similar shortcomings in present analytical methodology help explain--at least in part-- why even many of the "new" solutions to these problems appear to be falling short of the mark.

3. The third problem area is Air Transport Ground Traffic. An airport, or airport complex, represents a unique and unusually broad variety of types of traffic flow and traffic processing elements. The individual research needs in this group concern some of these types of traffic. Much remains to be learned about each of them and how they interact as a basis for specifying and designing more satisfactory systems, facilities and devices for such traffic processes. What is clearly required is a much better understanding of these phenomena and a much broader perspective of analysis of air transport ground traffic problems.

4. Air Transport Ground Facilities pose two kinds of problems, design and analysis. The first is overcoming the inertia of traditional practices in developing and analyzing specifications for physical facilities, and, in subsequent evaluation, of alternative designs. Even after construction, it is not obvious which designs are "better" than others. People are quite adaptive, so that, if a facility is under-designed or inappropriately designed the error may be extremely difficult to detect. One might occasionally argue that inadequate capacity has occurred as a result of "unanticipated growth and vigor of demand". Yet clearly

this becomes a transparent excuse when invoked consistently through successive generations of new facility designs. This general problem is particularly acute in terminal systems, since processing rates are generally extreme, time values high and sensitive to delay and discomfort, and space costs are at a premium. In short, efficiency from the viewpoints of facility users and operators is extremely important.

The second problem underlying this class of research needs is that of analysis. There is an apparent lack of a feedback mechanism ("performance measures") for scrutinizing, in follow up analyses, the "function of the form in practice" as a prerequisite to accepting the design of existing facilities as the norm for future designs. Too often errors of design continue to be passed from generation to generation. In a field as subject to rapid technological innovation as air transport, the consequences of continuing to apply traditional patterns of design and analysis are most likely to add to the present problems.

5. The fifth area of research need is the Aircraft-Ground Interface. Runway and taxiway system capacity is now as serious a bottleneck in the air transport system as is air traffic control. Intensive efforts need to attempt to reduce the time aircraft are on the runway. There are numerous possibilities for marginal improvements within the context of the traditional approach to take-off and landing of wheeled aircraft. What may prove to be substantially more beneficial--in terms of capacity, and ultimately perhaps even from a cost point of view--would be basic alterations in the aircraft-ground interface process. Airport pavements--runways and taxiways--are becoming increasingly complex structural systems as aircraft sizes and traffic volumes continue to increase. Therefore,

substantial efforts are required both for improving present methods, materials, and designs as well as for developing new interfacing concepts.

### Highways

The civil engineer is thoroughly involved in practically all phases of highway transportation, except perhaps vehicle design and manufacturing, and policing of highway operations. Major technical problems (surveying route locations, design of pavements and bridges, and the controlling requirement for a roadway over which to operate) led to the involvement of the civil engineer in activities ranging from planning and financing to traffic control and safety.

With the steady increase in automobiles and trucks, increases in population, and the corresponding increase in numbers of drivers and vehicle-miles of travel, the pressure for more highway facilities has mounted continuously. As a result, the technical problems of the civil engineer shifted suddenly from the historic rural location and pavement and bridge design to the total problems of urban areas and to traffic flow and safety problems involving human behavior.

Highway transportation, as a result, now involves practically every scientific discipline. The civil engineer, however, must still provide and maintain the facility, and so finds himself in serious need of interdisciplinary efforts.

Sub-optimization is a problem, also, for highways. The trend, in the past, to divide the responsibility into highway-driver-vehicle components, has led to little coordination in evolving a unified system. In fact, up until the formulation of the Federal Highway Administration, the Department of Transportation, in 1966, there was no single government

agency with total interest for highway transportation. Prior to that time, the responsibility of the Bureau of Public Roads was almost exclusively with the provision of the facilities over which the vehicles would move.

Highway transportation is also characterized by the decentralization of responsibility. Historically, roads have been a local responsibility. Vehicles have been the concern of the private sector. Policing operations have been a matter for the highway patrol or the state or community police. Integration of these efforts into a combined activity to meet the interests of the community are of a relatively recent origin.

The following summary of research needs concentrates on modal requirements. Many of the fundamental studies of Chapters 6 and 8 are not specifically included, but are nonetheless a part of the highway research needs.

The Research Committee of the Highway Division, ASCE, reported on research needs in June 1968 (50). This report included a summary of the national program of the U.S. Bureau of Public Roads as a typical over-all program of research needs. Subsequently, Report 55 of the National Cooperative Highway Research Program (NCHRP) was published, which contained an analysis of highway research needs (51).

The ASCE committee report provided a broad structure for highway research as shown in Figure 7.1. In Table 7-2, there is a summary of the U.S. Bureau of Public Roads research needs, referenced in the committee report.

The NCHRP report (51) produced a summary of 900 proposed research project statements developed from the files of the Highway Research Board and from discussions with authorities in the highway field. The

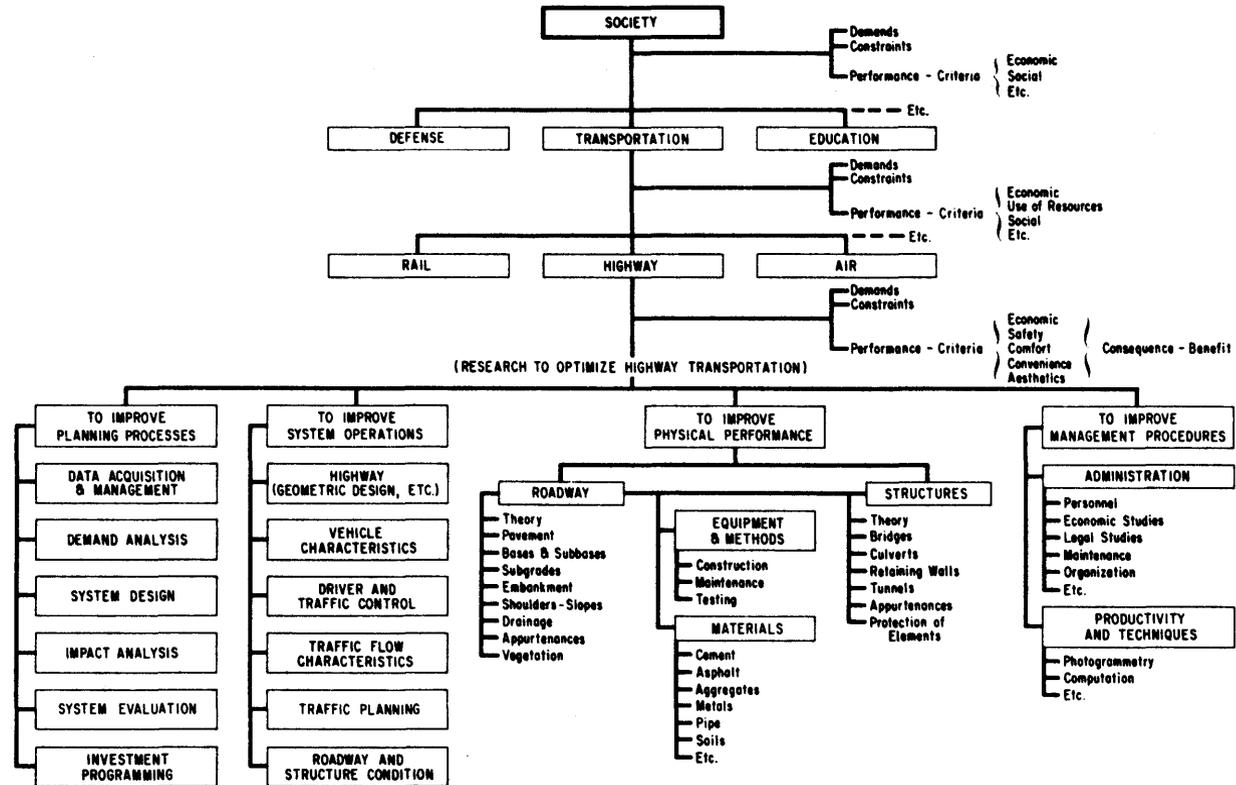


Figure 7.1 Structure for Needed Research in Highway Transportation (50)

TABLE 7-2 Research Needs in Highways\* (BPR)

THEORETICAL OR BASIC RESEARCH

## To Improve Planning Processes

- Project 1 - Factors Underlying Choice of Transportation.
- Project 2 - Economic Models of Urban Transport Efficiency.
- Project 3 - Analysis of the Functions of Transportation.

## To Improve Systems Operations

- Project 1 - Stream Flow.
- Project 2 - Network Flow.
- Project 3 - Driving Processes.

## To Improve Physical Performance

- Project 1 - Material Characteristics and Behavior.
- Project 2 - Dynamic Stresses in Structural System.
- Project 3 - Streambed Stability Adjacent to Structures.
- Project 4 - Behavior of System Components Under Cyclic Stress.

APPLIED RESEARCH AND DEVELOPMENT

## To Improve Planning Process

- Project 1 - Economic Consequences of Highway Transport to the Road User (Transport Decision Model).
- Project 2 - Effects of Highway Investments on Local Economies (Economic Impact).
- Project 3 - Underlying Factors in Urban Transportation Analysis.

## To Improve System Operation

- Project 1 - Accident Prevention and Minimization.
- Project 2 - Improved Utilization of High-Speed Highways.
- Project 3 - Improved Performance Under Adverse Environmental Conditions.
- Project 4 - Optimization of Flow on City Streets.

## To Improve Physical Performance

- Project 1 - Optimum Design Concepts for Bridges and Pavements.
- Project 2 - Prediction of Performance of Present Structural Designs.
- Project 3 - Criteria for Bridges and Pavements of the Future.
- Project 4 - Improved Performance, Economy, and Durability of Materials and Materials Systems.
- Project 5 - Improved Utilization of Natural Materials for Highway Construction.
- Project 6 - Protection Against Natural Hazards.
- Project 7 - Utilization of Fundamental Properties of Materials for Specifications as Related to Performance.

(Continued)

TABLE 7-2 Research Needs in Highways\* (BPR) Continued

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To Improve Physical Performance - (Cont'd.)

Project 8 - Construction Processes and Control.

Project 9 - Maintenance Operations and Management.

To Improve Management Procedures

Project 1 - Total Integrated Engineering System.

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\* A list of research needs advanced by the U.S. Bureau of Public Roads and listed in the Appendix to "Research Needs of Highway Transportation", Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 94, HW1, June 1968 (50).

approach advanced in the study requires the establishing of goals to which a research program can be addressed. For the goals assumed for the study, a program was developed, involving 253 projects in 13 problem areas. The goals and problem areas are summarized in Table 7-3.

More detail on the program of the U.S. Bureau of Public Roads was issued September 20, 1965, and is included in Appendix B. A comprehensive plan where each of the objectives is to be pursued has been developed by Bureau staff.

A detailed listing of specific highway problems was developed in the NCHRP study (51). Appendix C contains 253 project statements out of a total of 900. This listing includes those studies that were most responsive to the goals and problem areas that are included in Table 7-3.

Two subject-areas of importance to highway research are urban planning and safety. The transportation planning phases of civil engineering are included in Chapter 6 and in the programs of the Bureau of Public Roads and the NCHRP (Appendices B and C). The broader urban planning concerns are included in the major area of civil engineering research, titled "Environmental Engineering", and discussed in Chapter 8.

The civil engineering phases of highway safety are included in the summary of research needs of the Bureau of Public Roads and NCHRP. Many additional problems exist in highway safety (80), but only those that are closely allied to civil engineering are included.

#### Pipelines\*

All phases of the location, design, construction, maintenance and operation of pipelines are of interest to the civil engineer. As the

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\* Based on "Research Needs in Pipeline Engineering for the Decade 1966-1975", Committee on Research, Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 93, No. PL2, July 1967 (52).



TABLE 7-3 Research Needs in Highways\* (NCHRP) Continued

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Highway Transportation Research Goals -

3. To foster the integration of the highway with the community through improved identification and quantification of sociological, political, economic and aesthetic factors in highway transportation.

Problem Areas - (Cont'd.)

1. Aesthetic considerations in the design, maintenance, and operation of highways.
  2. Impact of various types of highway features upon environmental values.
  3. Accommodation of multiple use of right-of-way in urban areas.
- 

\* From "Research Needs in Highway Transportation" by Bertram D. Tallamy and Associates and Wilbur Smith and Associates, NCHRP Report 55, Highway Research Board, 1968 (51).

primary engineering discipline for construction in many industries utilizing pipelines, the civil engineer has worked closely with other technologies in all phases of the planning and management required for piping of energy sources and commodities from one point to another.

Within the total field of transportation, pipelines more than any other field has suffered from sub-optimization. For example, coal slurry was piped as early as 1914, but there is still very limited use of pipelines for solid materials. In light of its inherent advantages, lack of research and financial support has undoubtedly contributed to the lack of development of transport functions by pipelines.

In addition to the following summary of research needs, fundamental questions and technical problems in hydraulics, structures, soil mechanics, and other areas are included in Chapters 6 and 8.

Research needs for pipelines were developed by a 16-member ASCE committee composed of researchers and engineers from universities, research institutes, and several different industries allied to pipeline transportation. A bibliography (53) prepared by a second task committee is also of value in comprehending the nature of the research needs.

The following eleven areas, summarized in Table 7-4, were advanced for the 1966-1975 period:

1. Pipeline location
2. Design methods
3. Materials
4. New Construction Techniques
5. Pipeline, Railroad, and Highway Crossings
6. Pipeline Flotation

TABLE 7-4 Research Needs in Pipelines (52)

- 
1. Location
    - a. Electronic Surveying and Data Instruments
    - b. Photogrammetric Equipment and Methods
    - c. Geological Conditions and Investigations
    - d. Survey Control and Coordinate Systems
    - e. Cooperation with Other Utilities
  2. Design Methods
  3. Materials
    - a. Rigid Materials
    - b. Flexible Materials
    - c. Nonhomogeneous Combinations of Materials
    - d. New Product Research for Transporting
    - e. Fluids (Non-compressible)
    - f. Gases
    - g. Solids
  4. New Construction Techniques
  5. Pipeline, Railroad and Highway Crossings
  6. Pipeline Flotation
  7. Submarine Pipelines
    - a. Hydrodynamic Forces on Submarine Pipelines
    - b. Deep Water Pipelines
    - c. Requirements for Design of Submarine Pipelines
  8. Testing
    - a. Destructive
      - 1) Field
      - 2) Laboratory
      - 3) Mill-Plant Production Test
    - b. Non-destructive
      - 1) Pressure Test
      - 2) Radiographic
      - 3) Ultrasonic
      - 4) Leakage
  9. Unconventional Applications
    - a. Unusual Operating Conditions
      - 1) Cryogenic Service
      - 2) Extremely High Pressure
      - 3) Unique Method of Reducing Flow Resistance

(Continued)

TABLE 7-4 Research Needs in Pipelines (52)- Continued

- 
9. Unconventional Applications - (Cont'd.)
    - b. Solids Transmission
      - 1) By Compressible Fluid - Gas, Air, etc.
      - 2) By Non-compressible Fluid
    - c. The Pipeline as a Pneumatic Tube
      - 1) By Compressible Fluid
      - 2) By Non-compressible Fluid
    - d. Pipeline as a Process Plant
      - 1) Solids Transmission in Liquid Stream
      - 2) Mixed Liquid Stream
      - 3) Mixed Gas - Liquid Stream
  10. Automation and Computation
  11. Electronic Computer Application
-

7. Submarine Pipelines
8. Testing
9. Unconventional Applications
10. Automation and Computation
11. Electronic Computer Application.

The following is a brief description of these areas of research.

1. Location

A common denominator of all pipeline research, regardless of what is being transported, is that of pipeline location. It is of prime importance when considering economic feasibility of providing service or supplies to a new area. A better knowledge of the terrain, subsurface conditions, techniques, and requirements of location will make possible the opening of new markets previously thought to be uneconomical because of the difficulty of proper pipeline location.

In order for technical art to advance and keep pace within the over-all research program, it will be necessary to study, develop, and improve on the following activities.

- . Electronic Surveying and Data Instruments
- . Photogrammetric Equipment and Methods
- . Geological Conditions and Investigations
- . Survey Control and Coordinate Systems
- . Cooperation with Other Utilities.

2. Design Methods

Included within this research area is a preliminary plan for the standardization of design methods for pipelines. Within this realm are all of the transportable products and the many types of materials utilized for the pipe structural make-up. The needed research

encompasses extensive reviews and listing of the standards presently in use. It also includes the categorizing of areas requiring standardization with the ultimate objective of promoting new standards for improving the economics of pipeline transportation and improving safety to the general public.

### 3. Materials

The over-all objectives of this research are to perform the public service of compiling a ready reference for presently used materials, including their design formulae, safety factors, and methods of manufacture, and researching and developing possible new materials. This research will assist in replacing areas of ignorance with engineering information available in one compilation, and to develop better and more economical pipe materials for the transporting of fluids, gases and solids, in the following areas:

- . Rigid Materials
- . Flexible Materials
- . Nonhomogeneous Combinations of Materials
- . New Product Research for Transporting
- . Fluids (Noncompressible)
- . Gases
- . Solids.

### 4. New Construction Techniques

This area includes research in a continuing three-phase program:

Phase One: As new materials, techniques, equipment and construction methods evolve, addition to and modifications of, existing construction specifications for finished pipelines should be prepared.

Phase Two: Included in this phase are development of possible improvements to existing methods and of new ideas and techniques. Studies of construction stresses, under present-day techniques, are needed. Stress levels determined in this phase will serve as part of a "grading system" suggested for use in phase three.

Phase Three: This work will consist of on the job tests of new or improved techniques. In order that objective tests be made, a special test spread is needed to evaluate new techniques.

#### 5. Pipeline, Railroad and Highway Crossings

This research area includes a continuation of the present studies that have been accomplished by the Pipeline Division's Committee on Railroad and Highway Crossings. The Committee has established and published data completed from and by several organizations. The Committee was organized to provide specifications covering conduits under railways and highways transporting all types of materials. In 1959, a Research Council was formed that initiated studies to obtain fundamental data to be used by the Committee for designing casings and uncased carrier pipe crossings.

Additional test data are needed for larger pipe sizes in order to establish the experimental basis for a specification on uncased pipeline crossings and casings. To supply this information, the Research Council recommends additional research during the next 10-year period. The specific objectives are:

- a. To determine the stresses in pipe caused by (1) static application of simulated highway loads (flexible and rigid pavement), (2) static application of simulated railroad loads, (3) combination of the above with internal pressure, (4) dynamic application of railroad

loads, and (5) cumulative effects of a large number of cycles of railroad loads.

b. To determine the variation of stresses caused by the loads listed above as a function of depth of cover.

c. To determine soil pressures as a function of the variable listed in items a and b above.

## 6. Pipeline Flotation

This research area includes a continuation of the present studies that are being accomplished by the Pipeline Division's Research Council on Pipeline Flotation. After a period of study as a committee since 1959, actual research was initiated in 1965 and the committee changed to a Research Council. The studies are being made to consider the effect of a pipeline that has been installed and is subjected to the forces induced by inundation of the soils in which the pipe is embedded.

The over-all objective of the Council is to develop and investigate design criteria that can lead to a rational determination of the necessity for and amounts of weighting required to control pipeline flotation. The benefits will be (1) lower costs of construction and operation of pipelines through inundated areas, (2) to establish design methods on a definite engineering basis, and (3) to devise new methods of flotation control.

## 7. Submarine Pipelines

Research in this area includes studies of the external effect of the submarine pipelines' environmental climate on its stability during construction and for its intended lifetime use. The state of the art to date is in its infancy, while the use of submarine pipelines

is becoming a necessity for offshore mineral recovery. The purpose of the research is to improve the design criteria and construction techniques for submarine pipelines. The ultimate objective is to improve the economics involved in deep-water mineral recovery, improve safety conditions and standards, and discover new techniques and methods of energy transmission via aqueous conduits. Major areas are:

- . Hydrodynamic Forces on Submarine Pipelines
- . Deep Water Pipelines
- . Requirements for Design of Submarine Pipelines.

#### 8. Testing

Of vital importance to the pipeline industry is the capability of assuring the operation and structural integrity of pipeline systems. This is important from the standpoint of public safety and economics involved with pipeline failures. This area of testing is devoted to the following major areas:

- 1) Destructive
  - Field
  - Laboratory
  - Mill-Plant Production Test
- 2) Nondestructive
  - Pressure test
  - Radiographic
  - Ultrasonic
  - Leakage.

#### 9. Unconventional Applications

This area encompasses the fertile field of research based on the unlimited use and applications of pressure and temperature for

improvement of transmission of commodities. Also included herein is the necessary preliminary research for the unusual pipe materials and insulations required in these special applications. The intent of this research is to promote new concepts that will ultimately reduce the transportation cost of many commodities with the ensuing economic benefit to the public. Major areas are:

- . Unusual Operating Conditions
  - (a) Cryogenic Service
  - (b) Extremely High Pressure
  - (c) Unique Method of Reducing Flow Resistance
- . Solids Transmission
  - (a) By Compressible Fluid - Gas, Air, etc.
  - (b) By Noncompressible Fluid
- . The Pipeline as a Pneumatic Tube
  - (a) By Compressible Fluid
  - (b) By Noncompressible Fluid
- . Pipeline as a Process Plant
  - (a) Solids Transmission in Liquid Stream
  - (b) Mixed Liquid Stream
  - (c) Mixed Gas - Liquid Stream.

#### 10. Automation and Computation

This research area includes studies into the automatic operating data-acquisition methods and the accuracy of such systems. The purpose of this research area is to improve operating efficiencies and reduce the per unit cost of the commodities transported. One of the prime objectives of this part of the research program is to define the problems and establish definite parameters for the work.

## 11. Electronic Computer Application

These studies include investigations into the application of modern problem solving techniques to pipelines; including Monte Carlo Technique, Queueing Theory, and Linear Programming Techniques. Feasibility of their application to problems of pipeline design, maintenance, and operation will be conducted. The improvement of electronic computation techniques and programs will benefit the public from the standpoint of reduced cost of the design, construction, and maintenance operations.

### Railroads

As much as any area of transportation, railroads have been of historic interest to civil engineers in all phases of the location, design, construction, and maintenance of all types of railroad facilities. Over the years, civil engineers have become involved with the management, planning and operations as well. Railroad transportation is an activity requiring many disciplines other than civil engineering, however, and interdisciplinary efforts are normal.

Railroads are primarily a free enterprise operation under government control. Accordingly, research, new systems, and indirect effects have been necessarily constrained by requirements to pursue economically profitable undertakings. The combination of sub-optimization for various modes of transportation, high costs of innovations, government control, and conservative management, have resulted in less expansion of railroads, than, for example, in the free enterprise, but government-controlled, program for telephone service. The recent participation of the Federal Government in research and the increased interest in

furthering broad transportation goals is promising to eliminate adverse sub-optimization.

In addition to the following, civil engineering research needs for railroad facilities and operations are included in the fundamental problems that are listed in Chapters 6 and 8.

The primary sources of civil engineering research needs for railroads were a 1963 Committee Report (54) of the National Academy of Sciences and a report (55) to the Congress by the Office of High Speed Ground Transportation (OHSGT), U.S. Department of Transportation.

The summary of the OHSGT program for research needs, included in Table 7-5, covers all areas of research, even though some problems will be the primary responsibility of other disciplines. The following is a brief description of the major areas of research contained in the Congressional statement:

1. Systems Engineering
  2. High Speed Railroad
  3. Unconventional Transportation Systems
  4. Advanced Technology
  5. Demonstrations
1. Systems Engineering\*

"The rapid advance of technology in recent years provides a base for developing transportation systems that would be faster, more efficient, and more comfortable than present ones. The system engineering .... will provide information essential to determining what systems and what combinations of systems could serve to meet future transportation needs in urbanized regions of the United States."

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\*Reference 55, p. 21.

TABLE 7-5 Research Needs in High Speed  
Ground Transportation\*

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SYSTEMS ENGINEERING

Systems Engineering  
Procedures

Tech. Evaluation of Systems  
Engineering Proposals

Effect of Capacity on Operating Cost

Parametric Cost Model Theory

HIGH SPEED RAILROAD

Research Car Field Testing Program

Simulation of Test Track Operations

Design and Operation of Test Car Instrumentation

Rail Vehicle Dynamics

Use of Plasma Torch to Increase Adhesion

Wheel Rail Dynamics

Vehicle Suspension and Guidance

Active Suspension Feasibility

Dynamic Simulation of Suspension Systems

Dynamic Simulation of Auto Train Suspension

Experimental Track Structures

Computer Simulation of Track Structure

Research on Use of Polymers for Stabilizing RR Ballast

Vehicle Drive Systems

Gas Turbine Electric Propulsion System

New Drive Systems

Other Rail Related R&D

Feasibility of Auto Train Equipment

Wind Tunnel Testing of Freight Car Aerodynamics

Develop Surveillance Equipment for Rail Cars

Track, Wheel, Axle and Wheel

Profile Engineering

Potential Use of Linear Electric Motor as  
Booster for Locomotives

(Continued)

TABLE 7-5 Research Needs in High Speed Ground  
Transportation\* - Continued

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UNCONVENTIONAL TRANSPORTATION SYSTEMS

Tracked Air Cushion Vehicle

Self-stabilized Air Cushion Vehicle

Air Cushions

Potential of Flexible Diaphragm Air Cushion

Investigation of Air Cushion Seal Materials

Tube Vehicle Systems

Feasibility of Cryopumping

Feasibility of Air-Supported Vehicles in a Non-Evacuated  
Tube and Micro Wave Transmission

Aerodynamics of Tube Vehicle Stability

Drag of Vehicles in Tubes

Research in Aerodynamic Drag

Long Tube Resistance to High Speed Vehicles

ADVANCED TECHNOLOGY

Communication and Control

Feasibility of Surface Wave Guide Transmission Line

System Control Requirements

Coupled Waveguide Systems

New Communications Devices

Power Collection

Simulation

Non-Contact Method

Obstacle Surveillance

Laser Beams

New Detection Methods

Linear Induction Motor

Feasibility of Linear Induction Motors in HSGT

Feasibility of Advanced Electric Systems

Lateral Stability of Test Vehicle

Magnetic Suspension

Preliminary Research

(Continued)

TABLE 7-5 Research Needs in High Speed Ground  
Transportation\* - Continued

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ADVANCED TECHNOLOGY - Cont'd.

Tunneling

Feasibility of Tunneling by Flame Jet  
 External Augmentation of Velocity of Fluid Jets for Tunneling  
 Research in High Pressure Water Jet Delivery Optimization  
 for Tunneling  
 Soil Mechanics and Chemical, Thermal and Laser Techniques for  
 Rock Fracture  
 Rock Tunneling by Water Jets Using Cavitation Principle  
 Tunneling Research Requirements  
 Hypervelocity Fluid Jet Driver-System  
 Correlation of Rock Properties to Fracturability  
 Rock Breakage by Light-Gas Guns Firing Liquid Pellets

DEMONSTRATIONS

Lease of 2 Turbo Trains  
 Airport Access  
 Data Collection Activities  
 Auto-Train Demonstration

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\* From "Statement in Explanation of Request for High Speed Ground  
 Transportation Legislative Extension", Office of High Speed Ground  
 Transportation, U.S. Department of Transportation, May 28, 1968.

## 2. High Speed Railroad\*

"High speed railroad research and development [is needed] in order that the potential of wheel-supported concepts may be explored fully before major decisions are made on radically new systems. Rail passenger service will benefit from these efforts as will the future development of rail freight transportation, whether or not totally new systems are ever built . . . . In order to evaluate and advance wheel-rail technology within the broad framework of long-range needs, the underlying phenomena of rolling support and guidance, the theory of track structure behavior, and the application to this area of modern technology from other fields [needs to be studied.] Very little fundamental data exist on the physical phenomena involved in rolling support and wheel-rail interfaces, especially at high speeds. Such knowledge is necessary for analysis of current test results and for simulation of future operations."

## 3. Unconventional Transportation Systems\*\*

"A need exists to determine the relative advantages of improved existing systems and unconventional systems in meeting future transportation needs. Much of this work is, therefore, directed toward defining promising new transportation system alternatives.

The Office of High Speed Ground Transportation has concentrated research in unconventional systems, the past few years, on high speed tracked (or guided) air cushion vehicle systems and tube (or enclosed

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\*Reference 55, p. 23.

\*\*Reference 55, p. 27.

guideway) vehicle systems. Both offer promise for operation well above 250 miles per hour. The tracked air cushion vehicle (TACV) systems can be brought into operation earliest. Initiation of research on other novel systems will depend on the results of systems engineering studies.

A major reason for research on tube vehicle systems is the possibility of attaining high speeds with relatively low power consumption. In addition, tubes can provide all-weather operation, increased safety, reduced use of surface right-of-way, and can accelerate faster.

No base of experience exists for high speed vehicles operating in tubes. Thus, research and development is needed before the potential of tube vehicle systems can be estimated."

#### 4. Advanced Technology\*

"High speed ground transportation systems can be no better than the sub-systems of which they are composed, the construction methods by which they are built, or the materials of which they are made.

This research and development is being carried out, then, in the following major areas: guideways, communications and control, power collection, obstacle detection, linear electric motors, and magnetic suspension, and planning for a high speed ground transportation test facility.

Significant advantages are to be gained by the use of sub-surface routes for HSGT systems. Unfortunately, present costs for tunnel construction tend to make tunnels less attractive economically than surface routes. Wholly insufficient efforts have been devoted in the past,

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\*Reference 55, p. 29.

either by government or by industry, to advancing scientific and engineering knowledge of tunneling. Advancements in tunneling technology create many possibilities for the future development of economically feasible sub-surface systems.

High speed ground transportation will require improved communications to maintain safe and efficient operations. Unfortunately, there are an insufficient number of radio frequencies available to provide the necessary level of communications capacity. Research is therefore being carried out in nonradiating communications to determine their feasibility for HSGT systems.

For speeds more than 200 mph, it is apparent that a stiff contact-rail approach or a noncontact technique for electric traction power pick-up is necessary. Studies have been performed on noncontact electric energy transfer. This work evaluates possible techniques for transferring large amounts of electrical energy without physical contact, such as through induction or arc plasma transfer. Results so far are not encouraging for the early use of noncontact methods.

Safety is one of the most vital aspects of an HSGT system, since the consequences of accident are more serious at higher speeds. HSGT systems must, therefore, employ a separate guideway having no crossings at grade. It may be necessary to have an obstacle detection system protecting against possible collision with foreign objects on the guideway to guarantee the safety required by the speeds envisioned for HSGT. Obstacle detection systems may have application to conventional railroads as well.

Propulsion of ground transportation vehicles is typically accomplished by transmitting power through axles and wheels to a roadway or

rails. This method requires adhesion for the vehicle to accelerate or decelerate. To eliminate the need for adhesion for wheeled vehicles, or to propel an air cushion vehicle, research has centered on linear electric motors. Propeller driven and turbo-jet engines also eliminate the requirement for adhesion, however, they are less desirable because they are noisier, not as safe, and create more air pollution.

Magnetic suspension is being evaluated for use in those applications where neither wheels nor air cushions are feasible. A high speed vehicle operating in an evacuated tube may be one case where a magnetic suspension system is required."

#### Demonstrations\*

"Congress authorized demonstrations on finding that there is insufficient information about traveler needs and desires, particularly in intercity movements, to provide a sound basis for public and private investment policies. Within this broad context, there may be cited two specific and immediate uses for the data generated by demonstrations.

One is input for the Northeast Corridor Transportation Project. The information on public response to improvements in railroad intercity passenger service will shed light on the contribution that rail transportation can make toward meeting the need for additional transportation facilities in densely populated urbanized corridor-type areas around the country. In addition, by providing detailed analysis of public preference, shown by actual use and by payment for varying combinations of service, the demonstrations will indicate the relative weight of individual service components in attracting public patronage.

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\*Reference 55, p. 35.

The demonstrations will evaluate the influence of speed, schedule frequency, terminal convenience, comfort levels, fare structure, and will identify the relative impact of each on public acceptance. Since these basic elements of service are common to all modes of passenger transportation, the results of the corridor rail passenger demonstrations will be important in determining passenger preferences for all modes.

The second immediate application of information produced by the demonstrations is to indicate the limits of economic viability and customer acceptance of improved railroad passenger service over the country as a whole. The findings would provide a more up-to-date and realistic determination of the capacity of the present railroad network to meet new needs by testing, under revenue service conditions, the reliability of and traveler reaction to the latest in existing railroad technology."

In addition to the relatively current report of the U.S. Office of High Speed Ground Transportation, a 1963 summary of research programs, provided in Reference 54, is included in Appendix D. In an informal communication (56), the nature and causes of "shelling" of rails, relation between vertical load on the rail and the diameter of the wheel, equipment to locate internal defects in the rails, and the following problems were noted as requiring research:

1. Weighing freight cars in motion while they are coupled together.
2. Track profile gage and alignment measuring equipment.
3. Automatic car identification.
4. Rolling resistance of cars in classification yards.

5. The effects of 4-axle trucks on curves.
6. The cyclic rolling of some of the large cars, particularly on curves.
7. Determination of track maintenance by electronic computers.
8. Repeated load strength of prestressed and reinforced concrete under high-speed impact loading.
9. Nondestructive testing of wood.
10. The relation between the depth of bridges and their span.

### Waterways

Civil engineers play an important part in waterways in the provision of facilities, development and maintenance of channels in navigable streams, protection of coastal and river shorelines, and provision of navigational aids. As for the other phases of transportation, many other disciplines are required to provide the desired services; interdisciplinary efforts are needed.

Questions of possible sub-optimization arise from conditions created by the competitive nature of freight transportation and from the division of responsibilities. The development of ships, ports, harbors, streams, navigational aids and labor relations has been accomplished under various government agencies and parts of the private sector. The interface with other modes of transportation has also produced split responsibility. Due to the low cost of transport by waterways, a continued search is warranted for effective methods to improve the service.

Many of the research problems in this area are included in the general policy problems of Chapter 6 and in the basic programs of

Chapter 8. The overlap between transportation and water resources also leads to some relevant research being listed in the major area of "Water Resources Engineering".

The sources for the civil engineering research needs in waterways were preliminary reports of Committees of the Waterways and Harbor Division of ASCE (57).<sup>\*</sup> Some of the following items do not bear directly on transportation but are included as being part of the overall waterways and coastal engineering picture.

The research program is divided into the following four major areas:

1. Coastal Engineering
2. Ports and Harbors
3. Navigation and Flood Control
4. Regulation and Stabilization of Rivers.

Table 7-6 provides a summary of the program. The details on the programs will be contained in the report on "Research Needs for Water Resources Engineering" (58) and are not repeated herein. A brief summary of the programs is contained in the following sections.

1. Coastal Engineering

This area is concerned with problems related to stabilizing and improving shores, inlets, and estuaries from adverse effects of waves, tides, and storm surges. Shore protection, coastal storm protection, navigational channels and coastal structures are involved. More precise engineering knowledge is needed to meet the complex problems created by (a) the increase in population in the coastal area, (b) the large bulk of foreign and interstate commerce that utilizes

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<sup>\*</sup>Committee did not provide a complete report.

TABLE 7-6 Research Needs in Waterways (58)

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1. Coastal Engineering
    - a. Wave action in coastal waters
    - b. Shore processes
    - c. Tides and surges
    - d. Inlet studies
    - e. Estuary studies
    - f. Structure design in coastal areas
    - g. Effects of actions by man
    - h. Perfecting of improvement methods
  
  2. Ports and Harbors
    - a. Improvements in predicting and controlling waves, currents, and shoaling in harbors.
    - b. Improvements in anchoring and docking methods and facilities.
    - c. Improvements in cargo packaging, handling, and storage.
  
  3. Regulation and Stabilization of Rivers
    - a. Hydraulics and mechanics of flow in alluvial channels.
    - b. Materials in transport in alluvial channels.
    - c. Effect of stream flow regulation on alluvial channels
    - d. Use of dikes of regulation and bank protection.
    - e. Use of revetments for bank protection and stabilization.
    - f. Effects of dredging and spoil placement on alluvial streams.
    - g. Improvement in use of movable bed hydraulic models to study alluvial channels.
    - h. Elimination of obnoxious aquatic plants from alluvial channels.
  
  4. Navigation and Flood Control
    - a. Scientific Hydrology
    - b. Precipitation
    - c. Snow and Ice
    - d. Streamflow
    - e. Lakes
    - f. Erosion and Sedimentation
    - g. Effects of Man's Related Activities on Water
    - h. Watershed Protection
    - i. Techniques of Planning, Evaluation, and Cost Allocation
    - j. Water Law and Institutions
    - k. Non-Structural Alternatives for Flood Damage Prevention
    - l. Data Acquisition and Processing
    - m. Design of Engineering Works
    - n. Materials for Engineering Works
    - o. Construction, Operation, and Maintenance of Engineering Works
-

waterways, (c) the greater use of coastal areas for recreation, and (d) the increase in the draft of vessels since World War II.

## 2. Ports and Harbors

Problems in this area are related to planning, designing, maintaining and operating ports and harbors. The tendency to treat each port or harbor as an individual case has not led to the development of a unified theory or the best use of past experience. Urgently needed for the planning and designing of future ports and harbors is a program of research that would (1) collect, classify and organize available data, (2) develop methods of analysis to fill gaps in present knowledge, and (3) rationalize and normalize criteria and codes for design.

## 3. Regulation and Stabilization of Rivers

Included in this area are problems concerned with alluvial channels, including hydraulics of flow methods of controlling and stabilizing channels, regulation of high and low flows, and control of noxious plants. The development of rivers and their flood plains has led to the use of various means for control of flow and realignment of channels. Actions to control the river flow has had long-term adverse effects, many of which are just being felt. Interrelations of channel cross-section, velocity, sediment load, type of alluvial bed and flow hydrograph are poorly understood, but are necessary for regulating and stabilizing rivers.

## 4. Navigation and Flood Control

This research includes problems in the development of inland waterways and the control of floods and rivers. Though diverse in purposes, the two areas are closely related at the practical level.

The need for research can be traced to the steadily increasing use of inland waterways for shipping. The rapid growth of traffic using the Great Lakes, coastal harbors and channels, and inland and intracoastal channels has generated the need for enlargement, extension and modernization of many of the waterways. Flood control problems are related to both transport and non-transport effects. Much of the research needs for flood control are for reducing the social and economic costs of floods. Nonetheless, the solution to the problem of control of river flow will have a significant effect on transport by inland waterways.

## Chapter 8

## RESEARCH IN SUPPORTING AREAS

The emphases of the research needs of Chapters 6 and 7 are on specific requirements to advance the mission of an organization. The use of research as a tool of management (Chapter 5) was the principle under which research needs were examined. Effective research management will require that most of the research be directed to specific goals of the organization. Nonetheless, conduct of research "for the sake of research" is vital to the achievement of long-term objectives.

Within the planning, design, construction, maintenance, and operation of transport facilities, many disciplines, processes, and techniques are utilized. Each of these activities have research needs which reflect on the ultimate efficiency of transportation. Some of these needs are a part of the mission-oriented, high priority problems identified in Chapters 6 and 7. Others are more closely allied to technology and to the general advance of the state of the art.

These technology or discipline-oriented needs are most visible to the professionals involved, but imperfections can lead to the catastrophic collapse of a bridge, or to the less dramatic but troublesome complaints about signs on highways. To the professionals concerned, these gaps in knowledge are critical and failure to obtain support for research can be most frustrating.

All civil engineering research is "applied" research since technology is an applied science. Benefits can be obtained, therefore, from implementing any successful research effort.

There are also less direct benefits from non-mission oriented research. One of the most important is its tendency to divert an activity from long-established ruts or routines. Fresh insight into a process or technique is most likely to come from researchers who are removed from the urgency that characterizes operational activities. A second major benefit is the development of needed manpower. Research funding of educational institutions is particularly useful in this regard but even in an operational organization, non-mission oriented research can be a source of manpower development.

In this chapter, major areas are reviewed--both mission and non-mission oriented research programs that produce results which benefit transportation. The needs are discussed under the following headings:

- . Major Civil Engineering Programs
- . Fundamental Disciplines
- . Related Disciplines
- . Civil Engineering Processes
- . Techniques to Improve Capability of Civil Engineers.

Detailed summaries are not provided here, but are available in other reports in this series. The following description shows the nature of problems particularly relevant to transportation.

#### Major Civil Engineering Programs

In addition to transportation, civil engineering has been subdivided into the following major programs for the over-all study of civil engineering research needs: water resources, structures, and environment. None of these programs are completely separable from the other, but the division is a practical grouping of civil engineering technology.

## 1. Water Resources Engineering

Research needs in this area are primarily concerned with the quantity and quality problems in the consumption of water (58, 62, 63, 64). Questions of rainfall, runoff, and pipeline distribution for water resources are quite similar to those encountered in the drainage of transport facilities. Analyses of flood control and regulation and stabilization of rivers to assure adequate water supply and to protect floodplain areas have much in common with those for locating transport facilities and in the protection from flooding. Waterways transportation is particularly concerned with many of these problems. Studies of ground water flow, water table depths, and sub-surface exploration techniques for structural foundations are of no less consequence to transportation than they are to water resources.

The major research programs in water resources engineering are:

- . Waterways and Harbors
- . Hydraulics
- . Irrigation
- . Water Use in Sanitary Engineering.

The following studies from ASCE reports (63)\* provides an idea of the research needs for the urban water resources problem (see also Appendix E)

- 1) Research is needed on the planning process with regard to meeting over-all community goals; and socio-system simulation should be incorporated in the research.
- 2) Ways must be found to measure or evaluate social efficiency compatible with those existing for economic efficiency.

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\* Reference 63, p. 6-9.

- 3) Existing mathematical models for simulating the rainfall-runoff-quality process should be under continual testing and improvement, starting with the data now available.
- 4) The efficacy of selected existing drainage systems should be systematically evaluated and appraised, alternative hypothetical designs should be qualitatively tested and the most promising combinations and most effective practices should be identified.
- 5) A properly structured system analysis could provide a vital overview role for a national plan of urban water resources research.

Transportation interest in these subjects are primarily for economy and safety, that is, for the reduction in costs of constructing and maintaining facilities and for the safety features of surface drainage. The more directly affected transport systems (pipelines and waterways) have even greater interest.

## 2. Structural Engineering

Transportation is concerned with every type of structure, with the possible exception of massive dams, power stations and their distribution systems, and very tall buildings. Some structures, such as bridges and pavements, are for transport purposes only.

Structures technology is directed to the planning, design, construction and maintenance of buildings, bridges, pavements, drainage systems, port and harbor structures, and towers. Research progress in structures will inevitably advance transportation.

Many problems involving vibrations, resistance to earthquake stresses, foundation analyses, and fundamental analytic techniques are

of direct importance to transportation. Major advances in structural research will result in more economical facilities and in the development of unique facilities to meet special transport requirements (vibrations, massive loadings, difficult bridge locations, etc.) (59, 65, 66).

The major programs in structural research are (65):

- . Methods of Analysis and Design
- . Electronic Computation
- . Masonry and Reinforced Concrete
- . Metal Structures
- . Structural Plastics
- . Wood Structures
- . Buried Structures
- . Structures in Outer Space
- . Underwater Structures
- . New Structural Materials and Forms
- . Implementation of New Knowledge.

Additional detail is provided in Appendix E. The following are typical research needs (65)\* of particular interest in transportation:

1) Shell Structures: Despite the increasing use of shell structures, considerable research is needed to develop methods of analysis and design of complex shell structures even for static loads. Such structures are usually efficient load-carrying systems; however, of the infinite variety of shell forms that are available, only a comparative few of the simpler types have been studied to any significant extent.

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\* Reference 65, pp. 293, 294, 299, 302, 309.

Special attention must be given to shell stability problems, rib-stiffened plate and shell configurations, the effects of inelastic material behavior, creep buckling, and thermal effects.

2) Reliability of Structures: The old concept of safety based on allowable stress levels in the individual elements of a structure is inadequate to define the reliability of a structure. New methods are needed, taking into account the nondeterministic aspects of structural design (loads, material properties, fabrication techniques, methods of analysis, etc.) and the behavior of the entire structure as a "system" rather than as an assemblage of separate components. Further study is needed exploring such factors as the consequences of failure, errors in design, errors in fabrication and in erection, etc., on the required safety of a structure. How can a factor of safety reflect the nature of the loading (static, dynamic, single, repeated, reversed, etc.), the type of material used, the type of structure, etc.?

3) Cracking of Concrete: the cracking of concrete can be controlled to improve structural performance, but the best and most economical method of doing this is yet to be found. Methods of controlling this cracking are still under study and full success in this endeavor depends on fully understanding cracking phenomena. There has been some agreement on how these variables affect cracking. The natural phenomena of cracking is subject to great variation of width and spacing within the same specimen and this complicates the needed research.

4) Light-Weight Alloys: Light-weight metal alloys, notably aluminum, are becoming widely used for structural purposes. Because

the properties of these materials differ from those of steel, for which the background of knowledge from research and experience in civil engineering structures is greater, much additional research on structures made of light-weight alloys is needed. Of special importance in this area is the need for research on the fatigue strength of aluminum structures, including joints, and the application of plastic design methods to light-weight alloy structures. Further research is also needed on stability problems, especially those relating to thin-gage construction.

5) A detailed examination of nature's structures, some of which are made of very ductile materials and others of which are made of very brittle materials, might well give rise to new and more efficient structural forms and materials. Furthermore, it has been suggested that pressure-supported balloons, tents, tires, and rafts are small structures, the concept of which might be applicable, perhaps with modification, to major civil engineering structures. Engorging hollow structures or structural members with air, gas, or fluids under pressure is a means of prestressing and stress distribution that has been exploited to only a limited degree. Expansion of these principles using durable envelopes and well-sealed fluids could open new applications.

### 3. Environmental Engineering

Transportation has great interest in much of the research needs on environment. Noise and air pollution are typical interests. Esthetics, land environment, urban planning, and ecology are also of prime concern to transport interests.

Sanitary engineering is concerned with transporting sewage and many other types of urban wastes. Research in these areas is of particular interest to pipelines and to the drainage interests of all forms of transport. Stream pollution is of major concern to waterways.

The major programs in environmental engineering are (60, 67, 68):

- . Pollution
- . Sanitary Engineering
- . Urban Planning and Development
- . Recreation
- . Ecology
- . Esthetics
- . Land Environment
- . Bio-Environmental Engineering
- . Climatic and Weather Modifications.

The following are typical research needs of this area (68)\*:

1. We need to know how badly the streams are polluted; where the pollutants originate; how they act when mixed in a stream; their effects on the beneficial uses of water; and the changes occurring in the streams from year to year.

2. Other fruitful research would be the study of new and better methods of removing products of combustion from stack gases and vehicle exhausts. Equally important would be redesign of the processes that cause pollution or substitution of others with less pollution potential.

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\* Reference 68, pp. 30, 31, 85, 143, 242.

3) A comprehensive water-pollution-control program must be included for each river basin:

- a. Forecasts of population and industrial expansion.
- b. Hydrologic data and interpretative materials.
- c. Accurate determination of the physical, chemical and biological characteristics of streams, lakes, and reservoirs.
- d. Trends and volumes of water use and return to waterways as waste over the period of planning.
- e. Projections of treatment and waste removal needs for the planning period.
- f. Computations of stream-flow requirements to reduce concentrations of residual pollution following adequate treatment at source.
- g. Estimates of timing and costs of implementing the program of prevention and control.

4) In all urban areas motor vehicle emissions are, in varying degrees, already a significant source of pollution. The interrelationship between hydrocarbons and oxides of nitrogen when photochemical air pollution (smog) is produced in the presence of sunlight needs further elucidation. The role of particulates in the formation of smog and the mechanism by which smog irritates the eyes and causes damage to vegetation will require further research.

5) One of the principal problems in developing effective and efficient public works programs is the slowness with which modern management tools and techniques are finding their way into use in this field. A study of ways and means to accelerate this process of

modernization would be helpful. The identification and analysis of attributes that make for success in the realm of public works administration are needed. These attributes will vary with various clientele and with the public works function. Thus governmental officials, persons performing similar public works functions, interest group representatives, and persons in other public works areas should be surveyed.

Appendix E contains a broad outline of the health aspects of environmental research (68).

#### 4. Summary

The obvious overlap between these three areas and transportation suggests the desirability of close liaison between the research programs of the several areas. The interest of transportation in some of these problems suggests that cooperative funding is highly desirable, even though the problem is not keyed to a high-priority mission of transport. With insufficient funding for these programs, transportation will also suffer.

#### Fundamental Disciplines

Civil engineering technology is grounded in the physical sciences. Fundamental studies in mathematics, physics and chemistry are, therefore, of long-range interest. At a more applied level, engineering mechanics, soil mechanics, materials, surveying and photogrammetry, hydraulics, hydrology, and geology are of practical significance.

These basic subjects are the ultimate sources of a research advance in transportation facilities. While new transport systems can be evolved without research in any of these disciplines, such activity may be more engineering design than research. For most mission-oriented

transportation research, then, studies in one or more of these disciplines is practically always involved (61, 69, 70, 71, 72, 73). Typical problems from some of these areas are of particular interest to transportation. A more detailed summary is contained in Appendix F.

1. Hydrology (69, p. 78)

Studies and research are needed to provide reliable and practical methods of extending the sample of observed data to encompass the range of variability that may exist in hydrologic phenomena. An improved understanding is needed of the statistical characteristics of the hydrologic events, such as those represented by historical samples, the extent to which observed data can be considered random samples, etc. These statistical parameters need to be associated with physical parameters, allowing the use of data from one basin to another.

2. Surveying and Mapping (70, p. 34)

Use of photogrammetric methods in making all essential measurements and compiling maps needed for location, design, and construction, for land appraisal and procurement of rights-of-way, and for representation of the proposed solution to engineering problems; and in making measurements for computing construction pay quantities.

3. Soil Mechanics and Foundations (71, p. 19)

Volume changes of soils due to any cause can lead to undesirable settlements and deformations of overlying structures. The study of the compression characteristics (as distinct from consolidation) of soils is an important area of research need. Studies should include research data on structure performance.

#### 4. Engineering Mechanics (72, p. 11)

Application of Plastics to Structural Uses - The use of plastics in the solution of major structural problems has not been fully explored. The need for refinement of non-linear structural theory as well as a rational treatment of creep is evident.

#### 5. Hydraulics (73, Communication from Walter L. Moore)

Research on channel stability is a most urgent need in the sedimentation field at the present time. In this is included deterioration of natural waterways and the design of canals to transport sediment without scour or aggradation. Much of the research that has been done in this area has dealt with alluvial channels; there is also a need for work on channels in cohesive materials and on bank erosion in both cohesive and noncohesive materials. Problems included in this area include the entrainment transport and deposition of sediment as bed load or as suspended load. Also included are problems of degradation, aggradation, and local scour produced by structures built in channels, structures such as bridge piers, abutments, pumping stations, control structures, etc.

To provide a continuing expansion of knowledge in these areas, and to reduce the time and improve the effectiveness of mission-oriented research, funding of studies in these fundamental disciplines is required.

#### Related Disciplines

Transport interests of the civil engineer can be extended to all scientific disciplines. Some of these areas are further removed than others. Studies in economics, sociology, law, psychology, architecture

and some phases of agriculture, medicine and communications are particularly important to transport technology.

No precise line can be drawn between the civil engineer's direct and indirect interest in these related disciplines. At the applied research and development level, however, interdisciplinary efforts will be essential. Establishing requirements that are responsive to social objectives and developing relationships between transport service characteristics and variables of the social indicator type will require close cooperation with many disciplines and much interdisciplinary research.

The most fundamental research in these related disciplines will remain outside civil engineering. Interest, support, and applied research in these areas, should be maintained by civil engineering technology. Interdisciplinary research should be initiated and supported.

#### Civil Engineering Processes

For the processes of civil engineering, the benefits of research are not necessarily restricted to a specific program or activity.

These processes include:

- . Administration
- . Policy Development
- . Implementation
- . Planning
- . Design
- . Construction
- . Maintenance
- . Operations

Research in these areas is frequently not controlled by disciplines, transport mode, or subject area interests. On the other hand, some depend on the unique character of the problem. For example, some construction problems for bridges are quite different from those encountered in pavements; and those for steel materials are unlike those for soils and aggregates.

Research needs on processes can originate at any level, from discipline problems, to modes, to intermodal concerns. Technological capability and research competency are normally associated with processes, and research needs can be effectively analyzed and managed by considering improvements in the efficiencies of the processes.

Typical research needs for construction include: (74)\*

1. Equipment development: (a) Mechanical gang vibrators for consolidating mass concrete; (b) transfer vehicle for concrete which eliminates segregation; (c) hypervelocity fluid jet for tunnelling, quarrying, etc; (d) work vehicle capable of constructing on the floor of a continental shelf; (e) means to excavate sea floor sediments; (f) equipment for placing deep cutoff walls; (g) means to excavate rock to a neat line, rapidly, without explosives, and (h) improved means for drilling a hole in rock.

2. Methods or technique development: (a) Means to eliminate air bubbles along forms for concrete; (b) means to stabilize soft ocean sediments for maintaining visibility when working on the sea floor; (c) improved methods for compacting soils (rapidly in deep lifts); (d) investigation of the displacement of soil by repetitive shallow explosions; (e) excavation with nuclear explosives; (f) excavation

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\* Reference 74, p. 236.

incident to the emplacement of nuclear explosives; (g) hydraulics of channels created by nuclear explosives; (h) forming and handling techniques for high-density concrete for radiation shielding; (i) improved field welding and inspection of stainless steel primary cooling system in nuclear reactors; (j) stabilization of soil by thermal means; (k) improved exploitation of foreign literature related to construction equipment, and (l) application of industrial engineering techniques, e.g., time-motion study, to develop improved work methods and crew production.

A summary of the research needs in construction is contained in Appendix F. Needs on planning (81), design, maintenance and operations are included in Chapters 6 and 7 and in Appendices B, C, and E.

#### Techniques to Improve Capability of Civil Engineers

Specialized techniques that are or can be utilized for all the processes in civil engineering include:

- . Education
- . Computer Use
- . Programming (PERT, CPM, etc.)
- . Operations Research or Systems Analysis
- . Cost Effectiveness.

Research needs in these techniques are not restricted to transportation problems (61).

Present methods used in civil engineering education require study and evaluation. Many of the methods are an outgrowth of civil engineering practices of the past. This includes both transportation subjects and those that are basic to transportation. The constant

change of technology, the rapid increase in size of the graduate program, and present demands call for new and improved approaches to education. These needs involve methods to update the educational system, including the faculty, the subject matter presented, the facilities, and the techniques employed. Methods are needed for feedback of (a) the adequacy of the education, (b) the problems of the profession, and (c) research results.

The fast changing field of computers and computer capability requires research for applying the new technology to civil engineering activities. This research will be primarily applied and developmental in type. There is some fundamental work required for the special applications of civil engineering.

Programming of activities in many phases of civil engineering processes require research to optimize the results. Construction and maintenance operations are particularly in need of techniques for reducing costs and increasing the effectiveness of the results achieved with expended funds.

Operations research and systems analysis techniques can be extremely helpful for many areas of civil engineering, particularly where predictive theories do not exist. They can also assist in the extension of many available theories to include new variables.

Cost effectiveness methods for civil engineering have not been updated in ways that improve on the limited capabilities of conventional cost/benefit analyses. More precise criteria, more explicit objectives, and a predictive theory will provide the necessary basis for cost effectiveness analyses of alternatives. Research in this area will be handicapped until the research in the basic areas of criteria, objec-

tives and theory have been advanced sufficiently. In addition, the absence of predictive theories require that judgment be used as the means of estimating the effect of a change. For interim purposes, therefore, research is needed on methods for developing value judgments by consensus.

## Chapter 9

RESOURCE REQUIREMENTS FOR  
TRANSPORTATION RESEARCH

Resources that could be effectively used in transportation research far exceed the present level of funding. Because of insufficient research expenditures in the past, problems of noise, air pollution, safety, congestion, and an inadequate response to social and economic needs have been inherited. Continued inability or lack of priority to fund transportation research will compound existing problems and lead to new ones.

Considerations given to the need for transport research should not assume that efficient transportation is the real objective. The preceding analysis has demonstrated that transportation is the means to some end, and accordingly, the need to fund transport research is controlled by what society requires of transport to achieve other social and economic objectives.

In the following discussion of resource requirements, no attempt is made to make judgments on the relative importance of the contributions from transportation. Some requirements represent targets of opportunity for major social and economic gains. Others constitute efforts to eliminate serious deficiencies or inefficiencies. The requirements for research are real in the sense that progress will be possible if the work is successfully completed; they are real in the sense that serious deficiencies are predictable in the future, if the problems are not solved or circumvented.

### Sources of Transportation Funds

Transportation costs have been estimated to be \$180 - 190 billion-- 20 percent of the GNP. The amount is approximately equally divided between passengers and freight, although the former is slightly greater. Some 90 percent of the transportation expenditure is for highways and 10 percent is for all other.

The Federal, state and local government provide 10 percent (\$20 billion) of the transportation expenditures of which 90% (\$18 billion) is for highways, 7 percent (\$1.5 billion) is for air transportation, and 3 percent (\$0.7 billion) is for waterways. The larger expenditures for highways, air and waterways are required because of the governments' greater responsibilities, that is, the providing of facilities and the control of operations (highway traffic flow, airways and waterways).

Most of the expenditure for transportation (90 percent) comes directly from the private sector in the form of vehicle and operation costs. Railroads and pipelines are largely free-enterprise operations under government regulation, and derive their funds from user charges.

Transportation research expenditures by the Federal Government have increased rapidly in some areas during the past 10 years. In 1968, the level was \$281 million (27) of which \$214 million (75 percent) were for air transport (considering FAA only), \$38 million (13 percent) were for highways, and \$24 million (8 percent) were for high speed ground transportation.

Research expenditures by industry are not available, but the level is undoubtedly much greater than that expended by governments in

all areas, except air transportation. Neither NASA nor DOD expenditures are included in the mentioned air transport research. Certainly much of the \$4.6 billion research and development program of NASA and the \$3.6 billion research and development program of the Air Force are related to air transportation (82).

The civil engineering phases of transportation research are largely reflected in government funded studies. Of these, the greatest part of the civil engineering effort is in highway research. Most of the air transport research is for airways and safety.

Significant increases in transportation research funding in civil engineering areas would not mean increasing an already large expenditure in comparison to the private sector or government expenditures on transportation, or the level of government research in other areas. To the contrary, the level of this funding in 1968 for civil engineering research was of the order of 0.2 percent of the governments' expenditures for transportation - less than 20 cents of every \$100 expended, and in 1962, the level was .03 percent (3 cents per \$100). If problems related to civil engineering exist, it is due in part to a failure to support sufficient research over the past ten to twenty years.

There has also been very limited research in the areas of transport system development for specific social and economic activities. Research has tended to be mode-oriented and transport responsibilities of the Government have been limited. In highways, for example, the Federal role was simply assisting in the provision of the facility. The responsibility of local transport officials was in the provision of facilities and control of operation. There has been no designated responsibility for the analysis of social and economic programs with

a view to their unique needs for transport service. The formulation of the U.S. Department of Transportation and a number of similar departments at the state level provided the first opportunity or responsibility for such analyses. As a result, there is a large back-log of studies to determine the fundamental role of transportation in society.

Since civil engineering is primarily concerned with providing, maintaining and operating transport facilities, their major sources of research funds are the Federal and local governments. In addition, research for new systems in support of social objectives will show no dollar profit and will need to be financed by government.

#### Resource Requirements for Research on Transport Systems

Research on transportation systems, summarized in Tables 6-2 and 9-1, includes four categories of studies: (1) Methodology; (2) Requirements and Constraints; (3) New Systems, and (4) Transport Facilities. Development of estimates of resources required for these studies was guided by the principle of providing a significant level of effort, a level whereby significant gains could be achieved. Other levels of support, larger or smaller, could be applied, with greater or lesser benefits.

##### 1. Research Needs for Methodology

Of all the areas of transportation research, none is more critically in need of advance than is the area of analytic methods. Present techniques are dominated by modal approaches and by economic concepts concerned with fulfilling transport demand rather than achieving specific social objectives. The analytic capability of defining and analyzing transport systems to achieve non-economic objectives is practically non-existent.

TABLE 9-1 Research Resource Requirements for New Transport Systems

Subject	Annual Cost (\$ in Millions)	Five-Year Cost (\$ in Millions)	Ten-Year Cost (\$ in Millions)
<b>A. <u>Methodology</u></b>			
1. Establishing priorities on social values and their criteria	2	10	
2. Policy decisions on non-productive changes of requirements and constraints	2	10	
3. Estimating the level of service	2	10	
4. To predict the effect of a change in the input	5	25	
5. Benefits to social objectives of alternative levels of service	5	25	
6. Rate at which the level of service can be changed	2	10	
7. Information system for human resource development	8	40	
8. Interrelations between transport and other services	2	10	
Totals	28	140	280*
*maintain at \$28 million per year, but redistribute			
<b>B. <u>Requirements and Constraints</u></b>			
1. Specific constraints for the next twenty years, in five-year increments.	2	10	20
2. Minimum levels of service for urgent social objectives	2	10	20
3. Monitoring and adjusting the level of service	2	10	20
4. Specifying level of service to improve human resources development	2	10	20
Totals	8	40	80

(Continued)

TABLE 9-1 Research Resource Requirements for New Transport Systems - Continued

Subject	Annual Cost (\$ in Millions)	Five-Year Cost (\$ in Millions)	Ten-Year Cost (\$ in Millions)
<b>C. <u>New Systems</u></b>			
1. Urban home-to-work transport system	5	25	
a. Home-to-work transport system for low-income residents			
b. Employer incentive plan for the home-to-work trip			
2. Emergency response system	5	25	
3. Training program for jobs	2	10	
4. Transport system to cultural, recreational, educational, and hospital facilities for low-income group	5	25	
5. New level of service for trash and waste disposal	2	10	
6. Improved level of service for patrol activities	2	10	
7. Improved level of service for neighborhood mobility	2	10	
8. Improved level of service for freight distribution	2	10	
9. Improved level of service of transport for postal services	2	10	
Total	27	135	270**

\*\*Maintain at \$27 million per year, but redistribute. These costs do not include full-scale test and evaluation or demonstration projects.

(Continued)

TABLE 9-1 Research Resource Requirements for New Transport Systems - Continued

Subject	Annual Cost (\$ in Millions)	Five-Year Cost (\$ in Millions)	Ten-Year Cost (\$ in Millions)
<b>D. <u>Transport Facilities</u></b>			
1. Safety requirements for various modes	2	10	
2. Measures of performance of ground facilities	2	4	
3. Probability concept for level of service and social values	2	10	
4. Reducing construction costs of transport facilities	5	25	
5. Cost-effectiveness approach for maintenance and operation of facilities	2	10	
6. Tunneling	5	25	
7. Control systems to replace human operators	2	10	
8. New materials	2	10	
Total	22	104	204***
***Maintain at \$20 million per year for the five-year period but on new projects.			
Grand Totals	85	419	834

Of the eight listed studies, useful results should be sought within five years. For several, such as studies number 2, 3, 6, and 7, less than five years will be needed for a useful result. For the others, a five-year effort will produce usable techniques if properly financed and expedited.

For each of the first five years, no less than two million dollars should be allocated to each of the studies. For studies numbered 4 and 5, a higher level of five million per year is recommended, and for study number 7, an annual expenditure of \$10 million is recommended. This would amount to a total of \$28 million annually for the first five years. It is recommended that this same level, with a redistribution of funding be applied for the second five years. Over a 10-year period, the total would amount to \$280 million.

## 2. Research Needs on Requirements and Constraints

A minimum level of two million dollars per year would be required for each of the four to achieve adequate results in five years. Thereafter, the same level should be maintained for the next five years to improve the methodology and to implement objectives developed in the first five years. This would amount to \$8 million annually, and \$80 million for a 10-year period.

## 3. Research Needs for New Systems

The research phases for the first five years would require a minimum of two million dollars for each of the studies, exclusive of full-scale test and evaluation or demonstration projects. Five million dollars annually is recommended for studies 1, 2, and 4. The second five years would not involve research funding but would require funding for implementation. For the five-period, \$135 million would be required.

For the next five-year period, the same level of effort is recommended to improve on the systems or to develop new systems. For a 10-year period, a level of \$270 million is recommended.

#### 4. Research Needs for Transport Facilities

A minimum level of two million dollars per year is recommended for each of the eight studies. To achieve the objectives of studies 4 and 6, \$5 million per year is recommended for a 5-year period. Study 2 is for two years. For five years, the total recommended level of effort of this group of studies is \$104 million. For the succeeding five years, a level of \$100 million is recommended for new studies, and a 10-year total of \$204 million.

#### Resource Requirements for Research of Transport Modes

The estimates of research resources needed by the several modes were prepared by the committees and organizations that developed the research needs. The basis for the resource needs was primarily one of a desired level of effort to achieve a substantial advance.

##### 1. Air Transportation

The Aero-Space Transport Research Committee (47) referred to existing estimates of \$30 billion of public and private funding for air transportation through 1980. The report also referenced the FAA estimate of \$8.4 billion required of Federal Government for airports over the next decade. Of this, the Committee estimated that \$8.0 billion was to be expended in the areas recommended for research (Table 7-1). No estimate of level of effort for each research study area was developed, but an over-all estimate of 5 percent of the Federal Government's needs was recommended for research - \$40 million per year over the 10-year period. The present level of \$1.5 million per year was considered completely inadequate to cope with the problems of the future.

## 2. Highways

The ASCE Committee report (50) estimated that all levels of government would expend \$14 billion per year on highways, and recommended an annual research expenditure of 5 percent or \$600 million per year. No breakdown of this expenditure was provided.

various fields showed highway research by governments as 0.25 percent of expenditures as compared to (1) 3.0 percent of the GNP being expended for all types of research and development, (2) 4.7 percent of the money from vehicle sales expended by industry, and (3) 12.4 percent of the Department of Defense expenditures going for research. No over-all estimate of funding needs was developed, but existing research funds were considered "grossly inadequate". The requirements for the research shown in Table 7-3 were given as a \$25 million, as shown in Table 9-2.

## 3. Pipelines

The estimates of requirements provided by the ASCE committee report (52) for the period 1966-1975 were \$13 million. The breakdown by research area and years, as developed by the Committee, is given in Table 9-3. The level of effort recommended by the committee was significantly lower than that developed by other committees. This was probably due more to a difference in perspective and a desire to produce a "practical" answer rather than the percent of expenditure basis used in other areas.

The studies of the committee report appear to lend themselves to a more rapid pursuit of some or all of the objectives, and to be consistent with the other modes, the 10-year effort could be telescoped into five years. Furthermore, to achieve the level of advance to which

TABLE 9-2 Research Resource Requirements for  
Highways (NCHRP) (51)

Problem Area *	Estimated Funding		
	<u>Project</u>	<u>Initiation</u> (\$ Thousands)	<u>Total</u>
1-1	1,836	650	2,486
1-2	1,290	425	1,715
1-3	1,815	675	2,490
1-4	1,095	375	1,470
1-5	2,148	675	2,823
2-1	1,221	350	1,571
2-2	2,691	925	3,616
2-3	2,337	725	3,062
2-4	1,818	550	2,368
2-5	2,817	1,000	3,817
3-1	1,968	675	2,643
3-2	1,947	675	2,622
3-3	<u>1,329</u>	<u>450</u>	<u>1,779</u>
TOTALS	\$24,312	\$8,150	\$32,462
Minus duplication	<u>-5,766</u>	<u>-1,825</u>	<u>-7,591</u>
	\$18,546	\$6,325	\$24,871

\*See Appendix C for description of problem areas.

TABLE 9-3 Research Resource Requirements  
for Pipelines (52)

SUMMARY OF COSTS, IN THOUSANDS OF DOLLARS												
Research Area *	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Total	Originator
a. Location	—	100	175	175	175	175	175	175	175	175	1,500	William Quinn
b. Design Methods		15	15	35	35	40	40	40	40	40	300	R. J. Brown
c. Materials		10	20	30	40	40	40	40	40	40	300	Angus Slee
d. New Construction Techniques		40	150	450	800	800	250	800	800	550	5,140	John Bomba
e. Pipeline Crossings, Railroad and Highway	10	15	—	15	30	15	—	15	30	15	145	J. E. Thompson G. D. Mock
f. Pipeline Flotation		25	25	25	—	—	25	25	25	—	150	N. B. Caraway
g. Submarine Pipelines	—	25	50	80	170	200	200	170	80	50	1,025	R. J. Brown
h. Testing		20	60	90	120	150	150	150	120	120	980	Lowel Elder T. J. Atterbury
i. Unconventional Application		50	250	400	450	500	500	500	450	340	3,440	T. J. Atterbury
j. Automation		10	30	45	45	60	45	60	45	30	370	C. Klohn R. J. Brown
k. Electronic Computation		10	10	10	20	30	40	30	10	10	170	C. Klohn R. J. Brown
<b>Total</b>											<b>13,525</b>	

\*See Appendix C for description of problem areas.

the other modes are being addressed, a further increase of 1000 percent is recommended. The nature of the needed studies would be primarily in the costly areas of development of new types of pipeline application; i.e., unconventional applications. Increases of the preceding magnitude would call for an annual budget of \$26 million. These expenditures would need to be largely government funded, since the objectives would be more for social benefits than for economic return.

#### 4. Railroads

The resources required for civil engineering railroad research are based on the need to exploit rail transport to pursue non-economic values. The government's participation in railroad funding was estimated as \$24 million in 1968 for the high speed ground transportation program. For construction and maintenance of facilities, the phase most closely allied to civil engineering, private investment was \$1.6 billion in 1968 (75). Based on use of 5 percent for research, the requirements for private sector research would amount to \$80 million.

The estimate of requirements for the high speed ground transportation program was \$35 million per year (55), of which a large percent was for demonstration projects. Of the \$52 million appropriated for FY 1966 and FY 1967, the funding for the program is shown in Table 9-4.

No published estimates are available for succeeding years, but a minimum annual expenditure of \$35 million by governments for railroad research is recommended as the level of effort if non-economic benefits are to be developed. From private and public funds, the total would be \$115 million annually. This figure does not include a reduction in government funding for non-civil engineering programs.

TABLE 9-4 Research Resource Requirements  
for Railroads (OHSGT) (55)

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Systems engineering	\$ 6,200,000
High speed railroad R&D	6,755,000
Unconventional systems R&D	3,075,000
Advanced technology and test facility	6,745,000
Washington-New York demonstration	11,749,000
Boston-New York demonstration	8,426,000
Auto-train demonstration	3,887,000
Data collection	1,521,000
Administration	<u>1,614,000</u>
Total:	\$49,972,000
Data Program:	<u>2,028,000</u>
Total Appropriations:	\$52,000,000 *

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Note: For FY 1966 and FY 1967 only.

\*Total for the 2 years.

## 5. Waterways

Research resources for waterways, prepared by ASCE committees for the programs recommended (57), are listed in Table 9-5. For the coastal engineering phases, the \$5 million annual research costs represents less than two percent of the average yearly cost of new construction and maintenance. The rate of research expenditure for Ports and Harbors was estimated to be \$1.3 million per year; for Regulation and Stabilization of Rivers, \$6.6 million per year, and for Navigation and Flood Control, \$26 million per year. For the latter program, the research level is less than 1½ percent of the estimated \$8 billion annual program of needed navigation works and \$1 billion annual flood damages.

The annual research program averages \$38.7 million and the 10-year estimate is \$386.7 million.

### Resource Requirements for Research Basic to Transportation

Typical resource requirements for the research that contributes to transportation have been estimated as follows:

	<u>Annual</u> <u>(\$ in millions)</u>	<u>10-year</u> <u>(\$ in millions)</u>
Structures (65)	23	228
Urban Drainage (63)	30	300
Ground Water (73)	6	60
Soil Mechanics (71)	35	275
Surveying & Mapping (70)	varies	271
Construction (74)	1	10

There is no doubt that extensive needs exist for research of basic interest to transportation.

TABLE 9-5 Research Resource Requirements  
for Waterways (57)

Field of Study	Recommended Funding	
	Annual Cost (\$ in millions)	10-year Cost (\$ in millions)
Coastal Engineering	4.3	42.7
Ports and Harbors	1.3	13.0
Navigation and Flood Control	26.5	265.0
Regulation and Stabilization of Rivers	6.6	66.2
TOTALS	38.7	386.9

Continued support of these programs is essential to the advance of transportation. Some of the research in these areas is a part of the mission-oriented programs. But in order to be assured of the benefits from basic studies, a specified percent of the mission-oriented research program should be allocated to fundamental research programs. This policy would provide continuing support for increasing the "storehouse of knowledge" for future generation transport systems.

The recommended funding for these basic studies is 10 percent of the mission-oriented efforts. In the summary shown in Table 9-6, this amount was rounded to \$85 million per year, and \$900 million for a 10-year period.

#### Manpower and Facilities

Estimates of requirements for manpower and facilities are logically based on the total funding level of research. Various bases for such estimates have been used, but a figure of \$50,000 per year per professional is a reasonable base. Using this rate, a total of 20,000 professionals would be needed for the \$1 billion annual program that is recommended.

Of this total, it is probable that 7,000 (approximately one-third) should be civil engineers, the remainder coming from various scientific and engineering disciplines. Assuming that the present level of civil engineering research in government funded transportation programs is \$50 million, approximately 1,000 civil engineers are now available. Due to the high percent of government and university employment, the rate of \$50,000 per year per professional may be high, and the available number may be as great as 2,000. This would still indicate a need for 5,000 researchers.

TABLE 9-6 Summary of Resource Requirements  
for Transportation Research

	<u>One-Year Costs</u> (\$ in Millions)	<u>Ten-Year Costs</u> (\$ in Millions)
1. Transportation Systems		
a. Methodology	28	280
b. Requirements and Constraints	8	80
c. New Systems	27	270
d. Transportation Facilities	22	200
Total	85	830
2. Transport Modes		
a. Air Transport	40	400
b. Highway	600*	6000
c. Pipelines	26	260
d. Railroad	115**	1115
e. Waterways	39	390
Total	830	8165
Sub-Total	915	8995
3. Research Basic to Transportation 10 percent of mission-oriented studies	(rounded)  85	  900
TOTAL	1,000	9,895

\* Highway expenditure accounts for \$120 billion per year in the U.S., 4 times as much as all other transport combined. Studies in these areas should be directed to improving transport services to achieve the objectives now produced by highways.

\*\* Includes \$80 million from the private sector, which collects from users to provide facilities.

The remaining 13,000 professionals should be available through transfer from research programs in other areas, some of which have been reduced in recent years. There is no question but that experienced researchers would bring valuable insight into the transportation research program.

Regardless of whether transfers or new civil engineers are required, a strong need will exist for a continuing education program. These educational efforts could be effectively combined with both the mission-oriented and the fundamental research studies.

Facility requirements have been studied for some areas such as highway safety. The general observation can be made, however, that a serious deficiency exists in modern laboratories and field testing facilities for the civil engineering phases of transportation.

Many alternatives are available, ranging from a centralized transportation research center, to a decentralized series of centers, to the expansion and improvement of existing university, government and private facilities. While economy is frequently achieved through centralized operations, advantages can also be shown to come from a dispersed set of facilities.

The recommended level of funding for facilities will need to be greater for the first five years because of the inadequacy of the present plant. A level of 20 percent of the program requirements is recommended for the first five years and 10 percent thereafter. For the program summarized in Table 9-6, this would amount to \$200 million per year initially, and a total of \$1.5 billion for a ten-year period.

Summary

The following summary of the preceding requirements is:

Research programs	-	\$1 billion per year \$9.9 billion for 10-year period
Manpower	-	20,000 professionals
Facilities (Research)	-	\$200 million per year, initially \$1.5 billion for 10-year period

These requirements compare to a present expenditure of approximately \$50 million for the civil engineering phases of transportation. The ability to mount such a program in the near future is doubtful, but the need for such an effort can scarcely be questioned in the light of the present and future dependence of achieving social and economic objectives through transportation services. The annual expenditure is approximately 5 percent of the present government funding of transportation. It is not so large in light of the fact that it is:

- . Only 0.5 percent of the Nation's transport costs
- . Less than ten times larger than the Government contemplates for the SST alone
- . Less than 1/7 of the amount for research for defense purposes and equal to DOD's aeronautical research and development for 1968.
- . Approximately 1/4 of the budget for NASA
- . Less than 1/2 of the budget for the Atomic Energy Commission
- . Approximately equal to the recommendation by the Department of Housing and Urban Development for urban transport for a 5 - 15 year period (83).

If transportation is essential for health and individual welfare, for recreational and cultural activities as well as for the economy, transport research of the recommended level is essential.

APPENDIX A  
LIST OF REFERENCES

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APPENDIX B  
RESEARCH NEEDS  
U.S. Bureau of Public Roads

## APPENDIX B

The following outline of highway research was distributed September 20, 1965 by the U. S. Bureau of Public Roads. (23)

Cost estimates and more detailed plans were also prepared and are available from the Office of Research and Development, U. S. Bureau of Public Roads, Washington, D. C.

## TECHNICAL LISTING

## OF THE

## NATIONAL RESEARCH AND DEVELOPMENT PROGRAM

## I. New Concepts Research (Theoretical) - Future Role and Principles for Design of Highway Transport Systems. (See Figure 2)

Research over the past years has improved the design of highway transport systems to the point that design capability is limited mainly by a lack of understanding of the underlying characteristics of the systems. In order to make significant breakthroughs in the design, construction, and operation of highway transport, new concepts and more complete understanding are required of the fundamental nature of the components of that system and their interactions. The gain to be obtained by providing this knowledge will ultimately be seen in the time and dollar economics of construction, safety, and free flow of traffic. It will be especially evident in the design and operation of the complex networks demanded in urban areas.

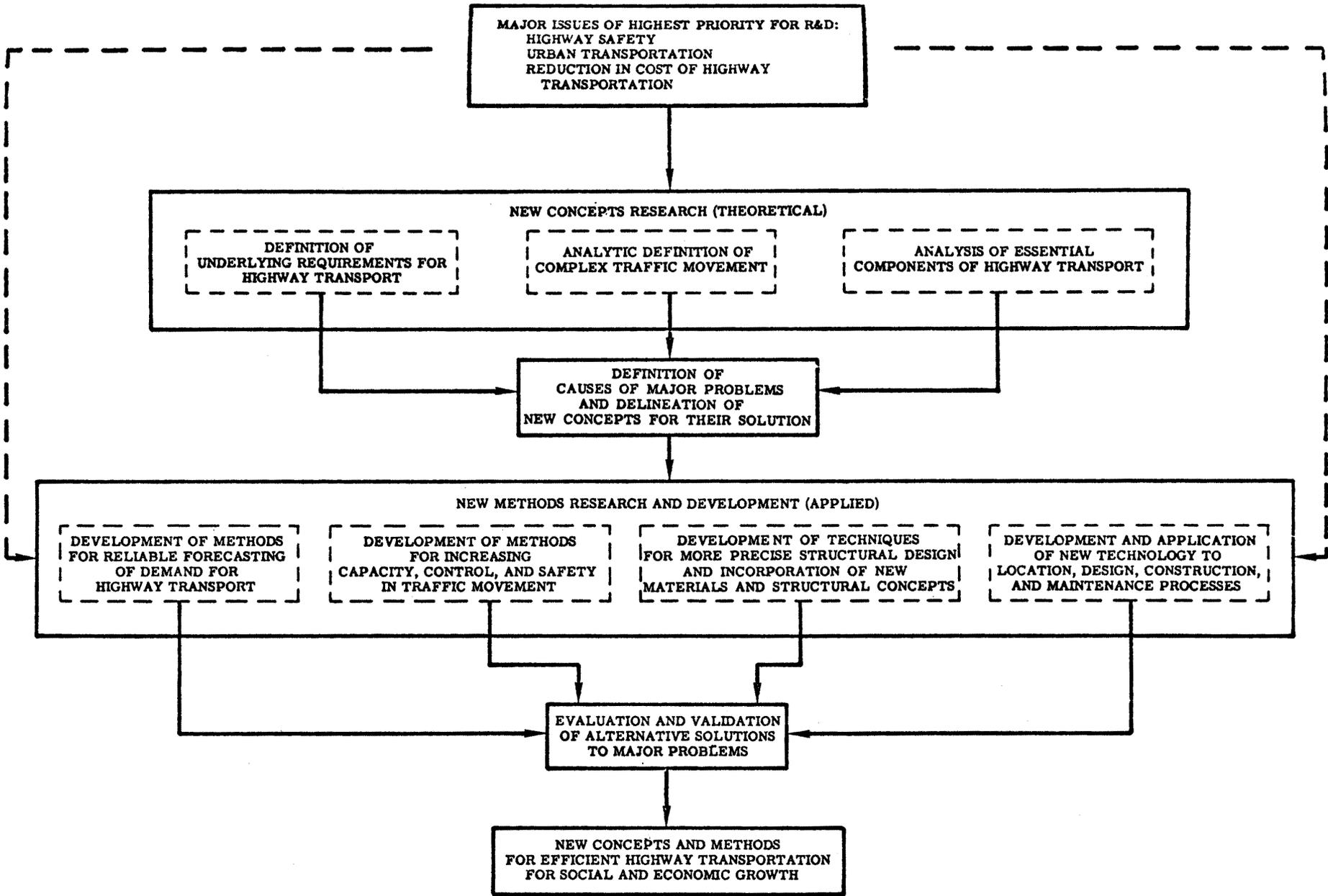
Obtaining these objectives will require a program of research in three areas central to highway transport design. These are: (1) definition of the underlying requirements for highway transport; (2) analytic definition of complex traffic movement; (3) analysis of the essential components of highway transport. The specific research considered most vital to each of these areas is outlined below.

## Highway Transportation Requirements

Objective: To define the underlying requirements for highway transportation.

At the present time our ability to predict the evolving demands for transportation and to measure the consequences of highway investment is severely limited. There is only meager quantitative understanding of the underlying social and economic forces that tend to make one mode dominant over the others. In part, this is due to the lack of valid methodology for reliable economic evaluation of alternative systems or alternative transportation plans. In order to provide more reliable measures and methods for transportation planning and decision making, a research effort is required that will define the fundamental social and economic factors that underlie the use of transportation.

In order to initiate these studies and to provide a more basic understanding of the factors involved, three research projects have been established.



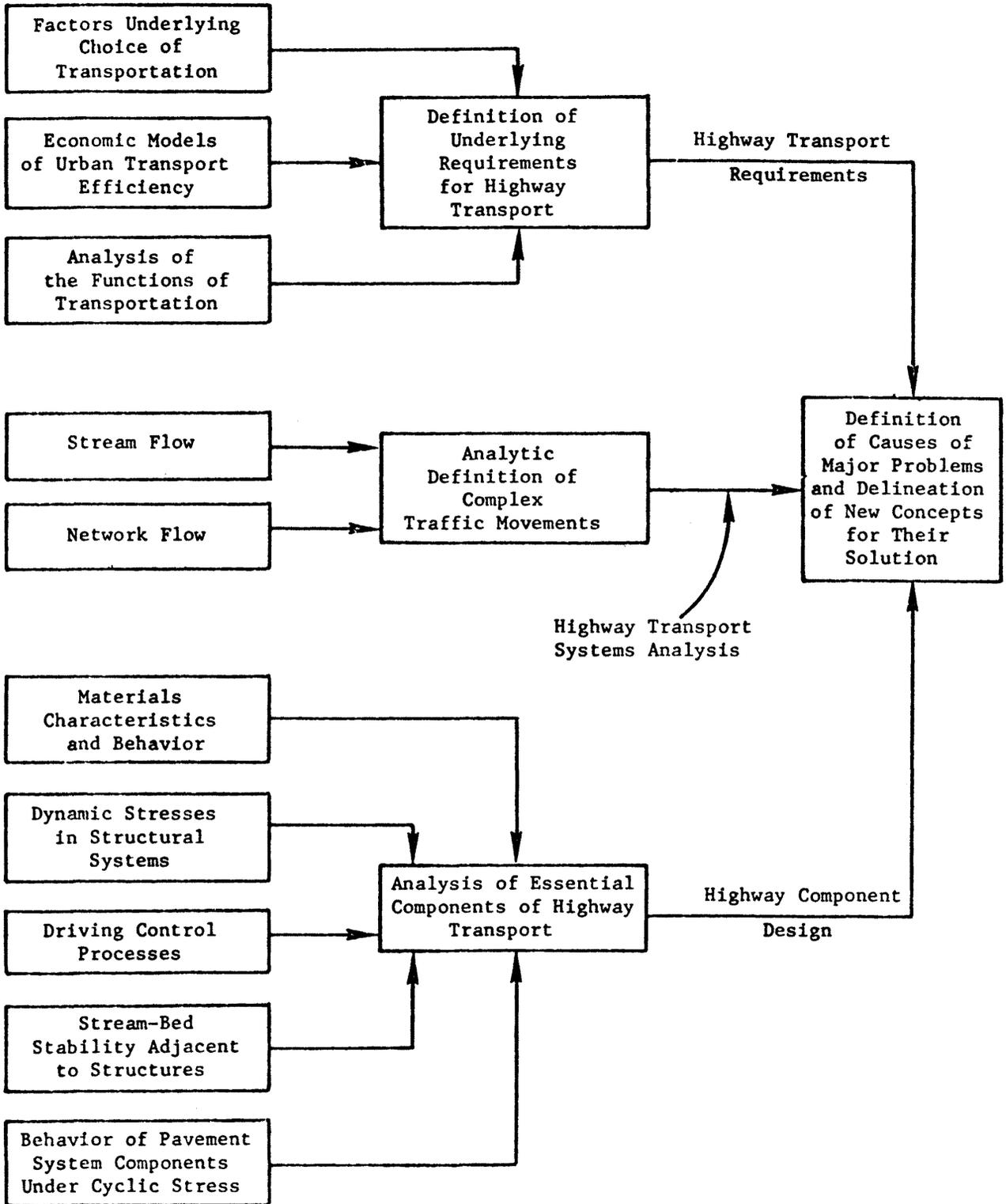
A NATIONAL PROGRAM OF RESEARCH AND DEVELOPMENT FOR HIGHWAY TRANSPORTATION

FIGURE 1

Project Area

Major Goal

Program Area



FUTURE ROLE AND PRINCIPLES FOR DESIGN OF TRANSPORT SYSTEMS (THEORETICAL RESEARCH)

FIGURE 2

1. Factors underlying choice of transportation

Objective: To define the criteria that determine transport preferences by the individual; to determine value scales upon which alternative transport choices are based; and to develop methods of measuring the preferences.

Scope: For the user, the choices between different modes of transportation are determined basically by two considerations. One is the individual's evaluation of the degree of satisfaction of each mode and its availability; and the other is the costs (or deterrents) of such travel. These factors are similar for business and individual users. It has become apparent that choices between modes are not always based upon simple economic considerations of least financial cost and maximum return. It is necessary to understand how transport choices are made, since the factors which underlie those choices are essential to predicting the use of transportation systems and desirable changes in such systems for developing the benefits and costs of highway transportation relative to alternative forms of transport, and to develop techniques to measure these preferences.

2. Economic models of urban transport efficiency

Objective: To develop economic models that simulate the present structural characteristics of an economy and its interrelationships with transportation components. In addition to this class of economic model, sub-models of transportation demand, of motivational response, and of cost must be developed and integrated.

Scope: Development of appropriate mathematical models of economic processes are essential for scaling the dynamic changes occurring in an economy and for defining quantitatively the interrelations between transportation and economies.

3. Analysis of the functions of transportation

Objective: To define analytically the underlying functions which determine the need for, performance of, and constraints on movement.

Scope: In order to provide a rational basis for the design and evaluation of existing and novel systems of transportation, a general theory of movement through space is essential. A complete analytic design of transportation requires a theoretical framework, which treats the functional requirements of transportation, the physical performance characteristics, and the physical and environmental constraints. The objective of this program is to develop a general theory of transportation which will allow specification of systems to meet specific requirements with predeterminate properties and known performance characteristics.

## Highway Transportation Systems Analysis

**Objective:** To obtain an analytic definition of complex traffic movements.

The nature of the flow of traffic on complex networks of roads and streets determines in great measure the operational efficiency and the utility of highway transport. In existing systems it is well known that considerably lower flow rates are obtained than theoretically possible. Furthermore, large flow rates depend on design characteristics which, in urban areas, increase the costs and cause competition with other social functions for available land. Part of the problem stems from the lack of understanding of the nature of the traffic flow process or the interaction between flows on the complex networks of city streets. A necessary prerequisite to the practical solution of this problem is a sufficient research effort which will provide definition of the nature of traffic flow in homogeneous streams and in networks. Two specific projects are proposed for analysis.

### 1. Stream flow

**Objective:** The purpose is to define in analytic terms the nature of the flow of traffic for a general class of moving elements.

**Scope:** Traffic efficiency and safety depend significantly upon the nature of the interrelations in streams of vehicles as well as upon the mechanical characteristics of individual vehicles. The basic mechanics underlying this flow process are, however, incompletely understood, with the consequence that there is limited capacity to control flow or the accidents that arise therefrom. Better understanding of the mechanics of traffic flow are required before alternative methods can be developed that will markedly improve the safety and efficiency of traffic movement.

### 2. Network flow

**Objective:** To define the characteristic equations of network flow for a general set of movement systems.

**Scope:** In concentrated urban areas, movement of traffic must take place on existing networks of streets. At the present time the main means for expediting such traffic is through standard traffic engineering procedures, generally on a section-by-section basis. However, it is recognized that the flow on any one segment interacts with other portions of the network. Thus, improvement of urban traffic flow must be conceived as a network optimization problem. The analysis of street networks, however, is complicated by the nature of human and vehicle characteristics which impose unique constraints to flow. The ultimate objective of this research is to provide an understanding of the nature of urban traffic movement and to provide the basis for improvement in traffic engineering of such systems.

## Highway Component Design

**Objective:** To develop improved analytic techniques for designing the components of highway transportation systems.

The design and construction of highways depend, to a large extent, upon the principles that are available to define the properties of the materials used, and the design criteria employed. Improvement in the speed, durability, and efficiency of construction, which defines the ultimate economy of highway engineering, requires more flexibility in the utilization of materials than currently is possible. Similarly, the ultimate safety that can be engineered into highway transport depends upon those principles which will define how the components of that system should be integrated. At present, the design and construction of highways are constrained by the lack of many of the principles that would optimize these processes. To initiate work in these areas, the following projects have been established:

### 1. Materials characteristics and behavior

**Objective:** To determine the constituents and physical structure of materials that control the behavior of engineering systems. Empirical and secondary relationships which are currently used lead to gross inaccuracies in predicting the performance of structures. Ultimately, construction techniques, test methods, and specifications can be based on fundamental characteristics.

**Scope:** Possibilities for making significant progress in acquiring basic knowledge of materials have been greatly enhanced by recent developments and improvements in instrumental techniques, such as: electron microscopy, nuclear magnetic resonance, spectroscopy, gas chromatography, x-ray diffraction, and radioactive tracer techniques. These and other available tools are necessary to define the complex characteristics of highway engineering materials. Major emphasis will be given to studies of natural materials--materials unique to highway use--and those manufactured materials that can be made economically available in the large quantities needed for highway construction.

Studies to be conducted will be classified under four major tasks as follow:

- a. Basic Constitution and Structure of Materials and their Relation to Engineering Properties
- b. Fundamental Interactions within Materials Systems
- c. Environmental Effects on Materials Systems
- d. Reactions and Mechanisms of Special Treatments for Improving Properties of Materials Systems

### 2. Dynamic stresses in structural systems

**Objective:** To develop mathematical equations and digital simulation techniques which properly reflect the influence of nonlinear and inelastic elements in highway pavements and structures on the development of dynamic stresses, and to determine the influence of surface profile and vehicle suspension systems on the dynamic loadings.

Scope: Present methods of design for highway bridges make allowance for dynamic effects by empirical methods based on experimental work and the results of linear elastic analysis. Pavement design methods consider dynamic loadings in an indirect manner. Much improved methods of analysis exist for both problems, but their use has been limited because they fail to reflect two important aspects of the problem; namely, (1) the nonlinear and visco-elastic effects in pavements or energy absorption at supports in bridges, and (2) the essentially random (stochastic) nature of the vehicle loadings. This project seeks to define the effects of these variables and to relate the statistical nature of dynamic stresses to the design problem.

This project is related to a number of applied research efforts of the program, including the prediction of the life expectancy of bridges and pavements, the rational design of flexible pavement systems, and questions related to the requirement for pavement smoothness and the steering control problem. Contract funds will be used to conduct certain fundamental analytical studies and to develop special-purpose instrumentation to be used in the collection of verification data.

3. Driving control processes

Objective: To define the processes by which a driver locates himself with reference to other vehicles and to the highway, to describe the information handling and decision-making processes involved in the driving task, and to define the mechanics of driver control of vehicular position in time and space.

Scope: The consideration of the human operator of a vehicle as a component in the highway transport system requires an understanding of his unique sensory and motor capabilities and limitations. In order to achieve maximum operational efficiency and safety in highway transport, these factors must be taken into account in the design of the highway and vehicle. Otherwise, the driver may be placed in situations where he is unable to handle adequately the functions of steering control, absolute velocity control, or relative velocity control, and a serious breakdown in performance may result. This is considered to be a main contributing factor in road accidents. Therefore, a concentrated research effort aimed at analysis of the driving task is essential and of paramount importance before any marked and economical improvements can be made in the operational efficiency of traffic flow and the safety of highway transport.

4. Streambed stability adjacent to structures

Objective: To define the forces which cause scour at structures in streambeds and to develop mathematical equations to compute depths and extent of scour.

Scope: Whenever an obstruction, such as a bridge pier, is placed in an alluvial streambed, forces are set up which cause removal of the bed material around the obstruction, the depth of this hole

becoming deeper as the flood stage rises. This phenomenon is called local scour. Unless the designer has anticipated the maximum depth of scour, or has found it possible and economical to get the foundation down to bedrock, there is danger that the footings will be undermined and the bridge collapsed. Such a failure occurred on an Interstate Highway Bridge on the Big Sioux River two years ago. Laboratory model investigations have provided qualitative answers identifying factors which affect the relative depth and extent of scour, but have failed to provide a reliable method of estimating the actual depth which would occur for an actual structure. The research will include analytical and experimental studies to define the mechanics of the scour process, development of techniques to measure scour as it occurs on field structures, correlation of field observations with developed theory, and, finally, development of a working method to compute probable depth and extent of scour for use in design of piers and other structures placed in streambeds.

5. Behavior of pavement system components under cyclic stress

Objective: To define in analytic terms the flow and fracture behavior of materials used in pavement systems, such as bituminous concrete, stabilized soil mixtures, and natural soils, under varying strain rates, states of stress, and ambient conditions, including the response to cycles of dynamic stress.

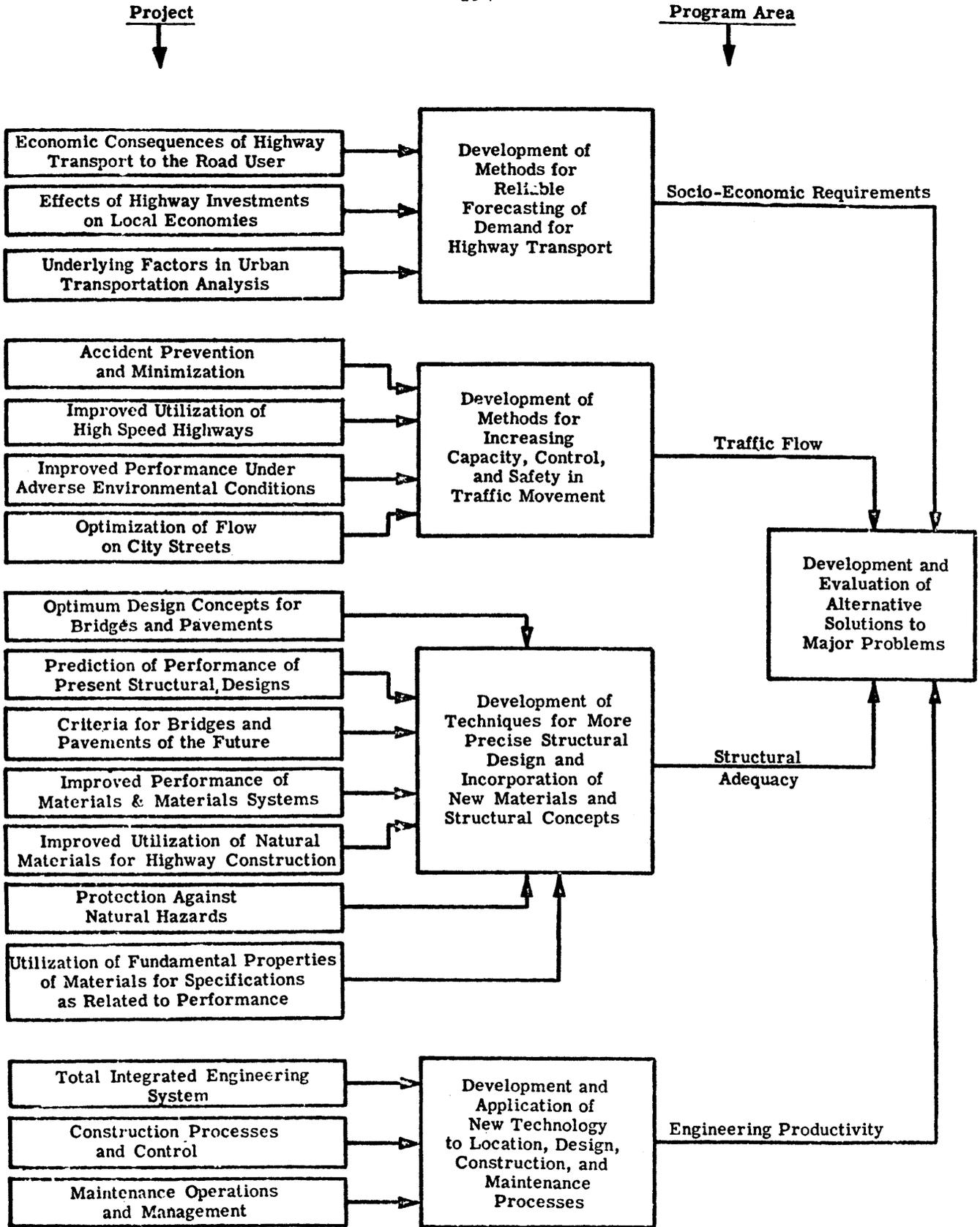
Scope: Development of a rational design theory for flexible pavement systems requires that the detailed response of component materials to complex states of stress and time-dependent cyclic loadings be known. Studies are anticipated in both the analytical field, to devise conceptual models of elastic, visco-elastic, and plastic materials which can be incorporated into stress analysis methods, and also in the experimental area, to measure these properties for typical material components and to determine how these properties may be modified by construction techniques or environment.

## II. New Methods Research and Development (Applied) - Development and Evaluation of Alternative Solutions to Major Problems. (See Figure 3)

Applied research and development must be aimed at solving real problems in highway engineering and administration within a reasonable length of time. These problems need to be identified and then assigned priority according to the likelihood that the payoff will be substantial. The payoff can be measured in savings in the cost of construction, operation or maintenance of highway facilities, in benefits to the highway users, and in benefits to the community and the nation as a whole. The total payoff should be expected to be many times the cost of the R&D program if the most significant problems are attacked.

The organization of a program of applied research and development must be closely integrated with major engineering and operational problems whose solution would provide high payoff within two to three years. The following major classification evolves from the sequence in the consideration of the function of transportation. Thus, the limits placed upon highways define the REQUIREMENTS which must be met. Secondly, the basic aim of the highway network is to move people and goods from one place to another; i.e., TRAFFIC FLOW. Thirdly, the pavements, bridges, and other structures must provide the STRUCTURAL ADEQUACY to resist load and climatic stresses. Finally, constant attention to ENGINEERING PRODUCTIVITY will be needed to keep abreast of changing technology.

1. Socio-economic Requirements: The development of methods for forecasting of demand for highway transportation and the defining of factors that generate both supply and demand for transportation.
2. Traffic Flow: Development of methods for increasing capacity, control, and safety in the movement of traffic, considering geometric design of the highway, design of vehicles, and performance capabilities of drivers.
3. Structural Adequacy: The development of techniques for the optimum structural design of pavements and their foundation, as well as bridges and drainage structures, and the development of methods to insure construction to optimum specifications. This includes also the analysis of existing and new highway construction materials for improving the economy and durability of highway structures.
4. Engineering Productivity: The development and application of new technology to location, design, construction, and maintenance processes.



NEW METHODS AND TECHNIQUES (APPLIED R&D)

FIGURE 3

The advantages to this classification for applied research and development include (a) the objective of a study can be more readily identified with the major function to which it is addressed; (b) comparisons between projects and priorities for studies can be more readily accomplished; and (c) benefits derived are divided so that advantages to the user are reflected primarily in the first two groups, whereas savings in government expenditures are primarily contained in the last two groups.

#### Socio-economic Requirements for Highway Transportation (Figure 4)

**Objective:** Development of methods for reliable forecasting of demand for highway transportation.

In order to determine the location and design requirements for highways and networks of highways, it is necessary to develop reliable methods for determining the demand for and the interrelation of this demand with the supply of available transportation. In addition, for adequate planning and evaluation of highway facilities, more complete techniques must be developed to measure and predict the social and economic consequences of highways. This requires research at three levels of the transportation design processes: (1) the economic and social benefits and costs to the road user; (2) the economic effects of highway investment on the local communities which they serve; and (3) the sociological and demographic forces determining highway usage and utility.

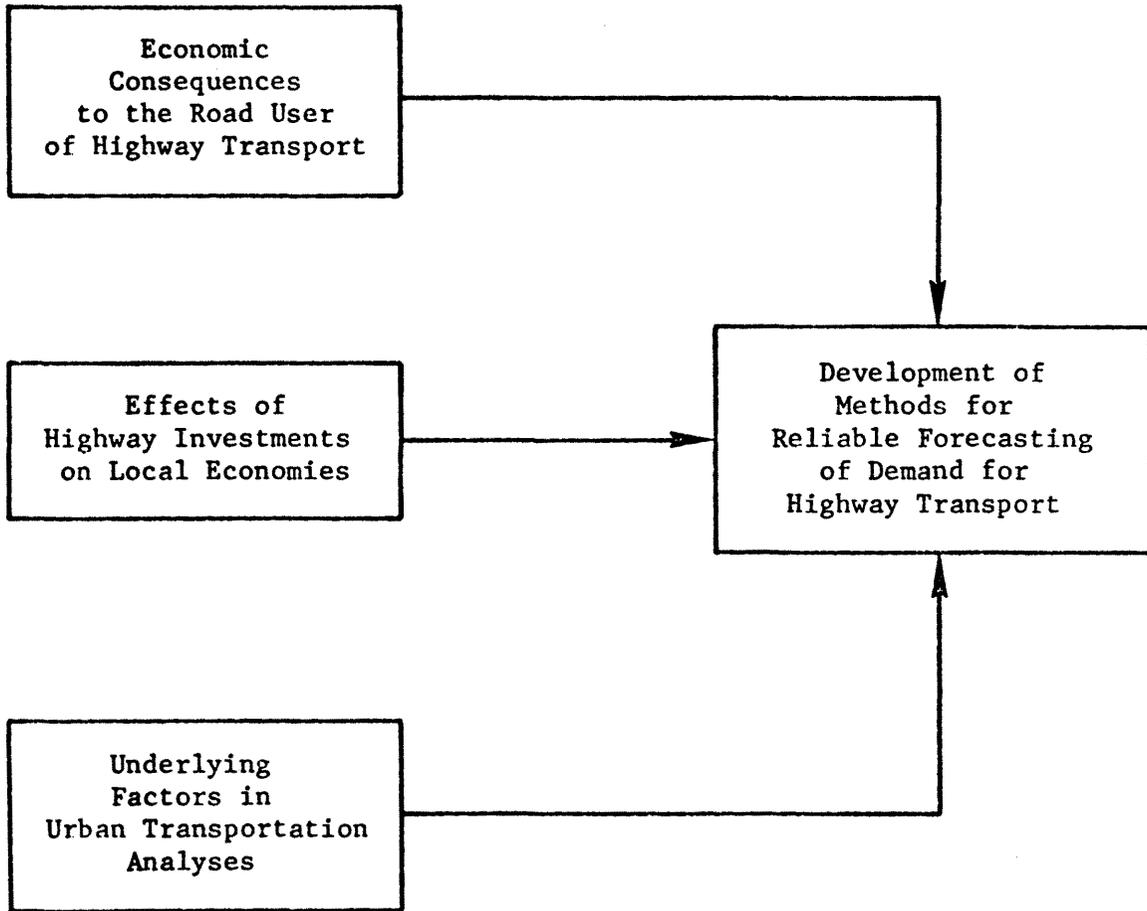
1. Economic consequences to the road user of highway transport

**Objective:** To determine the essential criteria that users employ to evaluate a highway and a routing to a destination, and to relate these criteria to the economics of transportation.

**Scope:** The satisfactions obtained and the ultimate highway and motor vehicle costs that the road user must bear are essential determinants of the economic efficiency in design and location of highways. Many of the factors that make up these determinants depend upon the user and his scales of value, as well as the characteristics of the highway facility itself. The results of these studies will provide measures of the factors determining the utility functions for the road user, and the means for their conversion into dollar terms. By deriving the relations for certain of the intangible factors and consequences of highway improvement, a specific solution of the benefit-cost analysis can be developed.

2. Effects of highway investment on local economies

**Objective:** To determine the effects of highway investment on changes in land value, land use, business activity, and market area influences of improved highways, and to develop a methodology of predicting these influences.



SOCIO-ECONOMIC REQUIREMENTS FOR HIGHWAY TRANSPORT

FIGURE 4

Scope: A problem of long-standing importance in highway transportation is the impact of new or improved facilities on economic activity adjacent to the highways, as well as within the communities in which they are placed. Over-all benefits from highways must be viewed in terms of the gains or losses accruing to highway-related businesses, as well as "spill-over" effects to other business activities. The output of this research will be a series of predictive relationships for measuring the economic impact of highways upon the land uses and business activities adjacent to highways.

The methodology and items to be considered will vary according to the complexity of the economic structures, the size and type of place to be studied, and the transportation dependence of the relevant activities.

3. Underlying factors in urban transportation analyses

Objective: To define the critical variables underlying urban transportation requirements and to develop methods for their rapid and reliable measurement.

Scope: Current methods of forecasting future highway requirements in urban areas demand complex and large-scale sampling of transportation users and usage patterns. Current techniques are extremely time-consuming and have potential for considerable range of error in future estimates. The purpose of studies in this area is to validate current forecasting assumptions and to determine the minimum number of variables that must be measured, and with what accuracy, to reliably predict future requirements. The ultimate aim is to develop rapid, improved procedures for determining transportation needs.

### Traffic Flow Requirements (Figure 5)

**Objective:** The development of methods for increasing capacity, control, and safety in traffic movement.

The efficiency of movement and control of traffic is the ultimate determinant of the adequacy of the design of highways. Problems arising in system operations have significant effects that equal or exceed the actual cost of the facility. Accidents, capacity constraints, delays, are all examples of user costs arising out of the limitations in the operating performance of the system. Because of the nature of the design or the constraints imposed on design, performance is compromised in many ways. Ultimately, the problem is to specify which restrictions are the most critical and to provide means to eliminate them either by additions to existing highway or incorporation in the design of new facilities. The specific operational problems that are most critical and for which improvements seem most possible are in the areas of (1) the reduction of certain classes of accidents; (2) the improvement in certain operating characteristics of high-speed highways; (3) improved performance under adverse environmental conditions; and (4) traffic movement on street networks.

#### 1. Accident prevention and minimization

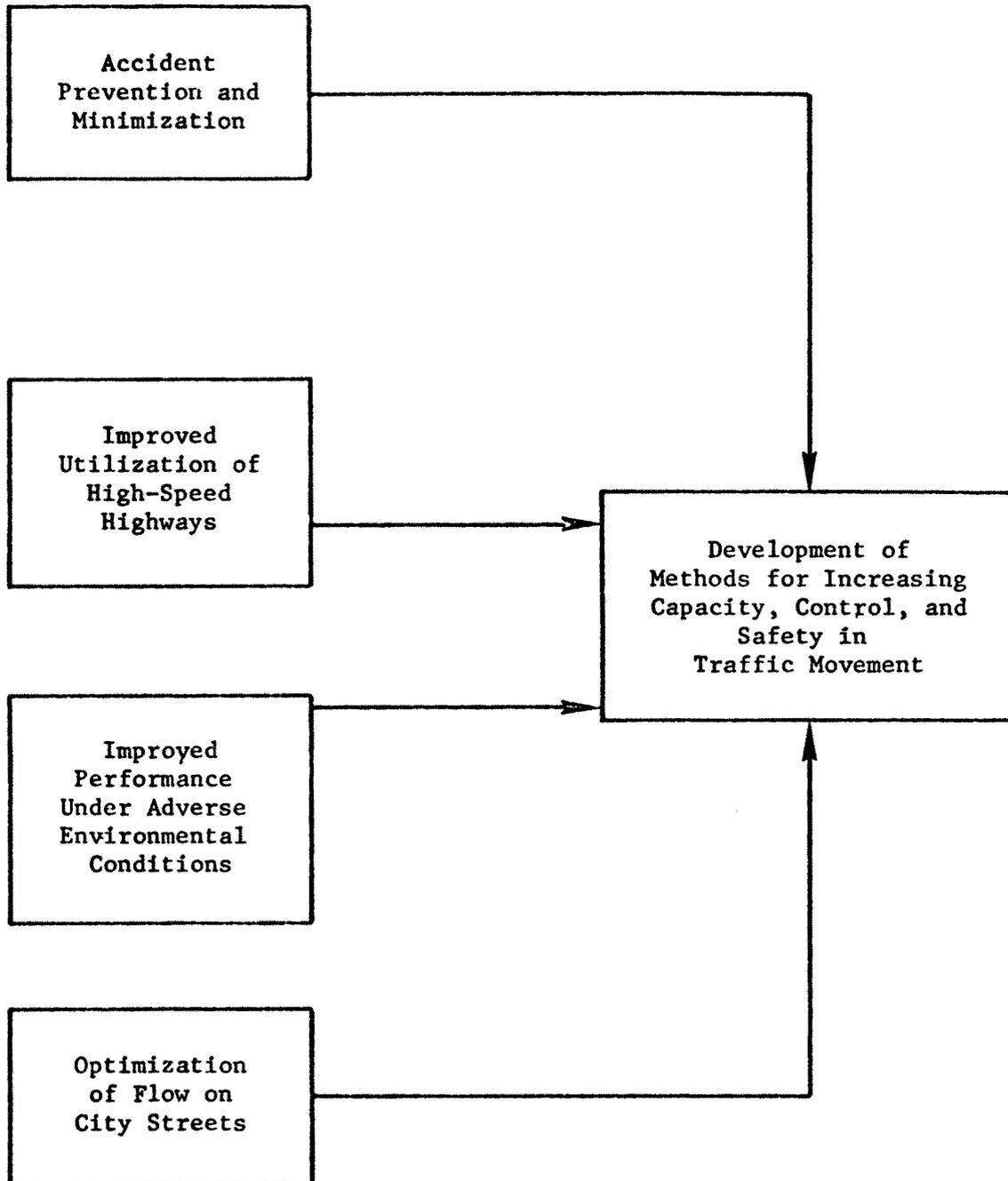
**Objective:** To provide alternative solutions for eliminating or minimizing the effects of the following classes of accidents (1) rear-end and head-on collisions on rural two-lane highways; (2) single-vehicle accidents in rural areas; and (3) urban intersections.

From what is now known, it is improbable that a general solution to the accident problem is possible within the next five years. It appears far more promising to concentrate research and development on those classes of accidents whose dynamics are understood and for which an economic solution appears possible. Implementation of this research should reduce accidents by 25 percent, injuries by 35 percent, and fatalities by 50 percent.

##### a. Rear-end and head-on collision prevention

**Objective:** To provide the needed accident data; to design information-processing and display systems; and to evaluate their effectiveness.

**Scope:** Most of the basic dynamics of the free overtaking rear-end collision accidents are known and it is possible to design and evaluate alternative systems for aiding the driver in solving the discrimination and judgment problems inherent in these situations and in head-on collisions as well. It is expected that within four years one or more systems will be developed that can significantly reduce these classes of collisions.



TRAFFIC FLOW REQUIREMENTS

FIGURE 5

b. Accident minimization, rural highways

Objective: To complete the solution of the structural design of barriers and to engineer that design into a system that can be installed at a cost of one-half that of present median barriers and guardrails.

Scope: For a second type, the single-vehicle accident, it appears possible at least to reduce severity. At present, these accidents account for approximately 60 percent of the total. In general, these accidents appear to occur at random. It is proposed to minimize their effects by guardrails and barrier devices. The problem is twofold. One is to determine the optimum structural design, and the other is the economy of construction. Other types of accidents would also have their effect minimized by such barriers.

c. Urban intersection accidents

Objective: To determine the interrelations between the information loading on the driver and control errors in speed and position and to develop information displays and control devices which minimize the uncertainty at urban intersections.

Scope: Approximately 60 percent of the collisions between vehicles in urban areas occur at intersections. This high frequency appears to be due to three factors: (a) high information loading on the driver; (b) ambiguity in decision operations; and (c) inaccuracy in relative velocity judgments. The purpose of studies in this area is to examine the dynamics of these accidents, especially as they relate to the geometry of the intersection and the response limitations of drivers. From this can be derived the modifications required in both information and control systems.

2. Improved utilization of high-speed highways

Objective: To improve the efficiency of traffic movement on high-volume freeways through developments in (1) the geometric design and (2) interchange utilization.

a. Geometric design requirements

Objective: To specify gradient, curvature, and sight distance requirements that will provide minimum turbulence in high-speed flow.

Scope: Research is required in this area to define the optimum characteristics that must be included in the basic design of the highway. These include criteria and methods for specifying sight distances, curvature, and gradient.

b. Interchange utilization

Objective: To define the optimum capacity of merging lanes which does not reduce mainstream capacity and to develop a ramp metering and merging control system which insures that both access points and mainstream traffic operate at maximum efficiency.

Scope: There is an important trade-off between access utilization and mainstream flow. At one end, present methods of injecting vehicles are inefficient and ramp capacity is low. At the other, merging introduces turbulence in mainstream flow which influences capacity and safety. The problem depends, to a large extent, under high-volume conditions, on the behavior of drivers in detecting acceptable gaps and adapting their merging to the movement of the gap. For most situations, the driver needs to be aided if optimum utilization of the ramp is to be obtained.

3. Improved performance under adverse environmental conditions

Objective: To increase highway safety and efficiency through the improvement of (1) night visibility conditions; and (2) pavement surface characteristics.

The safety and efficiency of traffic movements are markedly influenced by a variety of weather and similar conditions. Accident rates at night are approximately double those in daylight, and capacity is severely reduced under wet, icy, or foggy conditions. Of the wide range of environmental influences, two are proposed for study because of their significance. One is the degradation of performance in darkness, and the other is the effects on vehicle performance under poor surface conditions.

a. Night visibility

Objective: To define the effects of glare and restriction in visibility in darkness as they influence accidents, and to develop lighting and headlighting systems to minimize the effects of glare on sight distance in night driving.

Scope: In order to provide for safer and more effective use of highways at night, means must be found for reducing glare produced by present headlighting systems, and providing more efficient illumination of the driver's visual field. With reduced glare, seeing and comfort would be radically improved, traffic performance would be improved, and accident and fatality rates would be substantially reduced. The purpose of research in this area is to examine the feasibility and utility of alternative headlighting systems, including a polarized system, which can be efficiently substituted for the present system without a long transition period. Consideration will be given to public acceptance of systems, and benefits and costs will be evaluated, in addition to any undesirable side effects. Highway illumination will also be examined as first a supplement to vehicle lighting. Ultimately, it will be necessary to develop an optimum night driving environment.

b. Frictional characteristics

Objective: To define the mechanics of transition from rolling to sliding friction; to define the optimum pavement characteristics for maintaining high coefficients of friction; and to develop warning and braking control techniques for minimizing the loss of friction.

Scope: The area of frictional characteristics is the single most important factor in the operation of a high-speed facility. Under conditions of wet or icy pavements, the effective capacity of roadways decreases significantly. Research is required in three aspects of this problem in order to increase the utility of highway transport under wet conditions. One is the analysis of the tire-road interface at the transition between rolling and sliding friction. Such analysis will define tire and roadway characteristics required to reduce the sensitivity to lowered coefficient of friction. The second is the analysis of the roadway surface and its drainage characteristics. The third aspect is the prediction and control of skidding. Although skidding must always occur under certain conditions, the effective break-away point is determinant. If the factors determining incipient skidding can be measured, then it becomes possible to predict a skid and also to prevent it. The objective of this research, therefore, is to define the factors which determine incipient skidding.

4. Optimization of flow on city streets

Objective: To develop the design variables for network control systems; to develop signal systems and information devices whose interconnection can meet the optimum design requirements; and to develop communication systems for routing traffic through a network and, in so doing, obtain maximum utilization of street capacity.

Scope: At the present time, there is a generally low efficiency in the movement of traffic on street networks. However, the city streets are the dominant means of distributing traffic into and out of an urban area. The improvement in utilization of existing networks not only can reduce the need for new highways, but is also needed in order to make the urban freeways fulfill their essential functions. The major problems on networks of streets concern the control of traffic, and the availability of appropriate information to optimize control. Several alternatives exist for providing driver, traffic, and directional information based either in the roadway or in the vehicle. Coupled to the same specialized computer equipment as used for signal interconnection, the network flow data can be analyzed for both purposes and used to optimize network flow.

### Structural Adequacy Requirements (Figure 6)

**Objective:** Development of techniques for more precise structural design and incorporation of new materials and structural concepts.

Construction and maintenance costs of highways depend in large measure on the structural adequacy of the design in relation to the site conditions and the frequency of heavy loads. The optimization of design will become possible only as a better understanding of structural behavior is attained by well-planned research and development on the component materials and their performance in field structures. The greatest emphasis in this program will be placed on pavement design, where the need for development of reliable methods is most pressing.

1. Optimum design concepts for bridges and pavements

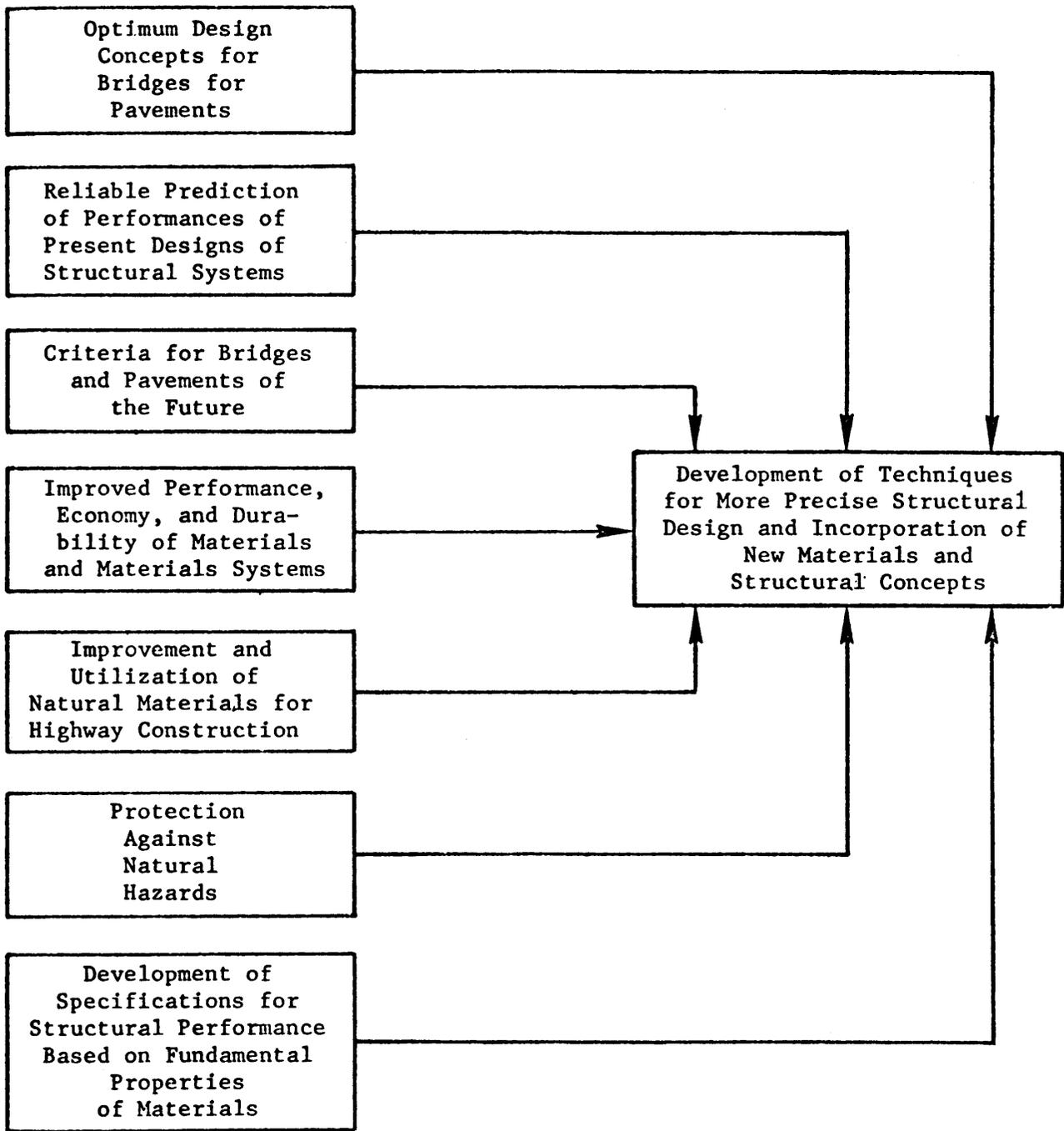
**Objective:** To improve design concepts and analysis methods for bridges and pavements to obtain uniform design standards, and to make optimum use of available materials with reliable prediction of behavior.

**Scope:** The achievement of optimum designs of structural systems such as bridges and flexible pavements is now largely dependent upon the experience and judgment of the designer. The reliability of his design is also somewhat dependent on his judgment, since not all aspects of its behavior can be based upon firm scientific analyses. This project will, therefore, seek to (1) remove elements of empiricism from the design process wherever possible; and (2) to systematize the design process by which a number of alternates which are all structurally sound may be quickly compared to obtain the best design within appropriate economic and aesthetic constraints. Initial efforts in this project will concentrate upon two specific tasks: the development of a rational design method for flexible pavements, and the optimization of the design of grillage type bridges, with and without skew.

2. Reliable prediction of performances of present designs of structural systems

**Objective:** To improve our ability to predict the future performance of bridges and the length of time of satisfactory performance which can be expected of our existing pavements, including the effects of possible large increases in size, weight, and frequency of heavy vehicles, and the influence of adverse environments.

**Scope:** The ability to predict the performance of existing pavements and structures and of those being built by current design criteria is essential to obtain a realistic picture of future maintenance and replacement requirements. Present methods are based upon hypotheses concerning the effects of increased size, weight and frequency of heavy loads. Such methods are inadequate but are the best that can be derived from existing empirical and incomplete knowledge concerning the cumulative damage due to loadings and adverse environmental conditions. The project will seek to place these predictions upon



STRUCTURAL ADEQUACY

FIGURE 6

an adequate scientific basis. It consists of two broad areas of study, the first aimed at a precise definition of the spectrum of loadings produced by the traffic stream and the environmental cycles, including dynamic effects, and the second concerned with the establishment of hypotheses to predict effects of this spectrum upon the stress levels in the system components and the development of a reliable hypothesis of cumulative damage.

3. Criteria for bridges and pavements of the future

Objective: To anticipate and obtain preliminary solutions for the special problems which will arise in providing structures and pavements for speeds in the 100-mile-per-hour range and vehicles with gross weight up to twice present limits.

Scope: The economics of highway transport and demands of the motoring public both point to a strong possibility of much higher speeds and much heavier loads, possibly in conjunction with substantial changes in the vehicles involved. Such changes will produce changes in the requirement for highway structural systems which may call for radical innovations and not merely proportionate increases in strength. Surface profile tolerance will become such a crucial element that the required tolerance may be quite impossible with existing systems and methods of construction. Dynamic effects will also be greatly amplified and may require bridges to be designed on stiffness criteria based on these dynamic effects. Both of these elements may be greatly modified by the type of vehicle suspension system to be permitted, and the consequences of a decision in this matter on the cost of the structural systems should be assessed. Finally, new criteria for the geometrics of such high-speed facilities will place new requirements on the structures for overpasses and ramps, and may also require the development of a complete new generation of protective structures.

All of the above studies must be carried out with an attempt to exploit fully the new structural materials and systems which are now available.

4. Improved performance, economy, and durability of materials and materials systems

Objective: To provide for greater efficiency and economy in highway construction and maintenance by seeking out the causes of deterioration; establishing more precise techniques for selecting materials; and developing, evaluating, and using new materials or new construction techniques to counteract destructive forces and environment.

Scope: New materials or new uses of existing materials will be evaluated through accelerated laboratory testing and field installations. Information developed by related tasks in the fundamental area will be integrated as they become available. New materials developed by independent industry research or in other scientific

fields will also be evaluated. Existing pavements and structures as well as new experimental construction will be examined and tests will be made to determine the causes for various levels of performance. The following two major tasks under this project are of primary concern at the present time:

- (1) Durability of Structural Concrete Bridge Decks, and
- (2) New Materials for Highways.

5. Improvement and utilization of natural materials for highway construction

Objective: To develop means for obtaining satisfactory performance from low-cost materials that are inherently substandard or borderline in quality.

Scope: The need for this project arises from three important situations: (1) the rapid nationwide depletion of acceptable aggregates; (2) the lack of good local materials for use as aggregates; and (3) the economic and practical limitations on the removal of unsuitable materials from the highway site.

The importance of the depletion of acceptable aggregates is often overlooked but the urgency of this problem can be illustrated by the estimate that the expanding highway construction program, in the 16-year period 1956 to 1972 will require 9 billion tons of sand, gravel, and crushed stone--an amount of material sufficient to build a wall from New York to San Francisco 100 feet high and 90 feet wide. The following two major tasks under this project are of primary concern at the present time:

- (1) Physical and Chemical Stabilization of Soils, and
- (2) Beneficiation of Substandard Aggregates.

6. Protection against natural hazards

Objective: To devise more effective means of protection of highway systems against the natural hazards of wind and flood.

Scope: The highway system is a vital element in the communications system, which must remain intact to maintain essential services in periods of major natural disasters such as floods and hurricanes. In addition, the occurrence of minor floods and heavy winds often causes great economic loss by destruction of highway elements or by delays to traffic movement by a temporary reduction of capacity. Although complete immunity to such losses cannot be expected within a reasonable cost, much can be done to improve present protective measures and to determine the justifiable investment on a sound basis. The initial efforts on this program will seek to exploit recent fundamental work on bridge pier scour to evolve designs for

bridges which will possess a much higher degree of safety in flood conditions and to modify the design methods for urban highway drainage to minimize delays to traffic. Studies will be required to expand the programs of field beneficiation of scour protection methods, and to implement detailed local studies of urban highway storm drainage by new procedures now under development in the fundamental program. In addition, field collection of data on full-sized structures is needed to study ways to protect major suspension bridges against the danger of aerodynamic instability due to wind.

7. Utilization of fundamental properties of materials for specifications as related to performance

Objective: To provide specifications, test methods, and design criteria for highway materials and materials systems based on fundamental operative characteristics and requirements rather than on empirical or secondary relationships.

Scope: Two tasks of major importance concern the analysis of asphalt binders and the evaluation of completely new materials for highway uses. In regard to asphalts, they have a wide range of physical and chemical properties. Because of the diversity and complexity of available materials, asphalt specifications have developed on a trial-and-error basis. Empirical tests have been relied upon to measure and control the properties of the materials within desired limits. However, there is often only an indirect relationship between the empirical parameters and the functional properties of the asphalt. Much greater use needs to be made of fundamental properties of asphaltic binders--rheology, durability, and composition. The relation of these properties to the properties of paving mixtures and thus to the performance of paving mixtures during construction and service must be determined for a wide range of typical asphalts in order to provide sound specifications.

Means must be developed to evaluate new materials or combinations of materials developed through fundamental research; materials developed by industry specifically for highway purposes or materials developed in other disciplines will be evaluated. Such evaluation must include three levels of effort: (1) initial screening on the basis of available data and existing general knowledge of the art to eliminate obviously unsuitable materials; (2) preliminary laboratory screening to demonstrate potential usefulness; and (3) thorough laboratory study and field evaluation to establish the limits of usefulness and the specifications for using the new product. Systematic procedures are required in order to provide new materials with known benefits as well as known limitations.

### Engineering Productivity Research (Figure 7)

Objective: The development and application of new technology to the location, design, construction, and maintenance processes.

Many of the steps in highway engineering and maintenance currently require extensive hand labor and complex manual computations. These operations not only are significant elements in the costs of highway construction and maintenance but also cause considerable increase in time required for the total construction process. In addition, the optimum ordering and organization of the total engineering and maintenance process has never been determined on an analytic basis. Such an operations analysis of these processes will provide a detailed methodology for providing optimum utilization of manpower and time. These two areas reflect the most promising areas for the greatest improvement in highway engineering and maintenance.

#### 1. Total integrated engineering system

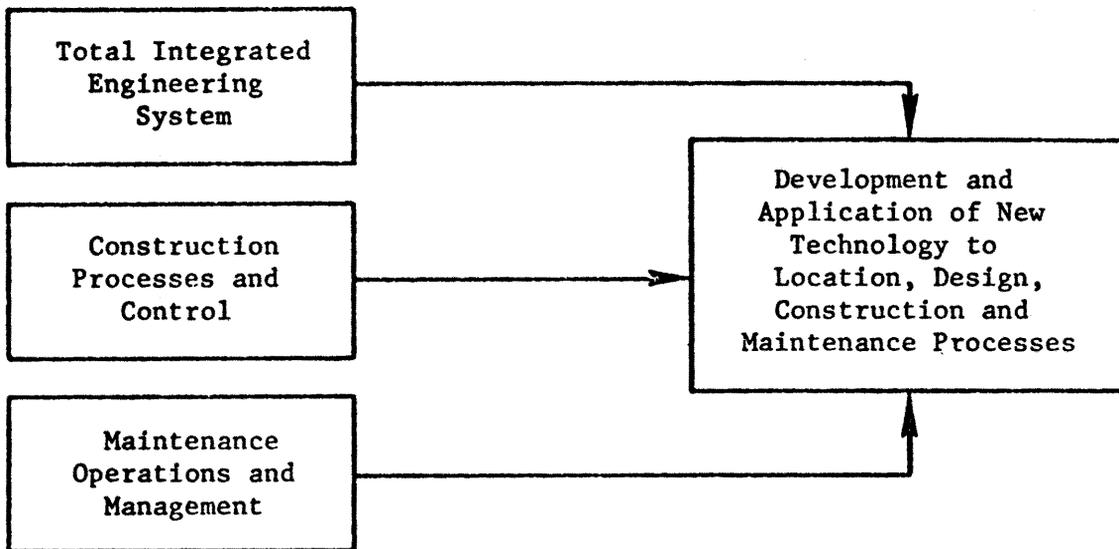
Objective: To develop a system for performing highway engineering in which available technological developments will be adapted to achieve optimum division of function between man and machine. Engineering operations now performed with little interrelationship will be combined into an integrated series of operations.

Scope: In order to take full advantage of existing computer technology in highway engineering, far more complete integration of the steps in that process is needed. Careful analysis of the variety and content of each step is needed in order to develop the logic for computer handling and in addition to define the new computer technology needed to improve the efficiency and economy of the engineering process. The goal is to develop an integrated system that will permit engineers to design highways more rapidly and efficiently, to control their construction, and to permit new methods of design.

#### 2. Construction processes and control

Objective: To develop improved specifications for the construction processes and improved control methods by which the productivity of the highway construction industry may be increased, thereby reducing construction costs, and controlling the quality of construction to a level compatible with the need.

Scope: In order to make marked improvements in construction process, intensive effort must be directed toward the development of quality control and acceptance inspection methods as well as the development of nondestructive test methods. Further, continuing evaluation of construction equipment and procedures is needed in order to develop criteria for improved equipment and construction practice.



ENGINEERING PRODUCTIVITY RESEARCH

FIGURE 7

3. Maintenance operations and management

Objective: To develop improved methods and equipment for the conduct of efficient and economic highway maintenance.

Scope: Maintenance operations are highly diversified activities involving scheduled and unscheduled actions requiring a variety of materials, skills, and equipment. In order to make these more efficient and economic, a thorough analysis of the operations is required. The optimum location and staffing of maintenance centers needs to be determined, as do the equipment and material supplies and their use. Further, new equipment needs to be developed as do more effective means of communication and information flow in order to make maintenance operations more readily responsive to unscheduled activities and to carry them out more effectively.

APPENDIX C  
HIGHWAY RESEARCH PROJECT STATEMENTS - NCHRP-HRB

## APPENDIX C

The following summary and list of projects are taken from Report 55 of the National Cooperative Highway Research Program of the Highway Research Board (51). This research was sponsored by the American Association of State Highway Officials in cooperation with the U.S. Bureau of Public Roads. The study, conducted as a joint venture by Bertran D. Tallamy and Associates and Wilbur Smith and Associates, was completed in 1968.

The procedure recommended in the study consists of identifying the goals of the appropriate organization, and the research problems that have been identified from both a technical and an administrative point of view. By computer sorting, the problems that are most relevant to the goals are identified. The study produced 900 research problems; the following summary shows 253 that are applicable to the assumed goals.

HIGHWAY TRANSPORTATION RESEARCH GOALS  
AND RELATED PROBLEM AREAS

HTR GOAL NO. 1: To improve highway planning, design and construction as part of an integrated transportation system.

Related Problem Areas

1. Quality control of highway construction
2. Design and construction criteria for the accommodation of maintenance
3. Standards for relating levels of service on freeways to economic and land-use considerations
4. Determination of sizes, weights and performance requirements (limits) for highway vehicles
5. Concepts and criteria for the integration of highways with other modes in the total transportation system

HTR GOAL NO. 2: To improve the role of highway transportation in optimizing land use and urban development by improving the safety, serviceability and operations of the present highway system.

Related Problem Areas

1. Accommodation or reduction of obstructive highway appurtenances
2. Utilization of existing streets and highways to their maximum capability
3. Operation of streets and highways during night-time and poor visibility periods
4. Development of maintenance techniques and equipment compatible with operating requirements on high-speed expressways
5. Surveillance and control of traffic flow on urban street and highway systems

HTR GOAL NO. 3: To foster the integration of the highway with the community through improved identification and quantification of sociological, political, economic and aesthetic factors in highway transportation.

Related Problem Areas

1. Aesthetic considerations in the design, maintenance and operation of highways
2. Impact of various types of design features of highways upon environmental values
3. Accommodation of multiple use of right-of-way in urban areas

PROBLEM AREA 1-1 PROJECT STATEMENTS  
QUALITY CONTROL OF HIGHWAY CONSTRUCTION

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
23 - 91	MC D (53)	\$ 70	41 - 29	SC 8	\$ 97
Improved specifications of minimum deformed fabric steel requirements for all classes and diameters of concrete culvert pipe.			Development of prototype equipment to measure pavement thickness by radioactive techniques.		
25 - 112	SGFB1 (37)	\$ 79	41 - 30	SC 8	\$ 97
Investigation, by means of high-pressure triaxial testing, deformation properties of Macadam bases and correlation of these characteristic with equivalent plate-load or dynamic test characteristics.			Development of a radioactive system to determine pavement strength.		
25 - 114	SGFB1 (37)	\$ 79	41 - 183	MOST	\$ 97
Laboratory testing and evaluation procedures for pavement surfacing and subsurfacing elements, relating to the field loading environment.			Development of rapid methods for quality control of maintenance materials.		
25 - 115	SGFB1 (37)	\$ 97	41 - 230	MOST (62)	\$ 97
Establishment of detailed criteria and techniques for the triaxial evaluation of paving materials.			Development of device to measure pavement contour including profile and transverse slope.		
26 - 69	MC C (52)	\$ 97	41 - 255	MOST (62)	\$145
Development of an improved procedure for specifying and controlling smoothness of pavement surface during construction.			Use of nuclear and sonic devices for determination of the position and condition of reinforcing steel and of the soundness of wood.		
26 - 463	D BO4 (61)	\$133	61 - 33	SC 8	\$ 97
Development of a non-contact, high speed profilometer.			Development of a laboratory device employing the use of a radioisotope to determine moisture and density of compacted samples.		
31 - 253	MOST	\$ 79	61 - 72	MC C3 (52)	\$ 97
Development of and instruments for field measurement of kinematic viscosity of asphalt in cut-back and emulsion form.			Field testing procedure for rapid and accurate determination of classification, optimum density, maximum moisture, and degree of compaction for soils.		
32 - 254	MOST (62)	\$ 97	61 - 153	SGFC1 (37)	\$ 79
Development of criteria for defining un-sound cement concrete and development of a test method for determining un-soundness.			Evaluation of presently available equipment and procedures for sampling sand and gravel deposits and development, if possible, of new equipment and techniques.		
33 - 1107	INT	\$ 70	62 - 97	SGFA1 (37)	\$ 61
Develop a field test to assure that the strength of field welds meets design standards.			Evaluation of properties of soils compacted in the field in relation to the properties of samples compacted by standard laboratory tests.		
34 - 76	MC D (52)	\$ 97	62 - 99	SGFA1 (37)	\$ 85
Determination of a sampling procedure for crushed stone which would give results with known degree of confidence.			Development of criteria needed for test rolling soils of different types and varying conditions to insure capability and establishment of a correlation between these data and subgrade bearing values.		
34 - 1009	INT	\$ 97	62 - 100	SGFA1 (37)	\$ 97
Develop material specifications and testing procedures that give recognition to statistical variations which will occur in large-scale testing programs.			Determination of the minimum compaction for all heights of embankment and all soil types to ensure that highway embankments will not consolidate by detrimental amounts.		
40 - 207	MOST (62)	\$115			
Development of guidelines for selecting regionally the best materials for the construction of non-skid surfaces, by means of a study of materials and methods used in the past.					

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
40 - 267	M O2 (62)	\$169	64 - 107	SGFA3 (37)	\$ 79
Development of standards for measuring the quality and adequacy of the maintenance performed on various highway systems and under various jurisdictions the object is to establish a level of maintenance economically justified on a benefit-cost ratio.			Development of laboratory tests to indicate qualitative and quantitative improvement of soils from the stabilization provided by sodium chloride and calcium chloride.		
			64 - 109	SGFA4 (37)	\$ 79
			Determination of uniform test procedures for quality control and durability of lime treated soils and aggregates.		

## PROBLEM AREA 1-2 PROJECT STATEMENTS

DESIGN AND CONSTRUCTION CRITERIA  
FOR THE ACCOMMODATION OF MAINTENANCE

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
23 - 440	D AO2 (61)	\$ 70	41 - 451	D A.5	\$ 97
Determination of feasibility of sloping pavements on divided highways to drain toward the median in order to minimize moisture concentration under the outside lane.			Establish criteria for evaluation of function, design, and location of highway rest areas.		
27 - 292	M 10 (62)	\$ 97	41 - 1006	INT	\$169
Definition of criteria and type of appurtenances to be used for maintenance facilities for large, long-span bridges. Initial construction should take into account need for maintenance facilities.			Evaluate highway design features-such as irregular or narrow turf areas, steep slopes, inaccessible areas, etc. to permit mechanization of maintenance activities such as mowing, cleaning, and painting. The resultant use of hand labor is costly and often dangerous.		
27 - 431	D AO2 (61)	\$100	51 - 388	TO 10	\$ 61
Balance of benefits against costs for shoulders on bridge structures and classification of structures on which full shoulders are warranted.			Determination of need for crossovers on the interstate system to prevent the interstate from becoming more hazardous.		
40 - 300	M 2	\$ 61	51 - 1162	INT	\$ 97
Study of feasibility of flush-mounting highway delineators to eliminate the maintenance problem presented by conventional type delineators.			Develop additives for asphalt and concrete pavements to prevent the formation of ice and to prevent slipperiness in wet weather.		
40 - 304	M 10 (62)	\$ 79	53 - 409	TO 10 (39)	\$115
Establishment of guidelines and methods for underdrain and filter material maintenance.			Determination of design criteria for shoulders on the interstate system which will have minimal cost for maintenance and capital improvement.		
40 - 387	TO 6 (45)	\$115	54 - 2210	TO 3 (39)	\$115
Prevention of the surface of bridges from icing prior to approach pavements.			Determine the differences in characteristics of traffic flow between spacious and constricted interchanges.		
40 - 561	FSCO4	\$115	55 - 2205	TO 2 (31)	\$ 97
Determination of effect upon the road user of maintenance operations.			Collection of data on weekend and recreational travel.		
40 - 1166	INT	\$115	64 - 1109	INT	\$ 97
Develop better snow and ice removal techniques and design highway cross sections to minimize snow drifting.			Approach slabs to bridge. A need exists to improve the design and maintenance technique of approach slabs to bridges.		
41 - 279	M 05	\$115			
Evaluation of existing buried-pipe and infrared ice-melting systems to determine minimum heat requirements and weaknesses in the design.					

## PROBLEM AREA 1-3 PROJECT STATEMENTS

STANDARDS FOR RELATING LEVELS OF SERVICE ON FREEWAYS  
TO ECONOMIC AND LAND-USE CONSIDERATIONS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
15 - 431	D A02 (61)	\$100	53 - 428	D A02 (61)	\$115
Balance of benefits against costs for shoulders on bridge structures and classification of structures on which full shoulders are warranted.			Determination of best geometric design for reducing the number of through lanes on freeways, including the location for interchange ramp terminals, the geometric design of transition areas and signing and delineation at the transition.		
15 - 583	FSCO6	\$ 97	53 - 432	D A02 (61)	\$ 85
Determination of the pricing of highway services, particularly the allocation of costs for added capacity for urban commuter traffic.			Establishment of specific design criteria for each highway interchange type and preparation of a comprehensive summary of selected existing interchanges relating vehicular operation to design variables.		
15 - 649	FSCO6	\$ 97	53 - 435	D A02 (61)	\$ 97
Study of the allocation of expressway costs including both user and non-user benefits.			Determination of the best type of intersection at a crossroad ramp terminal for different conditions and the development of basic designs for crossroad ramp terminals.		
15 - 2097	INT	\$ 97	53 - 436	D A02 (61)	\$ 97
Develop standards for the justification for various levels of service in both urban and rural areas.			Determination of minimum distances between successive ramp terminals and the minimum distances between an entering ramp and an exiting ramp under varying conditions.		
22 - 315	TO 03 (39)	\$ 79	53 - 439	D A02 (61)	\$ 79
Determination of best design for medians on urban expressways where right of way is costly or otherwise limited.			Determination of minimum distances from ramp termini to the end of access control for various crossroad ramp terminal designs and of minimum distance from ramp termini to crossovers on divided crossroads.		
22 - 359	TO 09 (24)	\$ 97	53 - 2209	TO 3 (39)	\$ 97
Study of when the net effect of traffic composition and loading in a given environmental situation requires additional lanes, or wider lanes, or wider shoulders, etc.			Evaluate effect of sight distance on traffic operations in the vicinity of freeway ramp terminals.		
22 - 408	TO 03 (39)	\$ 97	54 - 2205	TO 2 (31)	\$ 97
Determination of the structural requirements of shoulders for the design traffic and establishment of the relationship of the function of the shoulder structure to the through pavement structure.			Collection of data on weekend and recreational travel.		
22 - 410	TO 10 (39)	\$ 61	54 - 2210	TO 3 (39)	\$115
Establishment of the need, the criteria and desirable widths for left shoulders on multilane divided highways, particularly on the three lane directional highways.			Determine the differences in characteristics of traffic flow between spacious and constricted interchanges.		
22 - 422	D A02 (61)	\$ 85	55 - 353	TO 7	\$115
Determination of the condition under which a collector-distributor road is the most advantageous design.			Formulation of mathematical models on vehicular speeds in urban areas under various traffic and environmental conditions.		
22 - 430	D A02 (61)	\$115	55 - 376	TO 10 (45)	\$ 43
Evaluation of the performance and suitability of various narrow median designs to determine acceptable criteria for achieving safety and economy.			Development of a list of types of vehicles, animals, and equipment which should be prohibited from the interstate system.		
22 - 434	D A02 (61)	\$115	55 - 570	FSCO4	\$115
Determination desirable geometric design for freeway ramp terminals.			Determination of the benefits to users of improved highways and the benefits to the users of the older highways as a result of lowered volumes.		

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 2042	INT	\$ 97	55 - 2201	TO 2 (31)	\$ 79
Develop design standards for junior expressways to lessen right-of-way and construction cost requirements, as well as detrimental impact on land uses and other considerations.			Standardization of data collection area units.		
52 - 346	TO 07 (25)	\$ 79	83 - 713	L 05	\$ 61
Development of a method for rating or proposed traffic service facilities for the level of service provided.			Analysis of administration of access controls to indicate how legal controls can be made to reflect changing land use and traffic needs.		
53 - 425	D A02 (61)	\$ 79			
Determination of best type of acceleration and deceleration lanes applicable to at-grade intersections and interchange ramp entrance and exit terminals.					

## PROBLEM AREA 1-4 PROJECT STATEMENTS

DETERMINATION OF SIZES, WEIGHTS, AND PERFORMANCE REQUIREMENTS  
FOR HIGHWAY VEHICLES

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 1004	INT	\$115	55 - 351	TO 04	\$ 97
Determine firm limits on vehicle size and weight to permit long-range design planning.			Development of refined knowledge on the influence of trucks on the traffic-carrying capacities of intercity rural highways.		
31 - 55	MC A (50)	\$ 97	55 - 353	TO 7	\$115
Determination of effects on skid resistance of aggregate type, size and grading, surface texture, and the speed of the vehicle.			Formulation of mathematical models on vehicular speeds in urban areas under various traffic and environmental conditions.		
40 - 1011	INT	\$100	55 - 368	TO 12	\$115
Examine improved uniformity of highway laws regulating the design, construction, maintenance, and operation of highways.			Study of vehicle stopping characteristics at night in order to establish a design stopping sight distance analysis of operational factors such as object, headlight beam, roadway geometrics and safety factors, in order to propose a maximum night speed limit.		
51 - 19	UTP14	\$ 79	55 - 375	TO 12 (45)	\$ 85
Correlation between handling characteristics of various classes of vehicles and their safety records.			Development of criteria for speed limits on rural highways that would be established by particular road design rather than by blanket state-wide fiat.		
51 - 1153	INT	\$100	55 - 376	TO 10 (45)	\$ 43
Determine and disseminate to the vehicle driver optimum speeds for a given set of traffic conditions by using computers and other electronic devices.			Development of a list of types of vehicles, animals, and equipment which should be prohibited from the interstate system.		
52 - 2043	INT	\$ 79	55 - 635	FSCO4	\$133
Evaluate examination and licensing of drivers of certain age and physical capabilities and restrict certain vehicles in poor condition from high speed facilities.			Establishment of maximum, minimum, and optimum potential acceleration capabilities of passenger cars, single-unit trucks, and trailer combinations.		
55 - 18	UTP14	\$100	55 - 1030	INT	\$115
Establishment of guidelines for more consistent speed limits, based on vehicle, driver, and highway characteristics.			Relate demand for higher speeds and increasing of speed limits and need for more knowledge on speed considerations in vehicle-driver-highway system.		
55 - 332	TO 6 (45)	\$ 97			
Determination by brand names, of the role of design, size, and weight that vehicles play in traffic safety.					

## PROBLEM AREA 1-5 PROJECT STATEMENTS

CRITERIA FOR THE INTEGRATION OF HIGHWAYS  
WITH OTHER MODES IN THE TOTAL TRANSPORTATION SYSTEM

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
11 - 1051	INT	\$ 85	84 - 22	UTPO4	\$ 97
Determine acceptable levels of comfort, safety, convenience in planning various mixes of transportation modes.			Use of the cost and benefit estimates of urban transportation system studies to evaluate proposed systems. Suggested objectives would be preparation of lists of data for this evaluation process and then development of methods for evaluating proposed alternative systems.		
22 - 2004	INT	\$133	84 - 24	UTPO4	\$115
Develop guidelines on such matters as when to depress or elevate; how to relate freeways to parking facilities; how to coordinate with public transportation facilities in highways or otherwise; air rights; vehicular-pedestrian separations; road plans related to urban renewal program.			Quantitative description of the operation of urban passenger transfer points for all combinations of modes and development of models for simulating and evaluating different designs under various loadings.		
22 - 2210	TO 3 (39)	\$115	84 - 26	UTPO4	\$ 97
Determine the differences in characteristics of traffic flow between spacious and constricted interchanges.			Determination of the form of mass transit required in metropolitan areas and determination of which values should apply in search of new or modified mass transit systems.		
55 - 326	TO 01 (26)	\$ 79	84 - 545	FSCO2	\$ 97
Development of criteria for successful change of mode parking in all sized cities.			Determination of minimum transportation facilities needed for representative type of urban communities.		
55 - 344	TO 07 (25)	\$175	84 - 547	FSCO2	\$133
Quantification of the parameters that define the quality of traffic service on both rural and metropolitan transportation systems and relation of these parameters to each other.			Determination of the demand for mass transportation for commuting, by means of experimentation that may require subsidizing mass transit companies.		
55 - 401	TO 04	\$115	84 - 548	FSCO2	\$ 61
Determination and evaluation of all means of making transit services speedy and attractive in the more congested urban areas.			Develop guidelines for a highway construction program which will keep abreast of current needs and a study of overall future transportation requirements.		
55 - 2201	TO 2 (31)	\$ 79	84 - 558	FSCO3	\$ 85
Standardization of data collection area units.			Examination of the travel patterns and other factors that might be affected by the ability of the consumers to buy the type of transportation most desirable.		
55 - 2202	TO 2 (31)	\$133	84 - 600	FSCO7	\$ 85
Determine the differences in trip production per household obtained through the use of personal versus telephone interviewing methods.			Department of economics, finance, and administration study of the effect of metropolitan planning agencies in developing a metropolitan transportation system.		
55 - 2206	TO 2 (31)	\$115	84 - 619	FSCO1	\$115
Determine the sensitivity of assigned traffic to changes in trip distribution as calculated by mathematical models.			Collection of comparable cost data for alternative modes of urban passenger transportation, including social costs, portal-to-portal costs, seat-mile costs, parking costs, subsidized costs, journey-to work costs.		
81 - 2034	INT	\$115	84 - 2046	INT	\$115
Evaluate factors of urban life to help plan and provide improved urban environments and transportation in the future. Many socio-economic disciplines are involved, not just engineers and planners.			Evaluate possible changes in trains, buses, and taxis with particular emphasis on the interactions between combinations of these revised systems and consumer needs for urban transport, especially in low income areas of urban complexes.		
81 - 2200	TO 2 (31)	\$ 79			
Determination of adequate home interview sample sizes for transportation surveys.					

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
82 - 6	UTPC3	\$ 97	84 - 2205	TO 2 (31)	\$ 97
Development of a standard method for measuring the socio-economic characteristics and attitudes of users of mass transit, including a review of past practices in transit passengers studies.			Collection of data on weekend and recreational travel.		
84 - 20	UTPO4	\$115	90 - 1113	INT	\$ 97
Evaluation of feasibility of all bus transit operation in intermediate size cities which would utilize reserved rights of way and limited stops. The object would also include investigation of one or more of the most promising transportation systems in intermediate size cities.			Evaluate interface problems between transportation systems, to help speed and simplify the movement between systems.		
84 - 21	UTPO4	\$ 97	90 - 1150	INT	\$ 97
Determination of demand for transportation to and from major airports and the feasibility of a variety of means meeting this demand.			Develop scientific parameters for evaluating different modes of urban transportation.		

## PROBLEM AREA 2-1 PROJECT STATEMENTS

ACCOMMODATION OR REDUCTION OF OBSTRUCTIVE  
HIGHWAY APPURTENANCES

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 430	D A02 (61)	\$115	27 - 17	UTP14	\$ 79
Evaluation of the performance and suitability of various narrow median designs to determine acceptable criteria for achieving safety and economy.			Updating of a ASHO Bridge rail specifications through application of developments in structural dynamics and analytical methods of rail performance prediction.		
22 - 447	D A04	\$115	53 - 379	TO 06 (45)	\$115
Determination of the optimum height for guardrails.			Determination of how to effectively delineate or illuminate obstructions located within a roadway in order that a night driver might readily comprehend the object.		
22 - 449	D A04 (61)	\$133	53 - 380	TO 06 (45)	\$ 70
Design of guardrail end that will present a minimum hazard to vehicle striking it.			Determination of the best location for traffic signal faces with maximum signal face observance.		
22 - 732	TO 01	\$133	53 - 382	TO 05 (45)	\$ 85
Determination of traffic safety on free-ways related to location of lighting and sign structures.			Improvement of current signal design and installation practices through implementation of demonstrated human factors principles.		
22 - 1019	INT	\$145	53 - 2041	INT	\$145
Evaluate causes of accidents in relationship to the design of better highways and appurtenances.			Determine proper placement and design of supports for over the road structures to decrease collisions and reduce severity of accidents.		
24 - 390	TO 06 (46)	\$130	53 - 2045	INT	\$115
Study of the likelihood of accidents in terms of the proximity of fixed objects in order to design safer structures that must be kept closer to the travel ways and to establish safe offsets.			Develop guidelines relating to the expense, design standards, and placement of major sign structures.		
24 - 411	TO 03 (39)	\$ 97	53 - 2209	TO 3 (39)	\$ 97
Development of a standard for protection of physical elements adjacent to the shoulder area.			Evaluate effect of sight distance on traffic operations in the vicinity of freeway ramp terminals.		

## PROBLEM AREA 2-2 PROJECT STATEMENTS

UTILIZATION OF EXISTING STREETS AND HIGHWAYS  
TO THEIR MAXIMUM CAPABILITY

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
15 - 577	FSC05	\$ 97			
Study of the full costs of urban street systems.					
15 - 578	FSC05	\$ 97			
Improvement of techniques for valuation of urban streets systems and study of investments in typical urban areas.					
15 - 579	FSC05	\$115			
Development of a sufficiency railing system or index of adequacy for urban streets.					
15 - 1123	INT	\$ 97			
Develop a method for determinign the optimum number of lanes in a highway versus the construction of a new highway.					
51 - 386	TO 5	\$133			
Establishment of relationship between capacity and accidents, using pavement width available to entering traffic adn all volume to represent the capacity factor. The object is the eventual prediction of the number of accidents likely to occur at locations under similar conditions.					
51 - 1140	INT	\$ 79			
Determine guidelines for the optimum maximum number of lanes in the direction on highways for safety and economy's sake.					
53 - 308	TO 01 (26)	\$ 97			
Study the easily measurable demand factors which can be applied to the determination of parking and traffic needs for material streets and determination of the effects of timing and density controls on parking demands.					
53 - 312	TO 07 (25)	\$ 61			
Study of the actual installations of two types of intersections,					

## PROBLEM AREA 2-3 PROJECT STATEMENTS

OPERATION OF STREETS AND HIGHWAYS DURING  
NIGHT-TIME AND POOR VISIBILITY PERIODS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 359	TO 09 (24)	\$ 97	53 - 327	TO 11	\$100
Study of when the net effect of traffic composition and loading in a given environmental situation requires additional lanes, or wider lanes, or wider shoulders, etc.			Study of methods of alerting drivers to changes in conditions, determination of driver information needed for satisfactory driving, and effect of various kinds of distraction upon the transmission of information to the driver.		
22 - 423	D A02 (61)	\$115	53 - 331	TO 03	\$109
Determination of driver stopping distance to be used as a basis for minimum sight distance criteria for the design of highways. Information is needed for various types of pavement, for different sizes and types of tires, and for wet and dry pavements.			Investigation of possibility of using television monitor device in automobiles for penetrating fog.		
22 - 726	TO 01	\$169	53 - 368	TO 12	\$115
Determination of the optimum economic design for illumination level and uniformity of freeway lighting, related to accident occurrence.			Study of vehicle stopping characteristics at night in order to establish a design stopping sight distance. Analysis of operational factors such as object, headlight beam, roadway geometrics, and safety factors in order to propose a maximum night speed limit.		
22 - 730	TO 01	\$115	53 - 373	TO 06 (45)	\$ 61
Evaluate existing lighting on urban interstate freeways and develop practical economic improvements to meet optimum standards.			Study of need of reducing speed limit through signs on parts of the interstate system during hazardous weather.		
22 - 731	TO 01	\$ 97	53 - 374	TO 13 (45)	\$145
Establish proper design for adaptation level and interior tunnel illumination for optimum safety and traffic efficiency.			Development of warrants for lighting for interchanges on controlled-access highways to reduce accidents.		
22 - 732	TO 01	\$133	53 - 379	TO 06 (45)	\$115
Determination of traffic safety on freeways related to location of lighting and sign structures.			Determination of how to effectively delineate or illuminate constructions located within a roadway in order that a night driver might readily comprehend the object.		
22 - 733	TO 01	\$ 97	53 - 402	TO 10	\$ 97
Measurement of pavement directional brightness factors from typical viewing angles and luminaire placements and to summarize prior investigations.			Determination of how to detect stopped vehicles, how to approach them under severe and limited operating conditions, and what equipment and organization are necessary to move or remove the stoppage.		
22 - 734	TO 01	\$ 97	53 - 729	TO 01	\$ 85
Expand and consolidate prior studies of visibility under fog and rain conditions by special lighting.			Determine significant facts regarding use of illumination for highway traffic guide and control signs.		
22 - 735	TO 01	\$ 97	53 - 1014	INT	\$115
Evaluate different classes of urban streets by accident rates versus uniformity and levels of illumination.			Evaluate improvement of nighttime visibility provided by vehicle headlights.		
34 - 1188	INT	\$ 97	53 - 1029	INT	\$115
Determine the best type of street lighting for freeways.			Develop standards to improve present red rear lighting to inform following drivers of vehicle movements in lead vehicle.		
40 - 237	MOST	\$115	53 - 1134	INT	\$ 97
Determination of the cost and performance level of nighttime maintenance operations.			Develop devices to warn motorist of dangers on high-speed highways.		
40 - 277	M 05 (62)	\$ 97	53 - 2209	TO 3 (39)	\$ 97
Determination of the effect of traffic movement on the snow and ice melting process and the minimum heat necessary to keep traffic moving.			Evaluate effect of sight distance on traffic operations in the vicinity of freeway ramp terminals.		

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
41 - 228	MOST (62)	\$ 61	53 - 2212	TO 3 (39)	\$115
Optimization of illumination on snow-plowing vehicles.			Determine operation effect of sign placement on the traffic stream.		
53 - 35	SC 8	\$ 97	90 - 1189	INT	\$115
Investigation of nuclear materials as light sources for illumination of highway signs and their relative safety in use.			Study improved nighttime visibility on highways by better light reflectance and markings.		
53 - 256	MOST	\$ 97			
Investigation of nuclear devices, sensitive to temperature change, which would activate warning signals at time of icy, snowy, and frosty conditions.					

## PROBLEM AREA 2-4 PROJECT STATEMENTS

MAINTENANCE TECHNIQUES AND EQUIPMENT COMPATIBLE  
WITH OPERATING REQUIREMENTS ON HIGH-SPEED EXPRESSWAYS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 1006	INT	\$169	40 - 1002	INT	\$ 97
Evaluate highway design features - such as irregular or narrow turf areas, steep slopes, inaccessible areas, etc. to permit mechanization of maintenance activities such as mowing, cleaning, and painting. The resultant use of hand labor is costly and often dangerous.			Determine standards for traffic control during maintenance operations, because increasing traffic volumes make maintenance operations difficult, expensive, and dangerous to employees and highway users.		
27 - 292	M 10 (62)	\$ 97	40 - 1031	INT	\$ 85
Definition of criteria and type of appurtenances to be used for maintenance facilities for large, long-span bridges. Initial construction should take into account need for maintenance facilities.			Establish improved construction and traffic control techniques for handling re-surfacing projects on busy urban highways.		
31 - 235	MOST (62)	\$115	40 - 1165	INT	\$124
Improvement of techniques and equipment for bituminous surfaces.			Determine optimum manpower and equipment used in snow removal operations and perform systems analysis in scheduling work crews and determining time-cost factors relative to hiring extra men and equipment.		
31 - 241	MOST	\$100	40 - 1166	INT	\$115
Exploration of feasibility of pumping asphaltic patching material by a pneumatic method.			Develop better snow and ice removal techniques and design highway cross sections to minimize drifting		
40 - 182	MOST (62)	\$100	41 - 220	MOST (62)	\$145
Development of new pavement patching materials, capable of being placed with rapidity using minimum equipment.			Development of new litter pickup equipment which would perform the same function as a vacuum cleaner.		
40 - 204	MOST	\$100	41 - 221	MOST (62)	\$124
Development of fast-drying effective traffic paint and practical pre-painting, preparation of pavement surfaces.			Development of economical washing equipment for sign cleaning without traffic blockage.		
40 - 209	MOST (62)	\$ 79	41 - 223	MOST (62)	\$124
Improvement of methods for determining the optimum time for rehabilitation of existing pavements.			Development of an efficient rigid pavement joint cleaning machine.		
40 - 217	MOST	\$115	41 - 243	MOST	\$ 79
Development of new fast and inexpensive erosion control materials for highway maintenance.			Improvement of remote control methods of mowing for application to other maintenance operations, especially on the interstate system.		
40 - 252	MOST	\$ 79	41 - 279	M 05	\$115
Study of present communication requirements for highway maintenance and development of guidelines for optimum communication facilities.			Evaluation of existing buried-pipe and infrared ice-melting systems to determine minimum heat requirements and weaknesses in the design.		
40 - 300	M 2	\$ 61	41 - 281	M 05 (62)	\$115
Study of feasibility of flush-mounting highway delineators to eliminate the maintenance problem presented by conventional type delineators.			Evaluation of Tippmann's method of snow melting.		
40 - 561	FSC04	\$115	41 - 1038	INT	\$115
Determination of effect upon the road user of maintenance operations.			Establish the most economical size equipment for sign and paint striping maintenance operations.		

## PROBLEM AREA 2-5 PROJECT STATEMENTS

SURVEILLANCE AND CONTROL OF TRAFFIC FLOW ON  
URBAN STREET AND HIGHWAY SYSTEMS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
15 - 578	FSC05	\$ 97	53 - 348	TO 04	\$ 97
Improvement of techniques for valuation of urban streets systems and study of investments in typical urban areas.			Detection of reasons for unbalanced use of urban arterial lanes by drivers and development of suggested procedures for more balanced use.		
15 - 579	FSC05	\$115	53 - 356	TO 5	\$ 97
Development of a sufficiency rating system or index of adequacy for urban streets.			Study of factors affecting gap and lag acceptance under two-way stop and yield control and simulation of models for analysis of these controls.		
22 - 318	TO 03 (45)	\$ 97	53 - 360	TO 04	\$ 79
Minimization of lane changes and merging of traffic to fewer lanes at interchanges.			Determination of whether the banning of left turns at intersections on two-way streets is truly practical and if not, establishment of the feasibility of installation of multiphase signalization to accommodate the turns.		
22 - 319	TO 03 (45)	\$ 61	53 - 362	TO 04	\$ 61
Provision of a guide for minimum spacing of crossovers (median openings) on divided highways without control of access.			Determination of feasibility of coordinating essential midblock traffic entrances with the overall arterial signal progression.		
22 - 320	TO 03 (45)	\$ 79	53 - 363	TO 04	\$115
Development of a design for median for surface highways in urban areas, permitting good access to abutting property and achieving high capacity for through movements and maximum safety.			Comparison of the efficiency, as a group, of several streets making up a traffic corridor, when operating one-way as compared to two-way.		
22 - 424	D A03 (61)	\$ 97	53 - 364	TO 04	\$ 79
Increase of knowledge regarding the design and operation of 2-lane turning roadways including the determination of geometric criteria and the reevaluation of existing design standards for 2-lane left turns at grade.			Development of procedures for describing the level of service provided by two-way stop-controlled intersections under any specified volume conditions.		
22 - 425	D A02 (61)	\$ 79	53 - 365	TO 10	\$169
Determination of best type of acceleration and deceleration lanes applicable to at-grade intersections and interchange ramp entrance and exit terminals.			Development of design criteria for traffic control systems to control the distributor system as a function of the freeway demand.		
22 - 2059	INT	\$ 70	53 - 367	TO 10	\$145
Develop criteria for control of expressway access by functional design and incorporation of surveillance systems to prevent overloads and breakdown of transport facilities.			Determination of how to distribute traffic over freeways and arterial streets to best accommodate peak-hour movements of traffic.		
51 - 13	UTP14	\$ 97	53 - 373	TO 06 (45)	\$ 61
Continuation of analysis of roadside obstacle research begun by Mr. Stonex, with eventual development of an analytic model useful for design requirements.			Study of need of reducing speed limit through signs on parts of the interstate system during hazardous weather.		
51 - 232	MOST	\$ 97	53 - 378	TO 05 (45)	\$ 97
Evaluation of various means of providing effective, emergency communication systems on controlled access highways.			Determination of the best use of green arrows for split phase signal operation to provide uniform operation with minimal vehicular delay and conflicts.		
51 - 256	MOST	\$ 97	53 - 385	TO 05	\$ 43
Investigation of nuclear devices, sensitive to temperature change, which would activate warning signals at time of icy, snowy, and frosty conditions.			Determination of the amount of delay that pedestrian traffic causes vehicular traffic at a four-way stop controlled intersection.		

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
51 - 390	TO 06 (45)	\$130	53 - 402	TO 10	\$ 97
Study of the likelihood of accidents in terms of the proximity of fixed object in order to design safer structures that must be kept closer to the travel ways and to establish safe offsets.			Determination of how to detect stopped vehicles, how to approach them under severe and limited operating conditions, and what equipment and organization are necessary to move or remove the stoppage.		
52 - 327	TO 11	\$100	53 - 429	D A02 (61)	\$ 61
Study of methods of alerting drivers to changes in conditions, determination of driver information needed for satisfactory driving, and effect of various kinds of distraction upon the transmission of information to the driver.			Identification of criteria for the design and operation of reversible freeway roadways.		
52 - 329	TO 11	\$ 79	53 - 2062	INT	\$133
Analysis of the Driver's ability to acquire information by sensing relevant data from the environment about velocity, headway, and acceleration. Study of his methods of sensing and decision making in emergency situations. Develop models showing how information acquisition will affect flow, density, and highway safety.			Ways and means of diverting that portion of peak traffic which would congest the freeways but allow express buses entry, and devise ways to improve peak-hour flows on parallel surface facilities. Methods of informing motorists of alternate routes to their destinations.		
52 - 330	TO 03	\$ 97	54 - 357	TO 09 (24)	\$ 97
Identification and measurement of significant driver stimuli, motivations, and reactions affecting freeway driving.			Study of the relationship between traffic flow and the speed at which changes in density, speed, or flow are propagated along the roadway, the object is to estimate the probable effect of alternative courses of action in preventing high accident potential inherent in shock waves.		
52 - 343	TO 09 (24)	\$ 97	54 - 361	TO 04	\$ 97
Effect of speed on a driver's information reception capabilities.			Determination of the effectiveness of continuous reserved left-turn lane.		
52 - 352	TO 12	\$ 85	54 - 366	TO 10	\$ 97
Determination of factors which influence a motorist's selection of his desired travel lane.			Development of means for reducing the space required between vehicles without sacrificing safety or speed.		
52 - 358	TO 09 (24)	\$ 97	54 - 2205	TO 2 (31)	\$ 97
Study of car-following behavior, including the perception by the driver of the actions of the vehicle ahead and the influence on his decisions by these actions. The object is to improve the design of visual and electronic displays which assist drivers to measure their velocity, relative to the car ahead.			Collection of data on weekend and recreational travel.		
52 - 404	TO 10	\$ 97	54 - 2206	TO 2 (31)	\$115
Study of data on actual freeway blockages caused by distractions and study of effect of distractions on accident potential.			Determine the sensitivity of assigned traffic to changes in trip distribution as calculated by mathematical models.		
			54 - 2207	TO 2 (31)	\$ 97
			Develop a technique for estimating the movement of traffic in a small area at high speed.		
			84 - 2028	INT	\$115
			Develop guidelines for automatic vehicle controls to develop safer operations on motorways under high-capacity conditions.		

## PROBLEM AREA 3-1 PROJECT STATEMENTS

AESTHETIC CONSIDERATIONS IN THE DESIGN, MAINTENANCE,  
AND OPERATION OF HIGHWAYS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
11 - 258	MOST	\$ 70	22 - 2004	INT	\$133
Development of guidelines for maintenance operations and services to improve public relations and win public support of the highway program.			Develop guidelines on such matters as when to depress or elevate. How to relate free-ways to parking facilities. How to coordinate with public transportation facilities in highways or otherwise. Air rights. Vehicular-pedestrian separations. Road plans related to urban renewal program.		
11 - 621	FSC01	\$ 97	24 - 400	TO 07 (25)	\$109
Determination of techniques of land use control along highways, taking into account the costs, effectiveness, and public acceptance of land use guidance measures.			Determination of importance of esthetics as a traffic service quality and determination of a technique for measuring its importance.		
11 - 656	FSC07	\$ 97	24 - 451	D A 5	\$ 97
Determination of an effective method of administrative responsibility for urban highway extensions, so that those affected by the consequences of highway improvement are considered.			Establish criteria for evaluation of function, design, and location of highway rest areas.		
11 - 664	FSC08	\$115	24 - 452	D A05	\$ 97
Protection of natural landscape by legal or administrative devices.			Achievement of control of unsightly junkyards and vehicle graveyards by legislation.		
11 - 709	L 05	\$ 97	24 - 455	D A05	\$ 97
Study of the capability of highway and other public agencies to establish and administer corridor area land use controls and exploration of the range of authority to achieve desired scenic corridor development.			Study of the effect that various forms of landscape development have on property values adjacent to highways.		
13 - 10	UTPO3	\$100	24 - 607	FSC08	\$ 85
Reappraisal of relocation costs policy, evaluation of benefits to community by reducing displacee opposition, and formulation of a relocation costs concept which will result in greater public acceptance of decisions.			Effectiveness of federal provisions affecting outdoor advertising and identification of differing techniques for control of outdoor advertising.		
13 - 605	FSC08	\$ 115	24 - 665	FSC08	\$100
Determination of equitability of treatment to residents and businesses relocated from highway right-of-way and of manner to ease dislocations caused by highway programs.			Control of esthetics along highway right-of-way under police power.		
13 - 617	FSC08	\$ 61	24 - 672	LS 04	\$ 85
Relationship between the value of scenic easement and the value of the fee simple title of the property.			Study of sovereign powers of the state as they apply to lands and landuse in roadside areas around expressway interchanges.		
13 - 680	LS 02	\$ 97	24 - 1035	INT	\$ 85
Determination of rules for acquisition and valuation of air rights and easements for scenic purposes.			Develop guidelines for reducing maintenance costs since slope erosion, mowing 2/1 slopes, ditch cleaning and other roadside maintenance activities are increasingly costly on wide right-of-way yet interest in aesthetics makes good maintenance mandatory.		
15 - 622	FSC01	\$ 85	24 - 2036	INT	\$115
Measurement of the consequences of right-of-way displacement in terms of both compensable and non-compensable losses and recommendation of ameliorative procedures for individual inconvenience.			Determine characteristics, application, and desirability of various types of vegetation in different geographic locations.		
22 - 315	TO 03 (39)	\$ 79	70 - 608	FSC08	\$ 79
Determination of best design for medians on urban expressways where right of way is costly or otherwise limited.			Study of the use of highway right-of-way utilities and of problems of removing utilities from right-of-way property.		
			70 - 616	FSC08	\$ 79
			Study of guidelines and methods for establishing highway advertising rights.		

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 1006	INT	\$169	82 - 538	FSCO2	\$ 85
Evaluate highway design features - such as irregular or narrow turf areas, steep slopes, inaccessible areas, etc. To permit mechanization of maintenance activities such as mowing, cleaning, and painting. The resultant use of hand labor is costly and often dangerous.			Quantification of nonuser benefits of a highway by means of an index of impact.		
22 - 1034	INT	\$115	84 - 722	UTPO3	\$100
Develop economical guidelines and techniques for the improvement of highway aesthetics.			Determine the role of aesthetics as a community decision-making factor in alternative transportation systems selection, design and location.		

## PROBLEM AREA 3-2 PROJECT STATEMENTS

IMPACT OF VARIOUS TYPES OF DESIGN FEATURES  
OF HIGHWAYS UPON ENVIRONMENTAL VALUES

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
22 - 697	L 05	\$ 79	70 - 700	L 05	\$ 79
Study of various types of geometric design use in closure of streets and highways for control of access as they affect reasonableness of access and correlation with the judicial determination of whether a compensable injury to access has occurred.			Clarification of the extent to which frontage roads satisfy the requirement that roadside land not be deprived of reasonable access to adjacent highways.		
22 - 1025	INT	\$ 79	81 - 2030	INT	\$ 97
Evaluate build-up of interchange areas as it affects interchange operation and often thwarts design and operating plans.			Develop an up-to-date compendium of all pertinent knowledge concerning the broad subjects that influence regional planning. I. F. transit, drainage, roadway design, parking, sewerage, water supply, utility services.		
22 - 2029	INT	\$115	82 - 453	D A05	\$115
Develop standards suitable for use in environments where recognition must be given to the higher costs of interference with established land uses, and public utilities, connections to street systems must consider the safety of pedestrians and slower street traffic.			Establish physical standards for structures making multiple use of highway right-of-way including safety, strength, vibration, noise and air pollution.		
22 - 2042	INT	\$ 97	82 - 455	D A05	\$ 97
Develop design standards for junior expressways to lessen right-of-way and construction cost requirements, as well as detrimental impact on land uses and other considerations.			Study of the effect that various forms of landscape development have on property values adjacent to highways.		
24 - 612	FSC08	\$ 61	82 - 529	FSC01	\$ 97
Investigation of possible public action initiated to assure that businesses located near highways satisfy needs of highway users.			Determination of the effects of adding highways to an urban area with an existing highly developed system of roadways, including study of the relocation, tax rolls, and public services.		
24 - 665	FSC08	\$100	82 - 535	FSC01	\$115
Control of esthetics along highway right-of-way under police power.			Study of the economic and social effects of highways on neighborhoods.		
24 - 672	LS 04	\$ 85	82 - 544	FSC02	\$115
Study of sovereign powers of the state as they apply to lands and landuse in roadside areas around expressway interchanges.			Understanding of the influence of highway investment on private and other public investment, reorganization of land uses, relationship to demand in general, and the rate of economic growth.		
24 - 709	L 05	\$ 97	82 - 623	FSC08	\$ 97
Study of the capability of highway and other public agencies to establish and administer corridor area land use controls and exploration of the range of authority to achieve desired scenic corridor development.			Development of an economic model of simulate highway impact in order to determine the effects of transportation upon alternative communities and their economic activities.		
24 - 712	L 05	\$ 70	82 - 2004	INT	\$133
Analysis of the nature and extent of impact of private legal controls on highway in order to determine when regulation of roadside lands might be left to private means.			Develop guidelines on such matters as when to depress or elevate. How to relate free-ways to parking facilities. How to coordinate with public transportation facilities in highways or otherwise. Air rights. Vehicular-pedestrian separations. Road plans related to urban renewal program.		
24 - 1034	INT	\$115	83 - 4	UTPO2 (13)	\$ 97
Develop economical guidelines and techniques for the improvement of highway aesthetics.			Development of techniques for articulating land use planning goals, for evaluating alternatives, and for formulating a scale for relating community values to development form.		
55 - 321	TO 06 (45)	\$ 79			
Provision of design standards for width as a function of development density related to off-street parking supply for minor residential street.					

CODE NO.	SOURCE	COST
55 - 400	TO 07 (25)	\$109
Determination of importance of esthetics as a traffic service quality and determination of a technique for measuring its importance.		
55 - 401	TO 04	\$115
Determination and evaluation of all means of making transit services speedy and attractive in the more congested urban areas.		

CODE NO.	SOURCE	COST
83 - 518	FSC01	\$ 70
Determination of economic factors that underlie residential site selections by developers and by residents.		
83 - 526	FSC01	\$ 97
Study of land development and motor-vehicle uses at interchange points in order to develop the most desirable zoning and land use control at future interchanges.		
83 - 527	FSC01	\$115
Study of the role of highways in shaping land development and uses.		
84 - 205A	INT	\$ 97
Evaluate techniques for curtailing land developments as congested facilities restrain traffic flows.		

## PROBLEM AREA 3-3 PROJECT STATEMENTS

## ACCOMMODATION OF MULTIPLE USE OF RIGHT-OF-WAY IN URBAN AREAS

CODE NO.	SOURCE	COST	CODE NO.	SOURCE	COST
11 - 613	FSC08	\$115	82 - 538	FSC02	\$ 85
Study of utilization of air rights above and below public highways.			Quantification of nonuser benefits of a highway by means of an index of impact.		
11 - 714	L 05	\$ 70	82 - 2004	INT	\$133
Analysis of the state highway departments legal position when in possession of land being used for non-highway private purposes and formulation of the highway agencies management responsibilities.			Develop guidelines on such matters as when to depress or elevate. How to relate free-ways to parking facilities. How to coordinate with public transportation facilities in highways or otherwise. Air rights. Vehicular-pedestrian separations. Road plans related to urban renewal program.		
13 - 680	LS 02	\$ 97	83 - 516	FSC01	\$ 85
Determination of rules for acquisition and valuation of air rights and easements for scenic purposes.			Study of factors related to the total needs of an area which will insure that highway development will fit those needs.		
15 - 575	FSC05	\$ 85	83 - 524	FSC01	\$115
Relationship between highway development, public services, and tax bases.			Study of the effect of changes in land use on traffic and transportation patterns.		
15 - 708	L 05	\$ 85	83 - 526	FSC01	\$ 97
Study of capability of taxes and regulatory measures to control land uses adjacent to highways.			Study of land development and motor-vehicle uses at interchange points in order to develop the most desirable zoning and land use control at future interchanges.		
24 - 400	TO 07 (25)	\$109	83 - 527	FSC01	\$115
Determination of importance of esthetics as a traffic service quality and determination of a technique for measuring its importance.			Study of the role of highways in shaping land development and uses.		
24 - 455	D A05	\$ 97	83 - 621	FSC01	\$ 97
Study of the effect that various forms of landscape development have on property values adjacent to highways.			Determination of techniques of land use control along highways, taking into account the costs, effectiveness, and public acceptance of land use guidance measures.		
70 - 685	L 05	\$ 85	83 - 624	FSC01	\$115
Study of the legal problems involved in utilization of air space above and beneath highways.			Determination of optimum ratio of urban land use for transportation to total land area.		
82 - 453	D A05	\$115	84 - 546	FSC02	\$ 79
Establish physical standards for structures making multiple use of highway right-of-way including safety, strength, vibration, noise and air pollution.			Study of marginal cost of traffic lanes reserved for rapid transit.		

**APPENDIX D**  
**RESEARCH NEEDS FOR RAILROADS**

## APPENDIX D

The enclosed summary provides information available in 1963 to the Department of Commerce Committee on Science and Technology in the Railroad Industry, as contained in the report of the National Research Council, dated August 1963 (54). There is no evaluation of the status of the research projects that are listed. The report is available through the Clearinghouse for Federal Scientific and Technical Information, No. PB 166 882.

## FOREIGN RAILROAD RESEARCH AND DEVELOPMENT (54)

Japan

The Japanese National Railways have concentrated research in The Railway Technical Research Institute, which functions directly under the supervision of the Head Office, Japanese National Railways. The headquarters of the Institute is located at Hunitachi, on the outskirts of Tokyo, and there are six Test Stations dispersed about the islands. Now 63 years old, the Institute was in its early years primarily engaged in the testing of materials. It has in later years been transformed into an established research organization.

Personnel of the Institute total 907, including test station personnel. The functional breakdown of employees is as follows:

Administrative	236
Computer Center	16
Research Division	<u>655</u>
Total	907

The academic background of the employees is:

University degree	325	(36%)
Technical College	181	(20%)
Junior College	56	( 6%)
Senior High School	216	(24%)
Junior High School	<u>129</u>	(14%)
Total	907	

The "anticipated" budget for 1962 totalled 1,725 million yen, or a United States dollar equivalency (at 360 yen to the dollar) of about \$4.8 million.

The research program is carried out in a 35-laboratory complex.

The laboratories have the following designations:

Track

Structure

Architecture

Soil Mechanics

Geology

Maintenance & Construction Machinery

Signaling

Communication

Trolley

Electric Power

Power Machinery

Car Performance

Car Structure

Car Dynamics

Car Equipment

Machine Tool & Machining

Freight Transportation

Train Operation

Disaster Prevention

Ferry-boat

Station

Civil Engineering Investigation

Electrical Materials Investigation

Rolling Stock Investigation

Chemical Materials Investigation

Electrical Testing

Physical Testing

Chemical Testing

Instrumentation

Steels & Alloys

Welding

Chemistry

Physics

Automation

Operations Research

Some of the major research projects in the past few years have been the following:

- (1) Thermal expansion of long rail

Theoretical and experimental research on thermal expansion of long rail of the track in the field under temperature variation.

- (2) Formulas for judging the coefficient of impact for railway bridges were obtained.

- (3) Creep rupture of soil

A close relation between strain-rate and creep rupture life of soil was found through experiments. It has been used to predict the occurrence of a slope failure or landslide.

- (4) Rail inspection car (3'6" gauge, measuring speed 100 km/h).

- (5) Seat reservation system

Is now in practical use at Tokyo Station. This represents the first successful business use of digital machines ever made in this country.

- (6) Centralized control system of substations

A new idea of centralized control system for no-man substations numbering 20 or more was conceived and now tried on the Tohoku, Sanyo, Kagoshima, Joban, and other electrified lines.

## (7) Overhead wire for high-speed operation

Composed compound catenary was developed for the super-high-speed train operation.

## (8) Inductive interference between a D.C. electrified railway and telecommunication lines.

## (9) Establishment of the static test code on car bodies; impact tests (strength of bodies for the endwise shock load, mainly for freight cars); establishment of strength-calculation method of side-framing.

## (10) Application of induction-hardening to axles, armature-shafts, driving gears, springs, etc., with great improvement of fatigue strength.

## (11) Hunting of two-axle rolling stock and its prevention measure.

## (12) Vibration theory of bogie-car.

## (13) Study and development of air spring.

## (14) Analysis of the surface texture in the carbon steel rail.

## (15) Gas pressure welding

After having clarified the effects of welding factors on the welded strength of steel, this method was applied on the welding of reinforcing-bar, pile and rail. Now the welding of reinforcing-bar is widely practiced in the field of civil engineering and building construction, and gas pressure welding of rail is being very successfully applied in the field or at the workshops. It was decided to adopt this process for the long-rail track construction of new Tokaido line.

## (16) High molecular materials

Studies on deterioration mechanism of plastics, rubbers and fibers for the purpose of prolongation of their life; insulation for roofing of electric cars; covering cloth for freight cars; tie pad for railway.

## (17) 1) Aerodynamic force acting on a high-speed train at tunnel entrance.

2) Effects of the ground and a tunnel on the frictional drag of high-speed trains.

The current program of major items of research is being pursued by Research Teams, each of which is composed of representatives from the

appropriate laboratories with interests in the particular project. Program items are classified as "Top Priority" or as "Second Priority", and the current program is as follows:

Top Priority

1. Modernization of railway business operation by the aid of electronic computers
2. Track structure for high-speed operation
3. Rolling stock for high-speed operation
4. Braking system for high-speed operation
5. Signal system for high-speed operation
6. Overhead wire construction for high-speed operation
7. A.C. electrification
8. Improvement of performance of diesel locomotives and cars
9. Automatic train operation
10. Dynamics of high-speed vehicles

Second Priority

1. Modernization of track-maintenance work
2. Failure of embankment and cutting
3. Countermeasures for superannuated structures
4. Countermeasures for snow damage
5. Prevention of wheel slipping
6. Safeguarding of level crossings.

Through its "Technical Information Center," the Research Institute publishes a monthly periodical entitled Japanese Railway Engineering Abstracts. The various issues carry a wide selection of technical papers by the Research Center's own engineers and researchers, as well as

selected abstracts from 54 publications of a wide variety of other scientific and technical societies and institutions. A Quarterly Report is also published by the Research Institute. Each issue carries eight to ten studies in some depth on a variety of technical subjects of current interest to railroad people.

RESEARCH PROGRAM OF THE ASSOCIATION  
OF AMERICAN RAILROADS (54)

AAR MECHANICAL RESEARCH DIVISION BUDGET - 1963

	PROJECT	Budget Request
A M-30	Nuclear Energy for Railroad Operation	\$ 8,150
A M-48	Study of Energy Converter Systems	1,700
B M-3	Hot Box Research - General	17,800
B M-4	Journal Box Lubricating Materials	15,300
B M-5	Journal Bearing Development	9,950
B M-8	Axle Research	25,350
B M-9	Stresses in Diesel Wheels	0
B M-11	Diesel Oil and Lubricating Oil Filter Research	6,600
B M-14	Relation Between Track and Equipment	16,000
B M-24	Brake Cylinder Lubricants	1,300
B M-27	Air Brake Systems on Freight Cars	2,100
B M-29	Development of Journal Box Rear Seal	1,100
B M-33	Hot Box Detector	3,100
B M-34	Car Impact Studies	21,670
B M-35	Brake Beam Vibration Tests	3,100
B M-40	Roller Bearing for Freight Cars	6,200
B M-47	Economy Diesel Fuel Oil Investigation	1,800
B M-49	Sound & Vibration for Defect Detection in Equipment (Stanford Research)	8,200
B M-50	Draft Gear Design	6,100
B M-52	Automatic Car Identification Systems	7,700
B M-53	Study of Composition Shoes and Off-Tread Brakes	5,150
B M-55	Electrostatic Plastic Diesel Air Filters	1,100
B M-56	Determination of Axle Stresses by X-ray Diffraction	2,100
B M-58	Center Plate Lubrication	3,200
B M-60	High Capacity Cars	1,600
B M-61	Tests of Brake Cylinder Release Valves	0
C M-7	Hot Box Research - Additives	6,100
C M-15	Truck Side Frame and Bolster Tests	0
C M-16	Journal Box Lid Tests	0
C M-17	Geared Hand Brake Tests	0
C M-18	Tests of Lubricants for Roller Bearings	2,600
C M-19	Brake Beam Tests	0
C M-20	Car Compression Tests	0
C M-21	Draft Gear Tests	0
C M-22	Certification Tests of Roller Bearings	0
C M-23	Automatic Brake Slack Adjustors	0
C M-25	Air Hose Gaskets	550
C M-26	Air Leaks in Trains	550
C M-51	Freight Car Truck Design for 38" and 40" Wheels	1,100
C M-54	Diesel Engine Bi-Metallic Piston Rings	1,100
C M-57	Missile Transport Technical Service	2,600
C M-59	Freight Cars - Special Cushioning Devices	9,200
	GRAND TOTAL	<u>\$200,170</u>

Letters preceding project numbers stand for following classifications:  
A Basic Research, B Applied Research, and C Development.

RESEARCH PROGRAM OF THE ASSOCIATION  
OF AMERICAN RAILROADS (54) Cont'd.

AAR ENGINEERING RESEARCH DIVISION BUDGET - 1963

	PROJECT	Budget Request
A E-28	Long Range Weather Forecasting	\$ 1,000
B E-2	Roadbed Stabilization	15,100
B E-3	Control of Vegetation	600
B E-4	Further Development of Prestressed Concrete Ties	1,900
B E-7	Insulated Rail Joint Development	3,000
B E-8	Shelly Spots and Head Checks	20,200
B E-11	Welding Heat Treated Carbon Steel Frogs and Switches	1,300
B E-12	Specification Development for Tie Plate Fastenings and Tie Pads for Wood and Concrete Ties	12,300
B E-13	Design of Spirals	3,800
B E-14	Strength of Timber Stringers	1,000
B E-15	Application of Synthetic Resins and Adhesives	7,800
B E-19	Truss Bridge Research	5,000
B E-22	Steel Bridges	9,200
B E-23	Concrete Bridges	12,300
B E-24	Timber Bridges	4,100
B E-25	Relation of Wheel Load to Wheel Diameter	8,800
B E-26	Dynamic Action of Piggyback Cars in Regard to Clearance, Stability and Ride Qualities	10,300
B E-29	Detector Car Development	41,600
B E-33	Riding Qualities of Equipment Thru High Speed Turnouts	1,300
B E-34	Study Metallurgical Effects of Rail Cropping Methods	2,000
B E-35	Semi-Automatic Welding or Rail Batter and Burns	4,600
C E-5	Investigation of Failures in Control-Cooled Rail	3,000
C E-6	Rail Failure Statistics	4,700
C E-9	Prestressed Concrete Crossing Frog Support	500
C E-16	Non-Destructive Testing of Wood	5,000
C E-18	Shear Keys for Concrete Beams	2,700
C E-21	Termite Control Investigation	600
C E-25	Butt Welding of Rails	9,200
C E-31	Metallurgical Investigation of Basic Oxygen Steel for Rail and Joint Bars	2,200
C E-32	Corrosion of Deck Plates	1,000
D E-20	Feasibility of Determining Track Maintenance Requirements by Digital Computer Analysis	5,000
GRAND TOTAL		<u>\$201,100</u>

Letters preceding project numbers stand for following classifications:  
A Basic Research, B Applied Research, C Development, D Operations  
Research or Systems Analysis.

RESEARCH PROGRAM OF THE ASSOCIATION  
OF AMERICAN RAILROADS (54) Cont'd.Recapitulation of Budget

A. Basic Research	\$ 10,850
B. Applied Research	332,720
C. Development	52,700
D. Operations Research or Systems Analysis	5,000
	<hr/>
TOTAL	\$ 401,270

RESEARCH OF THE OFFICE OF RESEARCH AND EXPERIMENT (ORE)  
OF THE INTERNATIONAL UNION OF RAILROADS (UIC) (54)

ORE believes that railways are on the threshold of a new era and that passenger transportation must be greatly improved. Fundamental scientific work is being undertaken in passenger comfort, e.g., vibration of cars, noise levels, heating, ventilation, etc., and climatic chambers for such tests were placed in service in Vienna in 1961.

The current research program is composed of the following projects:

Behavior of Pantographs and the Overhead Equipment at High Speeds

Shunting Sensitivity of Track Circuits

Insulated Joints for Track Circuits

Safety Devices for Track Laid on Concrete or Steel Sleepers

Study of Signaling Relays with a View to Obtaining the Longest Life in Service Having Regard to Their Physical Dimensions

Study of Disturbances in Primary Circuits Owing to Harmonics Caused by the Use of Motive Power Units Equipped with Rectifiers

Transmission of Information between Rail and Motive Power Units

Protection of the Overhead Equipment against the Effects of Atmospheric Discharges

Protection of the Catenary and of the Pantographs against the Formation of Hoar Frost and Ice

Use of Magnetic and Electronic Devices on Motive Power Units and Hauled Vehicles for the Actuation of Traction, Heating, and Lighting Circuits

Wear of Contact Strips and of the Overhead Equipment when Using Metallic or Composite Contact Strips

Approach Time Equalizer for Flashing Light Installation for Level Crossings

Data Transmission by Means of Telephone Circuits at Average Speeds (500-1200 BAUDS)

Application of Hertzian Cables for Traffic Control Circuits

Strength of Bodies of Passenger Coaches

Constructional Arrangements for Improving the Riding Stability and the Guiding Quality of Electric and Diesel Locomotives and Vehicles

Standardization of Wagons

Standardization of Diesel Locomotives

Measuring Equipment Used for the Study of Comfort in Carriages

Buffers with a Large Work Absorption Capacity

Study of the Problem of Adhesion of Locomotives from the Point of View of Their Construction and Operation

Tests to be Carried Out on Behalf of the Commission on "Automatic Couplings"

Tests on the Track of the Riding Stability and the Guiding Quality of Vehicles by Means of a Special Vehicle

Determination of the Permissible Divergency of Forces Exerted on Each Wheel of a Vehicle; Development of a Measuring Apparatus

Study of the Optimum Damping of the Suspension Systems of Wagons so as to Enable Their Running, Under Loading Conditions, at Speeds of 80 km/hr on Tracks in an Average State of Repair

Elimination of Baffle-Plates from Cistern Wagons

Effect of Wagon Vibrations on Loads and Packing: Methods for Avoiding Damages that Could Be Attributed to Such Vibrations

Reduction of the Filling Time of the Brake Cylinder in the "Goods" Position

Study of a Detonator of Maximum Audibility Neither Endangering the Staff Nor the Material

Brake-Shoes Made From Synthetic Materials

Examination of Structures by Means of Fatigue Tests and Vibration Tests at Resonance

Filtration of the Combustion Air and the Cooling Air of Internal Combustion Engines and Cooling Air for Electric Machinery on Locomotives

Use of Synthetic Materials and Glued Connections for the Stressed Parts of Light Weight Rolling Stock

Heat Transmission Phenomena in Refrigerator Vans

Problems of Interaction of Vehicles and Track

Behaviour of the Metal of Rails under the Repeated Action of  
Wheels. Study of the Field of Stresses in the Elasto-Plastic Zone

Mutually Permissible Wear Profiles of Wheel-Types and of Points  
and Crossings

Lateral Stability of Rails, especially of Long Welded Rails

Technical and Economical Study of Tested Types of Concrete Sleepers

Determination of Dynamic Forces in Bridges

Quality of Rails and Means of Guaranteeing It

Application of Rubber for Bridge Supporting Plates

Loading of the Track, of the Ballast and of the Formation Due to  
Rolling Loads

Guiding Principles for the Design of Points and Crossings (UIC 54  
and UIC 60 Rail Profiles)

Continuous Measurement of the Speed of Wagons Shunted Over Humps

Special Rail Profile for Long Welded Rails

Protection of Materials

Problems Concerning the Quality of Lubricants

Bearing Lubricants

Superheated Steam Cylinder Oils

Oils for Internal Combustion Engines

Oils for Roller-Bearings

Modern Non-Destructive Methods for Materials Testing

Use of Synthetic Insulating Materials on Overhead Equipment: The  
Problem of Double Insulation

Study to Determine the Most Suitable Manufacturing and Impregnation  
Methods of Tarpaulins

APPENDIX E  
RESEARCH NEEDS FOR MAJOR AREAS

## APPENDIX E

The following summaries of the research needs of other major areas of civil engineering are provided to show the over-lapping interest that prevails. Cooperative efforts in many of these programs are highly desirable. Included are the following areas:

- . Water Resources Engineering (58)
- . Structural Engineering (including power) (65) (66)
- . Environmental Engineering (68)

SUMMARY  
OF  
WATER RESOURCES ENGINEERING  
RESEARCH NEEDS

The following quotation and schematic drawing, representing only a part of the Water Resources area, is taken from the preliminary draft of a report by the ASCE Urban Water Resources Research Program (63). Funds for the studies were made available by the Office of Water Resources Research of the U. S. Department of the Interior. The following is from pages 6 to 9, inclusive.

5. Fundamental Requirements

The major research needs identified by the "Non-Hydrologic Aspects" Task Committee follow; and the backgrounds for these recommendations are set forth in Appendix D:

a. At this stage, a serious effort should be made to bring about the creation of an appropriate entity for coordinating and undertaking urban water resources research; items of concern and definitions of what needs to be done that have been provided by the ASCE program should constitute a part of that research; and this entity should probably provide a translating function for effective communication between affected fields, particularly for interdisciplinary, interagency, intermunicipality, multidisciplinary and multiple-service communication.

b. More detailed information on costs and benefits of different scales of facilities is needed to arrive at equitable charge schedules and judicious selection among alternatives, particularly for water pollution abatement-water quality control.

c. Research is needed on the planning process with regard to meeting overall community goals; and socio-system simulation should be incorporated in the research.

d. The preferred institutional framework within which metropolitan water resources planning should take place remains to be identified.

e. With respect to environmental quality, if research is not now in progress on the efficacy and efficiency of mechanisms for measuring public attitudes and opinions, such as public hearings, it should be undertaken promptly; and similarly, on decision-making processes at all other levels.

f. Research is needed on institutions for management of water, at various levels, extending from an entire metropolis to the local neighborhood.

g. Serious study should be given to the effect in the past of technological change on social change, social change on technological change, and the relationship between them.

h. Ways must be found to measure or evaluate social efficiency compatible with those extant for economic efficiency.

## 6. Urban Water Resources Development

Considerable potential synergistic benefits could be obtained in comprehensive, multipurpose development of urban water, on a scale of involvement that in the aggregate could be much greater than for river basins. Reliable planning of water quantity and quality exchanges between the several urban water service functions is hampered particularly by a poor understanding of the urban rainfall-runoff-quality process. The primitive status of urban hydrology is the consequence of an absence of a meaningful body of field data. Techniques needed directly and indirectly for simulation in water resources planning, development and management are largely latent for a lack of suitable data to test and develop them. The input for the water cycle is precipitation, and little is known about it in the urban context. As opposed to data needed for simulation model development, a form of historical storm data is needed as inputs for planning, development and management.

The following research should be pursued simultaneously:

a. Plans being formulated by the USGS for the acquisition of rainfall-runoff-quality data and its dissemination (see Chapter III, Section 2) should be implemented as soon as possible, because model development is dependent on data availability and several years of data may be required for process mastery.

b. Existing mathematical models for simulating the rainfall-runoff-quality process should be under continual testing and improvement, starting with the small amount of data now available. Considerable detail and specification of needs are included in Appendix A, prepared by the "Methods of Analysis" Task Committee.

c. Research on metropolitan storms (see Appendix B) should be pursued not only to develop inputs suitable for future uses but for contemporary management and operation of works.

## 7. Urban Drainage

Because urban flooding is of considerable economic importance, in addition to the research cited in the preceding section, which would have a very strong bearing on drainage, the following studies are recommended by the "Damage and Storage" Task Committee (see Appendix C):

a. The amount and place of drainage facilities investment in the expenditures of local governments should be defined.

b. Needed policy revisions should be identified for removal of legal, political, jurisdictional, administrative, planning and other roadblocks to more efficient and effective drainage facilities development.

c. Much more knowledge on urban drainage flood damages are needed if marginal values are to be discerned, particularly on intangibles.

d. Consideration should be given to using future new towns as field laboratories by incorporating several different drainage schemes in the same town, utilizing different extents of storage and imaginative multipurpose works.

e. The efficacy of selected existing drainage systems should be systematically evaluated and appraised, alternative hypothetical designs should be qualitatively tested and the most promising combinations and most effective practices should be identified.

f. In conjunction with the preceding study, analyses should also be made of the inherent storage capacity of the selected existing drainage systems and the effects of varying degrees of hypothetical storage capacity designed for each catchment.

g. Compared with requirements for process evaluation, relatively simple simulation models could be used for the two studies immediately above, and these should be adapted or developed with the full cognizance, but preferable assistance, of process model researchers.

In addition (from the "Non-Hydrologic Aspects" Task Committee, Appendix D), legal considerations need research to develop solutions for the lack of uniformity in existing state law, which is divided and often mingled among common, civil and "reasonable use" rules. The law can provide means for minimizing conflicts by: a uniform drainage code; a uniform trial procedure; and enabling legislation for the effective organizing, governing, administration and financing of drainage districts. Fundamentally, a model law or uniform code based on drainage and ramifications of drainage is needed. The greatest problem in this area of law is the question of liability, which hinges on identification of who is responsible in a given instance.

## 8. Systems Analysis

The total water resources of urban areas have not been appraised on a comprehensive scale. Also, technical and economic systems analyses of the full spectrum of water occurrences and interactions should provide an overall reference for future research. The prefeasibility studies reported in Appendices G through J, and amplifications in Appendix K, clearly indicate the physical feasibility of such analyses. Their economic feasibility is not as evident, because of a lack of precedent for comparison.

A properly structured systems analysis could provide a vital overview role for a national plan of urban water resources research.

System simulation model design should be started immediately, continual cycling of refined versions of simulation and sensitivity analyses should next be undertaken, and an operational stage systems overview capability should be attained as soon as possible. A single approach may not be desirable. More than one level of development might be pursued concurrently, each for a particular type or scale of objective.

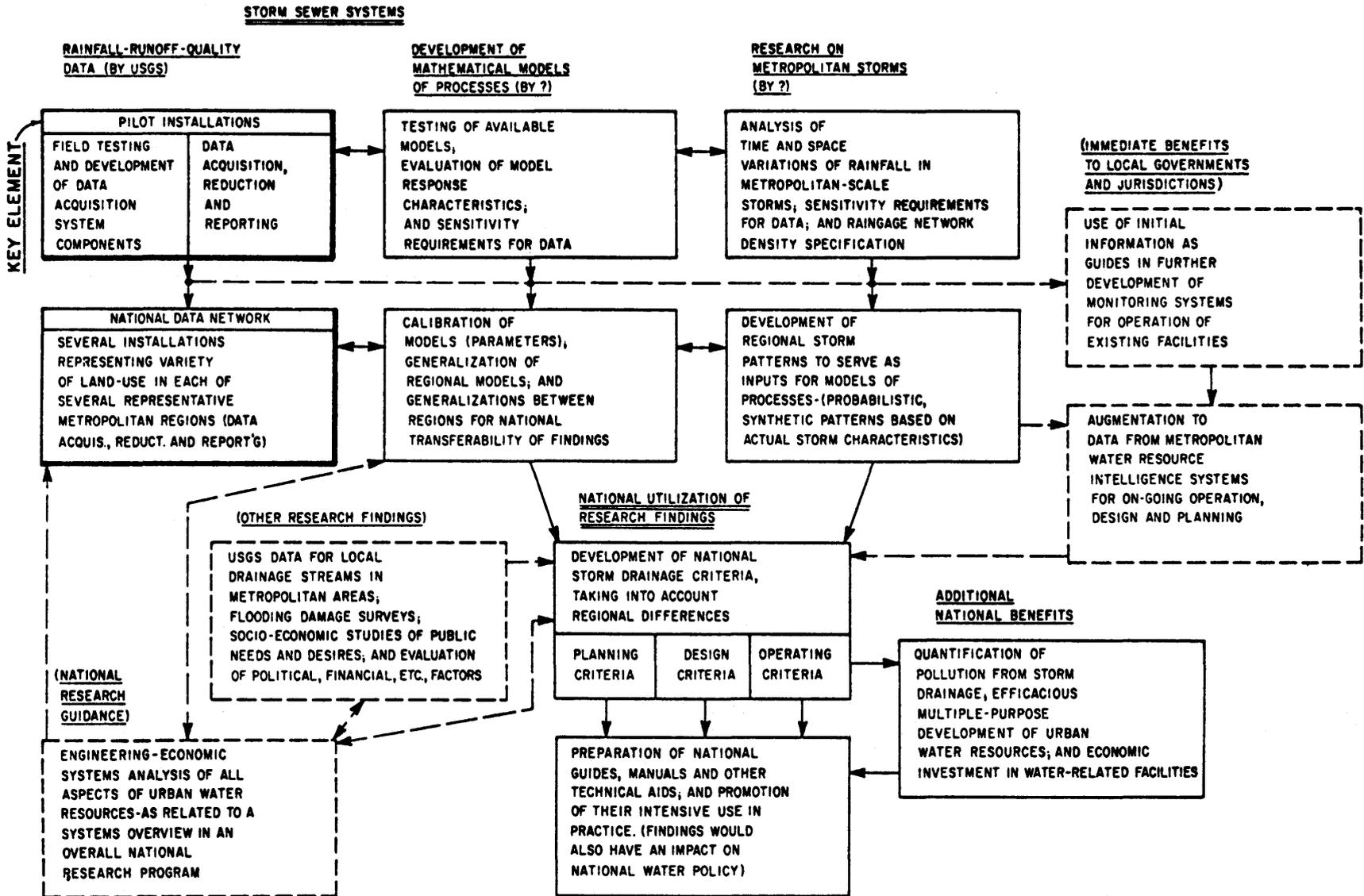


FIGURE 3 - RECOMMENDED PLAN FOR A NATIONAL PROGRAM OF URBAN STORM DRAINAGE RESEARCH.

SUMMARY  
OF  
STRUCTURAL ENGINEERING  
RESEARCH NEEDS  
(Including Power)  
(65) (66)

- A. Methods of Analysis and Design of Structures
1. General Methods of Analysis
    - . Frame and Truss Structures
    - . Shell Structures
    - . Suspended Structures
    - . Mass-Concrete Structures
  2. General Methods of Design
    - . Loadings on Structures
    - . Reliability of Structures
    - . Optimization in Structural Design
    - . Failure Criteria
  3. Use of Small-Scale Models
  4. Analysis and Design for Dynamic Loads
  5. Design of Towers
  6. Special Building Problems
  7. Experimental Verification of Design Analyses
- B. Application of Electronic Computers to Structural Engineering
- C. Masonry and Reinforced Concrete Structures
1. Composite construction
  2. Reinforced Concrete Slabs
  3. Folded Plate Construction
  4. Limit Design
  5. Precast Structural Concrete
  6. Prestressed Concrete
  7. Reinforced Concrete Columns
  8. Masonry Design and Practice
  9. Shear and Diagonal Tension
  10. Cracking of Concrete

11. Behavior of Complete Structure
12. Bond and Anchorage of Reinforcement
13. Torsion of R/C Members
14. Tensile Strength of Concrete
15. Reinforcing Materials and Methods
16. High Strength Concrete Structures
17. Deflection Predictions
18. Maintenance and Modifications

D. Metal Structures

1. Compression Members
2. Reticulated Structures
3. Light Gage Metal Structures
4. Light Weight Alloys
5. Plastic Design
6. "Core and Skin" Structures
7. Flexural Members
8. Structural Connections
9. Orthotropic Plate Structures
10. Tubular Structures
11. Fatigue
12. Fracture
13. Suspended Structures

E. Structural Plastics

1. Time and Temperature Effects
2. Behavior under Long Duration Loads
3. Fatigue Behavior
4. Properties of Structural Elements
5. Connections
6. Anchorage of Prestressing Strands
7. Use of Plastics in Composite Construction
8. Structural Use of Brittle Materials
9. Development of Design Procedures

F. Wood Structures

1. Composite Construction
2. Laminated Elements
3. Flexural Members
4. Plywood Panels
5. Wood Shell Roofs
6. Stability of Wood Members
7. Fire Retardant Treatments
8. Connections

G. Buried Structures

1. Free-Field Effects
2. Soil-Structure Interaction
3. Dynamic Analysis of Soil-Structure System
4. Shock Analyses
5. Structures in Ice and Snow

- H. Structures in Outer Space
- I. Underwater Structures
- J. Develop New Structural Materials and Geometrical Forms
- K. Implementation of New Knowledge

RESEARCH NEEDS ON POWER  
(66)

DETAILS OF PROGRAM

Based on the broad areas of need summarized above, research that could be of direct interest to civil engineers is needed in the following main areas:

1. Metallurgy.
2. Fuels for power production (including transportation, handling, and use).
3. Environmental problems of the power industry (air and water pollution, beauty).<sup>1</sup>
4. Structural improvements at power projects.
5. Waste disposal at power plants.
6. Peaking capacity in modern power systems.
7. Electrified transportation equipment.
8. Transmission.

Each of these main areas involves subdivisions that warrant separate research. Some of the more important subdivisions are listed below, but these do not constitute an exhaustive list. Research is currently underway in many of these subareas, and future work should supplement and not duplicate previous work. Many of the subareas are overlapping, but are listed where the primary interest seems to be.

1. **Metallurgy.**
  - a. Improved metals for boilers, tubes, turbine parts, reactor vessels, and other plant components.
2. **Fuels.**
  - a. Economical transportation of fuels.
  - b. Efficient coal handling and storage.
    1. Continuous vs. batch handling means.
    2. Radiant vs. convective car thawing vs. insulation.
    3. Coal slurry conveyance.
      - (a) Starting, stopping, and changing rate of flow in slurry; dewatering.
    4. Handling and use of low-grade coals.
  - c. Improved methods for handling reactor fuel.
3. **Environmental Problems.**
  - a. Temperature rise in water bodies as a result of power plant effluents.
    1. Relation of size and shape of water body to temperature rise distribution.
    2. Temperature stratification in lakes and reservoirs.
    3. Evaporation losses attributable to incremental temperature rise in lakes and streams.
    4. Rate of temperature equilibrium recovery in lakes and streams.
    5. Mixing patterns for effluents discharged into flowing streams.
    6. Correlation of river temperatures with plant heat discharges, weather conditions, and stream flow.
  - b. Oxygen depletion in storage reservoirs.
    1. Seasonal changes in oxygen-level stratification in reservoirs.
    2. Effect on downstream areas of low-level withdrawals.
    3. Reaeration devices.
  - c. Beauty-combining attractiveness and utility in structures that are economically supportable.
    1. Improved designs for plant housing, cooling towers, stacks, etc.
    2. Improved designs for substation, transmission, and distribution facilities.
      - (a) To reduce right-of-way requirements.
      - (b) To provide for multiple uses.
      - (c) Underground facilities.
    3. Improvements in transmission line right-of-way.
      - (a) Wildlife habitat.
      - (b) Landscaping.
      - (c) Retardation of growth in trees.
      - (d) Joint use of railroad, highway, or other cross-country right-of-way to limit number and extent of right-of-way scars.
  - d. Interaction with other resources uses.
    1. The influence of dams on fish and wildlife.
    2. Recreational use of reservoirs.
4. **Structural and Hydraulic Improvements at Power Plants.**
  - a. Improvements in methods of condenser water handling.
    1. Comparison of precast and cast-in-place circulating water conduits.
    2. Joints in water conduits.
  - b. Hydraulics of intake and discharge structures.
  - c. Hyperbolic cooling tower design criteria.
  - d. Foundation requirements for large power plants.
  - e. Vibration problems in hydro turbines.
    1. Draft tube surges - causes and prevention.
  - f. Measurement of turbine discharge and model testing.
  - g. Special structures for nuclear plants.
    1. Shielding materials and design.
    2. Prestressed concrete versus steel containment vessels.
5. **Waste Disposal at Power Plants.**
  - a. Fly ash collection, use, and disposal.
    1. Collection.
      - (a) Improved precipitators considering such devices as liquid film to prevent particle bounce-back and reentry into stack-gas flow.
      - (b) Bag collectors.
      - (c) Monitoring and sorting fly ash for consistency of carbon content, size of particles and pH.
    2. Uses.
      - (a) Sintering for use as light-weight concrete aggregate or for other purposes.
      - (b) As admixture for concrete, asphalt pavements, plastics, loam soils, etc.
      - (c) As a component in protective coatings for exposed or buried steel.
      - (d) Recovery of salable constituents.
      - (e) New uses for fly ash.
    3. Disposal.
      - (a) Land fill composition to produce productive soil.
      - (b) Slurry transportation.
      - (c) Dust control at storage and disposition area.
  - b. Disposal of radio-active waste materials from nuclear plants.
6. **Generating Capacity in Modern Power Systems.**
  - a. Pumped storage.
    1. Possible use of coastal locations.
    2. Economical means of obtaining more rapid start-up.
    3. Development of two-stage reversible units.
    4. Effective sealing of pumped storage reservoirs.
      - (a) Concrete versus asphaltic lining.
      - (b) Joints in concrete.
      - (c) Drainage behind reservoir linings.
      - (d) Evaporation retardation.
  - b. New methods for meeting peaking needs (civil engineering aspects of).
  - c. New base load generation.
    1. Magneto-hydrodynamic generation - AC and DC.
    2. Other types of generation, as appropriate.
7. **Electrified Transportation Equipment (civil engineering features of).**
  - a. Improved power-transfer equipment for high-speed trains.
  - b. Improved arrangements for underground conductors and transfer contacts for rail equipment.
  - c. Improved overhead structural design.
8. **Transmission (civil engineering features of).**
  - a. Super cooling and superconductors.
  - b. Lasers.

SUMMARY OF  
ENVIRONMENTAL ENGINEERING  
RESEARCH NEEDS

The following outline of the health aspects of the urban environmental problem represents only one area of Environmental Engineering. The outline, quoted in a summary of research needs (68), was contained in the report "Environmental Health Problems" by the Committee on Environmental Health Problems. The report was submitted in 1962 to the Surgeon General of the Public Health Service, U. S. Department of Health, Education, and Welfare, and is available as P.H.S. Publication No. 908, Washington, D. C.

Description of Research Area	Category	Priority
To assess health problems related directly to metropolitanism - - - - -	B	I
(a) To compare chronic disease rates in urban and rural populations -	B	I
(b) To compare communicable disease rates in crowded urban areas versus sparsely populated areas - - - - -	B	I
(c) To determine the effects on health of levels of community noise - - -	B	I
(d) To evaluate health values of open spaces - - - - -	B	I
To determine effects of environmental facilities on metropolitan development patterns, and vice versa; relationships to changing forms of metropolitan areas and patterns of land use - - - - -	B, O, A	I, II, III
(a) To determine capacities, costs, operational characteristics, and space requirements of various types of sanitation facilities and services as related to the planning function - - -	OA	II
(b) To determine the role and limitations of various types of sanitation systems and residential development, by general classification, in serving future land use plans and urban area - - - - -	OA	II
(c) To determine the effects of change in form of sanitation services and facilities on urban development - - - - -	B	II
(d) To determine the effects of land use patterns on sanitation and environmental health services (various patterns and levels of service) - - - - -	B	II
(e) To determine the effects of various levels of user charges on operation and utilization of public and private sanitation and environmental health service and facilities; also the effects of different levels of charge on land use as well as on all utilization of systems - - - - -	AB	I
(f) To determine theoretical limitations of possible degrees of substitutions for various types of services and facilities-	AB	I
(g) To determine zones of influence of major trunklines of water and sewer facilities in terms of residential and industrial development - - - - -	AB	II

Description of Research Area	Category	Priority
(h) To develop concepts of points of diminishing returns and break-even points for sanitation and environmental health facilities, in relation to unit components - - - - -	B	I
(i) To develop methods for projecting the range of possible future facility patterns within which we have choice--	B	III
(j) To assess forces shaping urban areas--	AB	I
(k) To determine restraints on change due to institutional, physical, or financial factors - - - - -	AB	II
(l) To determine the relation of national, industrial, and population changes to urban environmental health projections--	B	III
Criteria development --		
(a) To identify fundamental criteria for use in environmental health planning --	B	I
(b) To develop methods for use of mathematical models, systems analysis, and computers for evaluation of interaction and the effect of various criteria - -	B	I
(c) To research the methodology of sampling techniques, survey techniques, and other tools needed for studies - - - - -	OB	I
Social values related to environmental health --		
(a) To determine the effects of various types and levels of environmental and sanitation services on individual and family life; also neighborhood relations - - - - -	AB	II
(b) To assess the effects of open areas and recreational areas in relation to planning of residential development - - - -	O	III
(c) To determine the effects of social customs and ethnic tendencies on the use and effectiveness of environmental health measures - - - - -	B	III
(d) To evaluate greater population mobility-- short term and long term--in relation to environmental health planning - - - - -	OB	II
(e) To identify and refine social criteria for decision making in environmental health planning - - - - -	B	II
Economic development -- industrial, transportation --		
(a) To determine the effect of industrial growth and development on planning for environmental health and sanitation requirements - - - - -	A	III

Description of Research Area	Category	Priority
(b) To determine the effect of changes, such as shift of commercial activity from central core to fringe areas, on environmental health facilities and services - - - - -	A	III
(c) To measure and analyze costs and benefits of alternative interurban systems and services and their on location and growth of industrial and commercial areas - - - - -	AB	II
<b>Interrelationship between environmental health facilities and services and other programs such as urban renewal, urban highway, and airport programs--</b>		
(a) To develop methods of collaboration among planners and program operators in different fields of activity - - - - -	A	I
(b) To study the impacts of urban renewal highway, and airport programs on environmental health and sanitation facilities and service programs - - -	O	II
(c) To determine the effect of changing modes of transportation (i.e., to mass transit) on development of metropolitan sanitation services - - - - -	O	II
<b>Intergovernmental relationships, financing, and administration--</b>		
(a) To evaluate various systems of laws and regulation to their effectiveness as environmental health controls - - - -	A	I
(b) To define conflicting governmental programs of public works or regulations as they affect environmental health - - -	A	III
(c) To identify and evaluate trends in forms of government as they relate to environmental health - - - - -	A	III
(d) To determine the effectiveness of various forms of financing sanitation facilities and services - - - - -	A	II
(e) To determine the effect of different levels of government on administration and financing of environmental sanitation facilities and services - - - - -	AO	I
(f) To evaluate the effectiveness of communication between government and citizenry on environmental health problems - - - - -	AO	II
(g) To identify and analyze the decision-making process - - - - -	B	II

Ref. 3, p. 108 - 110. Housing and Occupied Space.  
Description of Research Area

Category

Priority

To formulate minimum standards for residences and occupied structures to satisfy the physical, physiological, and psychological needs of man, and to formulate desirable standards for residences and occupied structures to fulfill the desires of man and to provide efficiency and comfort of living; such minimum and desirable standards to include, but not limited to--

B

I

- (a) Room sizes:
  - (1) Floor area.
  - (2) Room volume.
  - (3) Limiting dimensions; e.g., ceiling heights.
- (b) Thermal factors; including air temperature, radiant temperature, air movement and relative humidity:
  - (1) For warmth.
  - (2) For cooling.
- (c) Ventilation:
  - (1) Air cleanliness.
  - (2) Removal of odors.
- (d) Illumination; quantity and quality standards:
  - (1) Natural lighting.
  - (2) Artificial lighting.
- (e) Noise; including that from internal and external sources:
  - (1) Relationship to hearing.
  - (2) As a disturbing factor of sleep.
- (f) Vibration; including that from internal and external sources.

To formulate criteria for the design of neighborhoods for planners, developers, etc., to provide a healthful residential environment including, but not limited to - - - - -

AO

II

- (a) Basic requirements for site selection:
  - (1) Physical characteristics of the site.
  - (2) Proximity to hazards and nuisances.
  - (3) Essential community facilities.
- (b) Utilities and services:
  - (1) Water supply.
  - (2) Sewage disposal.
  - (3) Refuse and garbage disposal.
  - (4) Telephone, electricity, and fuel.
- (c) Land use:
  - (1) Housing and population densities.
  - (2) Development of open space.

Description of Research Area	Category	Priority
(d) Vehicular and pedestrian facilities: (1) Roads and streets. (2) Vehicle parking. (3) Walkways.		
To evaluate the adequacy of present governmental controls to create and maintain a healthful residential environment and to propose amendments and/or supplements as necessary, including - - - - -	A0	II
(a) Building codes. (b) Housing codes. (c) Fire and safety codes. (d) Zoning codes. (e) Subdivision regulations. (f) Other administrative legal instruments.		
To determine the relationship of housing to health and to identify the causative and contributing factors:		
(a) communicable disease - - - - - (b) mental illness - - - - - (c) chronic disease - - - - - (d) well-being - - - - -	B B B B	I I I III
To determine the role of the following in causing or contributing to home accidents:		
(a) Design - - - - - (1) Of the dwelling unit and structure. (2) Of the installed equipment and facilities. (3) Of furniture and household utensils. (4) Of the neighborhood.	B	I
(b) Illumination - - - - - (c) Noise and vibration - - - - - (d) Toxic or irritating gases, dust and fumes--	B B B	II II I
To determine the mechanism of the transmission of airborne disease organisms in dwellings and structures heated or cooled by circulating air--	B	II
To evaluate the public health significance of exposure over long periods of time to low concentrations of toxic or irritant gases, fumes, dust, etc - - - -	B	I
(a) In the residential environment. (b) In other occupied space.		
To revise the American Public Health Association's Appraisal Method to Evaluate the Quality of Housing - - - - -	A0	I
(a) To provide a technique for epidemiologists and others to use in studying housing and health.		

Description of Research Area	Category	Priority
(b) To provide an instrument for redevelopment officials, planners, and others to determine areas of communities which need corrective action to provide a healthful environment and indicate the type of corrective action that is needed.		
(c) To develop a precise index of the hygiene quality of an individual dwelling unit or structure.		
To evaluate the role of housing in the transmission of virus diseases to man - - - - -	B0	II
To determine if a relationship exists between juvenile delinquency and housing quality - -	B	II
To develop more effective and efficient methods of treating solid and liquid wastes on-site in residential areas, particularly in the suburbs and urban fringe areas - - - - -	B	III
To develop effective means of protecting inhabitants of residences from radio-active substances including fallout - - - - -	B	I
To develop criteria for the elderly and the handicapped to provide a healthful residential environment for them living independently to the maximum practical degree - - - - -	B0	I
To determine adequacy of mobile homes as places of prolonged residence of families with and without children - - - - -	0	III
To formulate design standards for mobile home parks to create a healthful residential environment	0	III
To define housing standards for itinerant workers --	A0	III

**APPENDIX F**  
**RESEARCH NEEDS OF RELATED**  
**DISCIPLINES AND PROCESSES**

## APPENDIX F

The following pages outline some of the basic disciplines and processes of fundamental interest to transportation.

RESEARCH NEEDS  
SUMMARIES

A. Surface-Water Hydrology Research Needs (69)

1. Stochastic hydrologic procedures
2. Channel losses in ephemeral streams
3. Water use by natural vegetation
4. Economical flow records of desert streams
5. Conservation of flood runoff
6. Electronic digital computers
7. Improved quantitative measurement of precipitation
8. Radioactive and chemical tracers

B. Surveying and Mapping (70)

	10-year costs (\$ in millions)
1. Land Surveying	21.9
2. Engineering Surveys for Design and Construction	56.3
3. Geodetic Surveying, Geodetic Engineering or Geodesy	44.4
4. Cartographic Surveying, Cartographic Engineering, or Map and Chart Surveying	75.9
5. Aerial Survey Services	38.0
6. Cartography (not requiring original surveys)	34.2
<b>Total</b>	<b>270.7</b>

C. Construction (74)

	10-year costs (\$ in millions)
1. Construction Management and Research	1.8
2. Construction Engineering Research (equipment)	5.0
3. Construction Engineering Research (technique)	3.0
<b>Total</b>	<b>9.8</b>

D. Soil Mechanics (71)

1. Soil Properties

- . General characteristics of soils
- . Strength and deformation characteristics of soils
- . Expansion characteristics of soils
- . Compression characteristics of soils
- . Permeability of soils
- . Secondary Compression

2. Dynamic Behavior of Soils

- . Transmission and damping of small amplitude waves
- . Transmission of large amplitude waves
- . Shear strength of soils under dynamic loads
- . Effect of seepage and dynamic pressure gradients on the strength of soils

3. Method of determining soil properties
  - . Exploration procedures
  - . Laboratory testing procedures
  - . In-place testing procedures
  - . Instrumentation for field observations
4. Water and Moisture Movement in and over soils
  - . Flow through earth structures
  - . Seepage control
  - . Drainage and ground water problems
  - . Drainability of soils
  - . Moisture accumulation
  - . Soil erosion protection
5. Improvement of soil characteristics
  - . Field compaction of soils
  - . Soil stabilization with admixture
  - . Soil stabilization by electro-osmosis
  - . Thermal stabilization
  - . Treatment of problem soils
  - . Utilization of soils of secondary quality
6. Frost Action, Permafrost and Thermal Effects
7. Soil Mechanics Design Problems
  - . Stability analyses
  - . Earth pressure
  - . Settlement and consolidation
  - . Earth dams
  - . Foundation and Embankment Stability during earthquakes
8. Stress Distribution
9. Foundation Design and Construction
10. Engineering Geology
11. Properties of Rock and Rock Masses
  - . Laboratory tests
  - . In situ tests
  - . Tests on engineering structures
  - . Borehole stress and strain gages
  - . Laboratory equipment
  - . Correlation of test data

12. Rock Mechanics
    - . Deformation and Failure
    - . Design Methods
    - . Seepage
    - . Grouting
    - . Classification
  13. Construction Practices
  14. Requirements - \$35 million built up within five years and maintained at \$35 million per year for a second five years
- E. Engineering Mechanics (72)
1. Solid Mechanics
    - . Determination of material properties and observed response
    - . Development of theory
    - . Methods of problem solving
  2. Fluid Mechanics
    - . Flow in conduits
    - . Fluid-structure Interaction
    - . Problems of fluid environment
  3. New areas of Engineering Mechanics