HIGHWAY RESEARCH RECORD

Number 169

Highway Research
and
Urban Transportation Planning
in
Other Countries

4 Reports

Subject Area
90 Highway Research (General)

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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Special Committee on International Cooperative Activities

(As of December 31, 1966)

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Foreword

The four papers in this RECORD give an overview of worldwide transportation research. Their diverse subjects cover activities now current on five continents and will interest the professional highway community around the world. These subjects include an analysis of highway research under way in 19 countries, the strategy of research administration in Canada, a theoretical analysis of the city center that compares the traffic capacity of 30 cities, and a look at renewal planning in transportation in Tokyo, the world's largest city.

In the first paper, Robert O. Swain reports on the worldwide inventory of current road research that the International Road Federation has been assembling since 1962. Among other things the Federation is attempting to gage the usefulness of the research and assess the extent of its use. By the end of 1966 it had initiated inventories in 35 countries and published interim reports for 19. More than 2, 300 research projects are listed for these 19 countries; the total for all 35 countries is expected to be around 3, 000.

Mr. Swain's paper analyzes the subjects of research by country and attempts a comparative analysis. This inventory, the first on a worldwide basis, will contribute greatly to the spread of useful road research information.

In the second paper, Gordon Campbell discusses the efforts of the Canadian Good Roads Association to identify the strategy of research administration in Canada by correlating and reporting on research being conducted by some 78 organizations. During 1966 an estimated $2. 4 million was spent on road research, with 366 individual projects reported. These reports, like those of the IRF inventory reported in the first paper in this RECORD, are supplied to the Highway Research Board's Highway Research Information Service.

Mr. Campbell gives an insight into the way the CGRA, in a way similar to the Board in the United States, serves a decentralized research effort by stimulating and correlating research and disseminating the findings. Contents of the total program are analyzed with the clear implication that Canadian research is applicable in large part in every country.

R. J. Smeed, in the third paper, presents a technical and objective discussion of the road capacity of city centers. He evolves a statistical method for determining and comparing the capacities of the city center for various configurations of traffic ways, and then goes on to apply his capacity formula to determine the theoretical capacity in 18 towns in Great Britain and in 12 towns in other countries.

In the final paper in this record, Masao Yamada explains how the Tokyo Metropolitan Government, through law, policy and planning, inaugurated an urban renewal plan in 1950. Tokyo, the capital city of Japan, now counts a population of 11 million in a 1, 200 square mile area and it has more than a million registered motor vehicles. As Mr. Yamada points out, these pressures require optimum restructuring of land uses. One of the innovations he discusses is the multipurpose use of expressway rights-of-way, which are now being considered in the United States.

Contents

A Preliminary Analysis of Current Research Projects in Nineteen Countries

ROBERT O. SWAIN, President, International Road Federation, Washington, D. C.

•WHEN the International Road Federation set out four years ago to produce a worldwide inventory of current research and development, it did so in a spirit of research, to find out first how it could be done, what methods should be used, and indeed whether it would be possible to achieve a sufficient coverage for the results to be valuable.

A second objective was to determine what effort would be required, what kind of professional talent was needed, and how much it would cost. A third purpose was to gage the usefulness of the work, the extent to which the results would be used, and how to meet any demand that might arise.

It is not yet possible to answer all these points, but after four years, and with the full cooperation of a great number of organizations, especially the Organization for Economic Cooperation and Development and the U. S. Bureau of Public Roads, a pattern has emerged. The results are encouraging and have indeed generated a far greater worldwide interest in what is in total a vast worldwide spread of highway research than could have been foreseen.

Last year Sir William Glanville, IRF consultant and former Director of the British Road Research Laboratory, and I reported to this meeting on IRF's progress and accomplishments. We were still thinking in pioneering terms. Ours was still a new and rather exciting adventure. We feel now that so much has been achieved that the need for and the value of the inventory are accepted facts.

By the end of 1966, inventories had been initiated in 35 countries and reports had been published for 19 countries. These inventories include most of the countries of Western Europe, most of the Western Hemisphere, the Orient from Japan to Australia, some of the Middle East, and a start in Africa. In addition, and as a means of keeping these data current, five countries have been or are being re-inventoried.

Two interim reports have been published which list in excess of 2, 300 reports of research projects. Figure 1 shows the number of projects inventoried in the 19 countries included in these two IRF reports.

From the inventories of the 35 countries, the Federation expects a total of some 3, 000 projects covering current research and development in areas of roads and road transport. All of these projects will be, or have been recorded in IRF's formal reports to the U. S. Bureau of Public Roads, which has contributed financially to this work. Selected projects have been filed in the systems of the U. K. Road Research Laboratory and of the Organization for Economic Cooperation and Development, and, through the latter organization, with the Laboratoire des Ponts et Chaussees (Bridge and Road Laboratory) in Paris where the abstracts are in French, and the Forschungsgesellschaft für das Strassenwesen (Road Research Association) in Cologne, where the abstracts are in German. The cooperation of all of these bodies has been one of the important features contributing to the success attained.

It is anticipated, that in addition to the storage and retrieval systems already in operation, other countries will wish to establish centers for this type of information in additional languages to assure worldwide utilization by highway engineers and scientists.

Paper sponsored by Special Committee on International Cooperative Activities and presented at the 46th Annual Meeting.

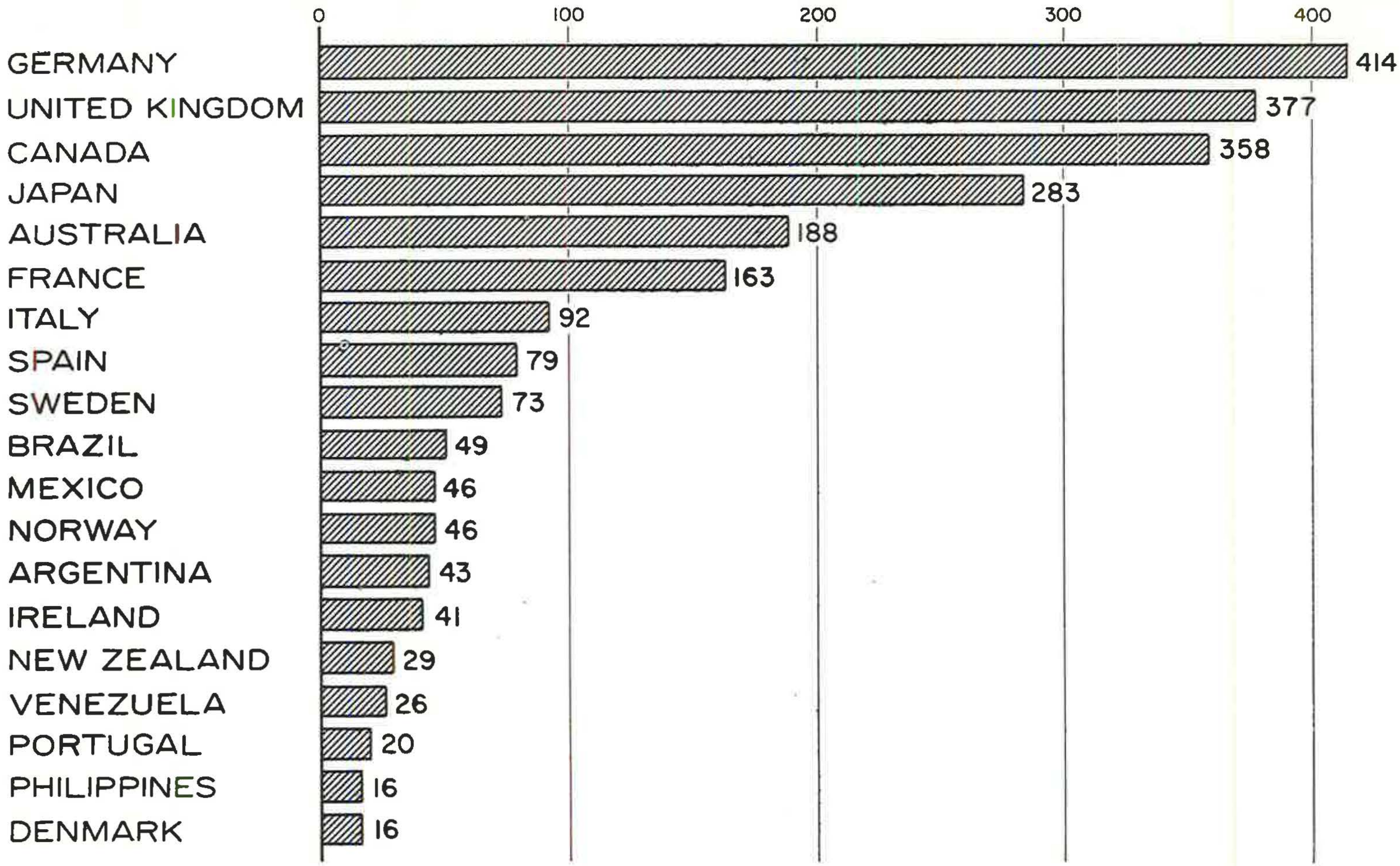

Figure 1. Number of highway research projects reported from 19 countries, 1964-1965.

The inventory through the Highway Research Information Service (HRIS) has supplied printouts of selected projects and these have been generously circulated to interested countries and agencies. As the circulation has widened, the demand for copies of the various documents has steadily increased. Our second Interim Report, covering 17 countries, has been widely distributed and is in such demand that it has now been published and is on sale by the U. S. Department of Commerce. This, in itself, shows the value put upon the information collected. Not only is the information itself proving of value to research engineers and others, but also it has already shown up areas of duplication and has indicated where modification of research previously proposed is desirable. In at least one instance it has shown that research that had been planned was unnecessary.

Our original objective was the general one of creating an international exchange of information on current highway research, so as to reduce unnecessary and wasteful duplication of effort, and to facilitate the dissemination of information about useful discoveries. "Storage and retrieval" is a phrase in common use these days, and it was understood from the beginning that all research projects tabulated by the International Road Federation and transmitted to the Bureau of Public Roads would be turned over to the HRIS of the Highway Research Board for computer processing and storage.

This has been done as our information has been gathered, and basic data for thousands of research projects from many countries are now filed on tapes, from which they can be retrieved and printed out in a matter of minutes. We have also been associated with the establishment of research information exchange centers in other countries, some under the auspices of the Organization for Economic Cooperation and Development, where our research data are being filed.

It is significant that an inventory sheet has been developed, standardized and adopted by the IRF and the OECD in collaboration with the U. S. Bureau of Public Roads (Fig. 2), while still another encouraging development has been the contribution of personnel by other countries to this work. In addition to U. S. Bureau of Public Roads personnel who are participating in actual field work abroad, Great Britain has made a large number of professionals available for various phases of the project and France has provided for the services of four prominent researchers for the current work.

One of the most interesting aspects of the IRF work has been the increased interest generated in research and development. Another important aspect is reflected in the discovery of some projects of special interest in all of the countries inventoried to date.

Having reached the stage where the mechanics of storage, retrieval, and exchange are largely determined we can now examine and evaluate what we have acquired and see what we can do with it. This paper presents a preliminary analysis of the results, plus two other important elements: (a) an example of how the use of the inventories has helped in directing attention to the latest design features for a certain road facility; and (b) case histories of research and development in other countries in an attempt to determine how research is developed, how it is conducted, the basic results, and what implementation, if any, is made of these results.

Even without the help of the computer it has been obvious that our reported research projects have touched on almost every conceivable field of inquiry relating to highways and highway transportation. We have not yet listed any research on highway excavation by nuclear blasting, nor have we any reports on lunar soil stabilization, but perhaps we have not looked in the right places. When a need for such research is felt (indeed, as we write, a probe has been reported as having tested the hardness of the moon's surface) we are sure it will be undertaken somewhere. Meanwhile there is plenty to interest us in the current programs. We are discovering what fields are being cultivated, and where.

For filing purposes the HRIS classified research reports into 34 coded fields or areas, as follows:

11-Transportation Administration; 12-Personnel Management; 13-Land Acquisition; 14-Transportation Finance; 15-Transportation Economics; 21-Photogrammetry; 22-

DIRR — FICHE PROJET – RESEARCH PROJECT SHEET – FORSCHUNGSARBEIT — IRRD

Fiche préparée par l'OCDE en collaboration avec l'IRF – Sheet prepared by OECD in collaboration with IRF – Vordruck von der OECD in Zusammenarbeit mit der IRF aufgestellt

1. INTITULÉ DE LA RECHERCHE / PROJECT TITLE / TITEL DER FORSCHUNGSARBEIT :

PAYS / COUNTRY / LAND

R

DIRR / IRRD — HRIS

NUMÉRO / NUMBER / NUMMER

2. LABORATOIRE CHARGÉ DE LA RECHERCHE - ADRESSE / RESEARCH ORGANIZATION IN CHARGE - ADDRESS / BEAUFTRAGTE STELLE :

3. CHERCHEUR (S) / RESEARCH TEAM / BEARBEITER :

FICHE PROGRAMME N° / PROJECT NUMBER / Nr.

4. FINANCEMENT PAR / SPONSOR / AUFTRAGGEBER :

5. COUT / COSTS / KOSTEN :

TOTAL / GESAMT	ANNUEL / ANNUAL / JAEHRLICH
	Devises locales Local Currency Landeswaehrung
	US $

DATE DE DÉBUT / STARTING DATE / BEGINN

FIN PREVUE POUR / ESTIMATED COMPLETION DATE
VORAUSSICHTLICHER ABSCHLUSS

TERMINÉ / COMPLETED / BEENDET ☐

DATE / DATUM

DESCRIPTEURS PROPOSES / SUGGESTED DESCRIPTORS
VORGESCHLAGENE DESCRIPTOREN

6. BUTS POURSUIVIS / AIMS / AUFGABE (RÉSUMÉ / SUMMARY / REFERAT)

7. ÉTAT D'AVANCEMENT A CE JOUR / PRESENT POSITION / STAND DER FORSCHUNGSARBEIT :

DATE / DATUM

Fiche préparée par / Sheet prepared by / Ausgestellt von :

Date / Datum :

MOTS-CLÉS / KEYWORDS / STICHWÖRTER	CODE / KENN-NUM.	MOTS-CLÉS / KEYWORDS / STICHWÖRTER	CODE / KENN-NUM.
RESEARCH PROJECT	3378		

TERMES ADDITIONNELS / ADDITIONAL TERMS
ZUSÄTZLICHE STICHWÖRTER

1
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8. TITRE, AUTEUR(S) ET DATE DES RAPPORTS PUBLIES / TITLE, AUTHOR(S) AND DATE OF PUBLICATION OF REPORTS / TITEL, VERFASSER UND DATUM DER VORLIEGENDEN BERICHTE :

N° FICHE-DOCUMENT-DIRR
No. OF IRRD INFORMATION SHEET
Nr. IRRD-DOKUMENTATIONSBLATT

Figure 2. IRF-OECD highway research project sheet.

Highway Design; 23-Highway Drainage; 24-Roadside Development; 25-Pavement Design; 26-Pavement Performance; 27-Bridge Design; 31-Bituminous Materials and Mixes; 32-Cement and Concrete; 33-Construction; 34-General Materials; 35-Mineral Aggregates; 40-Maintenance, General; 41-Construction and Maintenance Equipment; 51-Highway Safety; 52-Road User Characteristics; 53-Traffic Control and Operations; 54-Traffic Flow; 55-Traffic Measurements; 61-Exploration-Classifications (Soils); 62-Foundations (Soils); 63-Mechanics (Earth Mass); 64-Soil Science; 70-Legal Studies; 81-Urban Transportation Administration; 82-Urban Community Values; 83-Urban Land Use; 84-Urban Transportation Systems; and 90-Highway Research, General.

This classification offers a convenient basis for reviewing the research activities in different parts of the world, though it is clearly impractical in this report to compare 19 countries in each of 34 subject areas. It must suffice to make a few general observations and to point out some of the more conspicuous national characteristics.

There appears to be no general pattern of distribution of the projects for all the countries, or even for selected groupings of what might seem to be similar countries, geographically or socially. Figure 3 shows the numbers of research projects assigned by the Highway Research Information Service to each of the subject areas. It should be noted that many projects have been counted here in two or more areas.

The largest single subject area is that of Bridge Design (area 27), with more than 8 percent of all the projects. But Bridge Design can include a variety of elements like metallurgy, foundations, pavements, and traffic capacity, and covers all types of structures from interchange overpasses to monumental suspension bridges. And there is only this one designated subject area to catch everything specifically related to bridge design, whereas other broad subjects—soils, materials, traffic, for example—offer a number of area subclassifications among which projects may be distributed. Several countries, however, notably Portugal and Japan, were engaged in the planning or construction of major bridges. The total for the group of seven subject areas generally related to highway design (areas 21 to 27) is 25 percent of all projects.

Soils, Foundations and Earth Mechanics, in a group of four related subject areas (61 to 64), constitute another peak in the diagram, as might be expected. A comparison of the individual countries shows that soils studies rank generally higher where highway systems are in the earlier development stages. This group comprises 17 percent of the total.

The field of Materials is broken down into five subject areas (31 to 35), together making up a fairly substantial share (21 percent of the total) well distributed among all of the countries.

On the other hand, Maintenance ranks quite low, along with Construction and Maintenance Equipment (areas 40 and 41). At first this seems surprising, but it can be explained in part, perhaps, by the circumstance that heavy equipment is usually developed and supplied by large manufacturers as a commercial enterprise and research and development are for the most part regarded as individual stock-in-trade.

Traffic and Safety, as a group of five subject areas (51 to 55), receive considerable attention. As might be expected, the emphasis in this field is found to be higher in the countries with well-developed highway systems.

The remaining subject areas, many of them more specialized or sophisticated, are conspicuous by their low showing. Land Acquisition (13), is represented by a single project. Personnel Management (12), Transportation Finance (14), Roadside Development (24), and Legal Studies (70) have a few scattered projects, and the four areas comprising urban problems (81 to 84) together include only 5 percent of the total. These last are, of course, fairly well limited to the more urbanized countries.

For comparison, Figure 4 shows the distribution of United States research projects in the HRIS files, by primary subject areas, in July 1966. Here Cement and Concrete (area 32) is the number one research activity, with Bridge Design (27) and Highway Safety (51) equally represented for second place, and General Materials (34) falling fourth. In most of these major areas, at least, the worldwide emphasis appears to parallel roughly that of the United States.

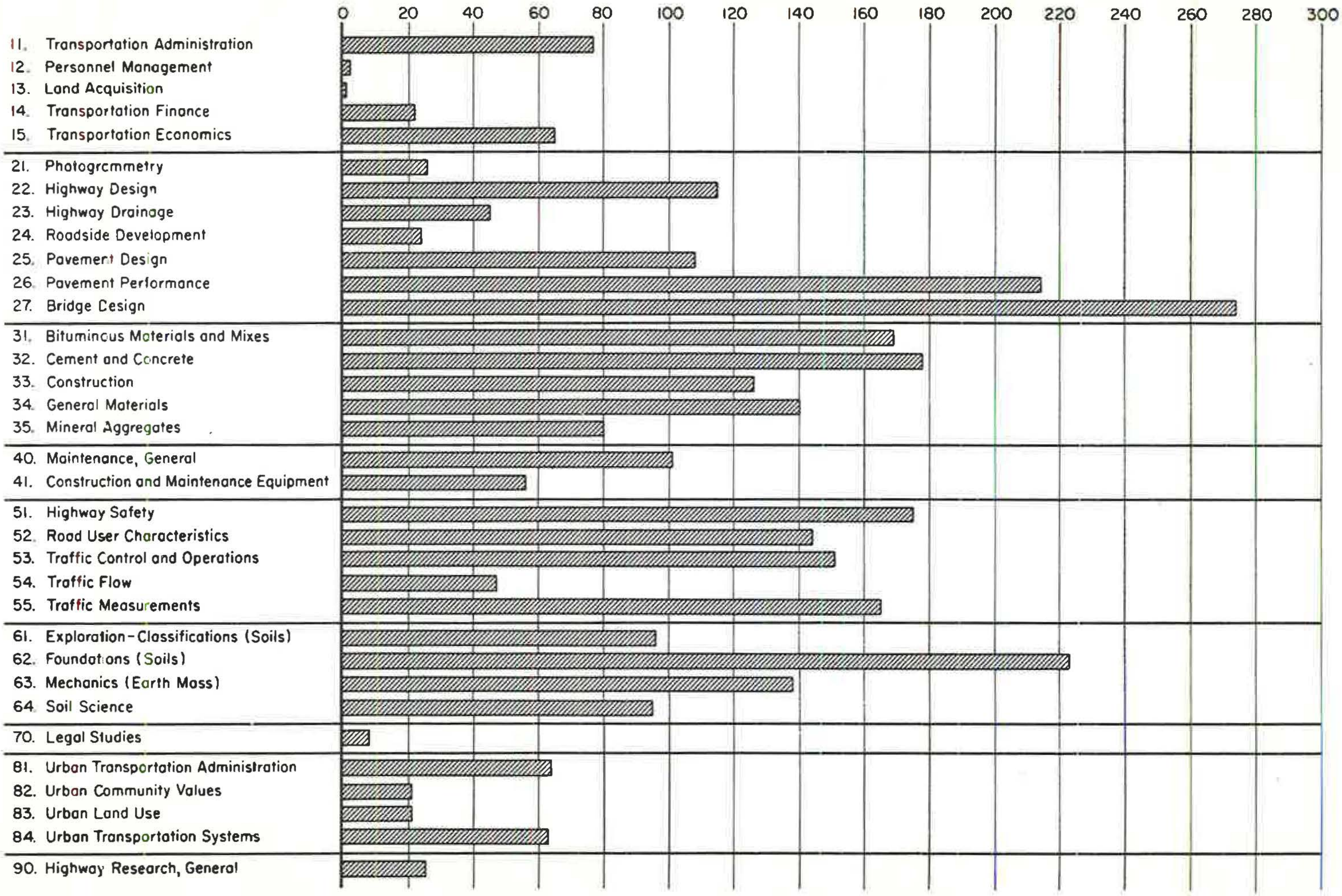

Figure 3. Number of highway research projects reported in each subject area; 19 countries, 1964-1965.

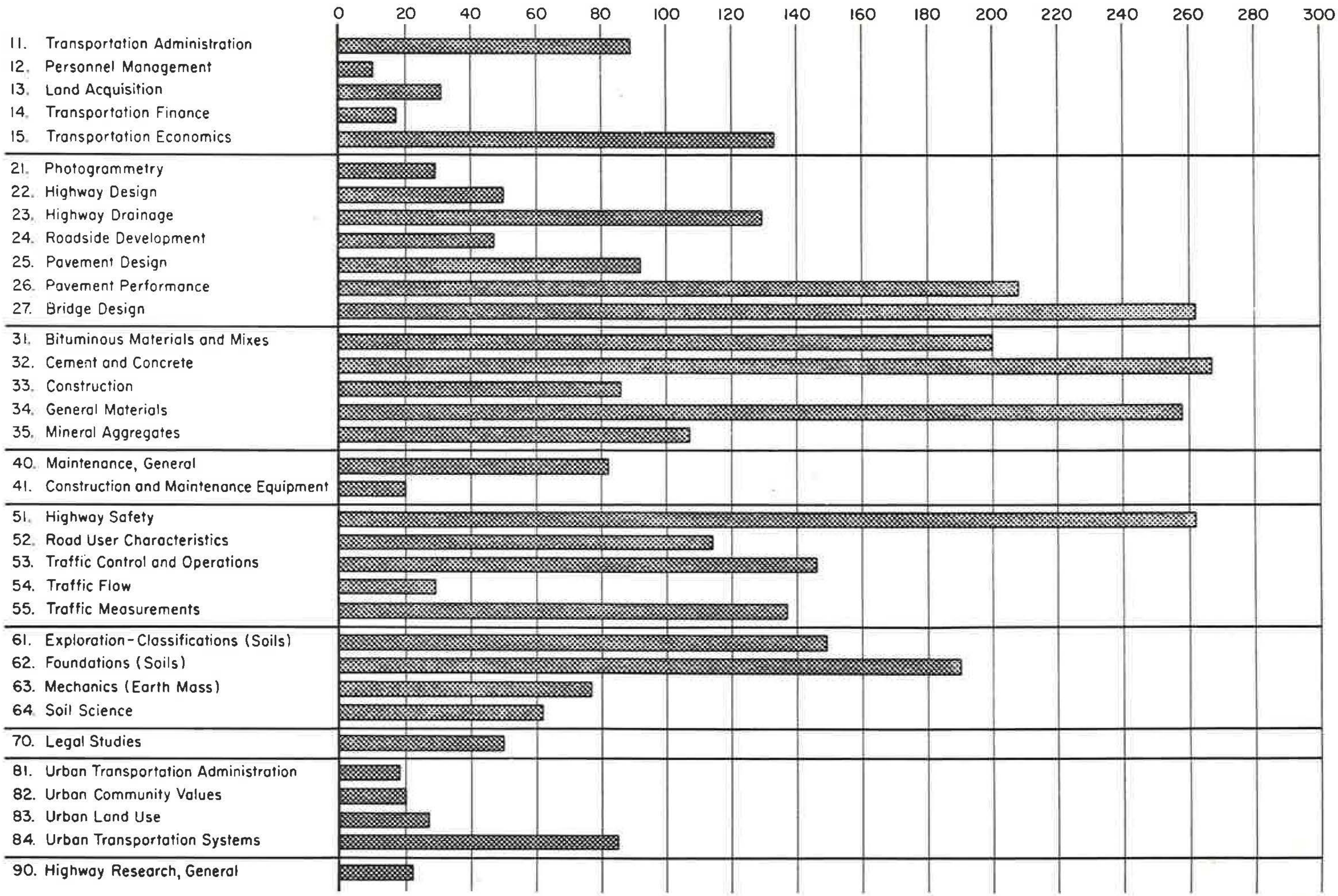

Figure 4. Number of highway research projects by primary subject area, United States (HRIS files, July 1966).

It is when we look at the individual countries, and particularly when we compare them, that we find contrasts and similarities of special interest. As previously indicated, there are few consistent patterns to be observed. This is demonstrated in Figure 5 where three major European countries are compared (Germany, the United Kingdom and France), along with the other three largest countries (Canada, Japan and Australia) in terms of number of projects. Where there is much research, the distribution of projects tends to fill out, and the peaks of concentration level off somewhat. But there are still conspicuous differences in emphasis. Germany stresses pavement performance and pavement materials but gives substantial attention also to traffic and safety.

In the United Kingdom, Bridge Design looms high, but perhaps less significantly than the good showing in Safety and Traffic. France is also conspicuous in Safety. In Australia, Pavement Performance and Soils stand high. Japan emphasizes Bridge Design—partly due to a proposed major suspension bridge—but also stresses Foundations and Soils in an area plagued by earthquakes and unstable volcanic soils. Canada is generally strong over the whole range from Highway Design, Materials, and Soils to Traffic and Safety.

As a second group of countries, the smaller European countries are diagrammed in Figure 6 (Italy, Portugal, Spain, Norway, Sweden, Ireland and Denmark). For these countries the numbers are generally too small to give important significance to their distribution. The peak for Bridge Design in Portugal, for example, can be attributed to the investigations related to the construction of a major bridge, but it represents actually only five research projects. These projects have been completed and will not appear in the 1966 survey.

Italy emphasizes Bridge Design, Safety and Traffic. In Spain, Materials are of first importance, but there is also interest in Pavement Performance and Traffic Measurements. Norway is interested in Transportation Administration and Transportation Economics, and shows more than the usual interest in urban problems. Sweden's major effort at the time of the inventory was in Highway Safety. Ireland, though its research was limited, shows a wide distribution, with considerable emphasis on administrative and legal matters, as well as Soils and Foundations. Denmark is also limited in its research, but with some concentration on materials and construction.

Figure 7 shows certain Latin American countries, together with New Zealand and the Philippines. Argentina and Brazil emphasize Materials, Soils and Foundations. Mexico has no research in Bituminous Materials but is strong on Soils and Soil Mechanics (Earth Mass). Iron- and oil-rich Venezuela finds more time for urban considerations. New Zealand shows interest in a number of fields, without conspicuous concentration. The Philippines, with few projects, is most concerned with Materials. In all of these countries, however, the number of projects is small, and it takes only a few projects in any field to make a disproportionate showing.

During 1966, the Federation has been continuing its research inventory in the 16 additional countries—Belgium, The Netherlands, Luxembourg, Switzerland, Austria, Finland, Poland, Greece, Turkey, Lebanon, Nigeria, South Africa, Bolivia, Colombia, Peru, and Chile—provided for in our extended program. The volume of research in these countries as a group appears to be well below what we discovered in our previous program. It will, however, round out a substantial worldwide survey. In addition, continuing inventories are under way in the United Kingdom, France and Portugal.

Already the Federation activities have expanded far beyond the original limited scope of the research inventories. Last year we were asked by the Bureau of Public Roads to provide information covering research we had reported from the United Kingdom relative to "break-away" lamp posts designed to reduce the severity of motor vehicle accidents. The available evidence indicated that both the United States and the United Kingdom were fairly well advanced in this field, but that neither was fully aware of all that was being done. Our representative accordingly observed research at Texas A and M University and at the highway departments of Minnesota and New Jersey, as well as that at the U. K. Road Research Laboratory. His report indicated that specifications developed in the United States assured the Interstate Highway System of the safest design of this highway facility. Other special projects are now to be explored, and it is hoped that such work can be carried on to the point of coordinating multilateral projects.

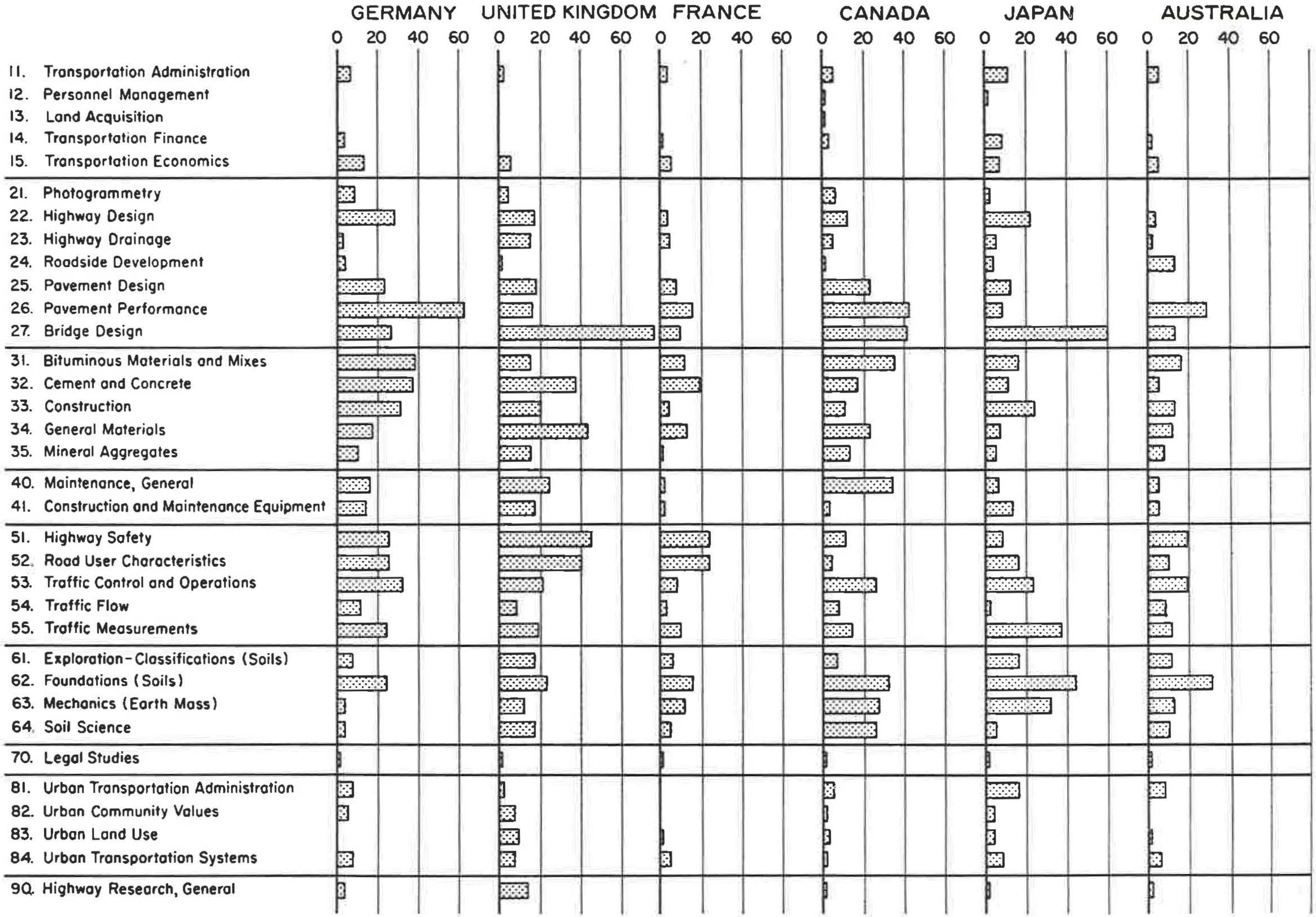

Figure 5. Number of highway research projects by subject areas in leading countries, 1965.

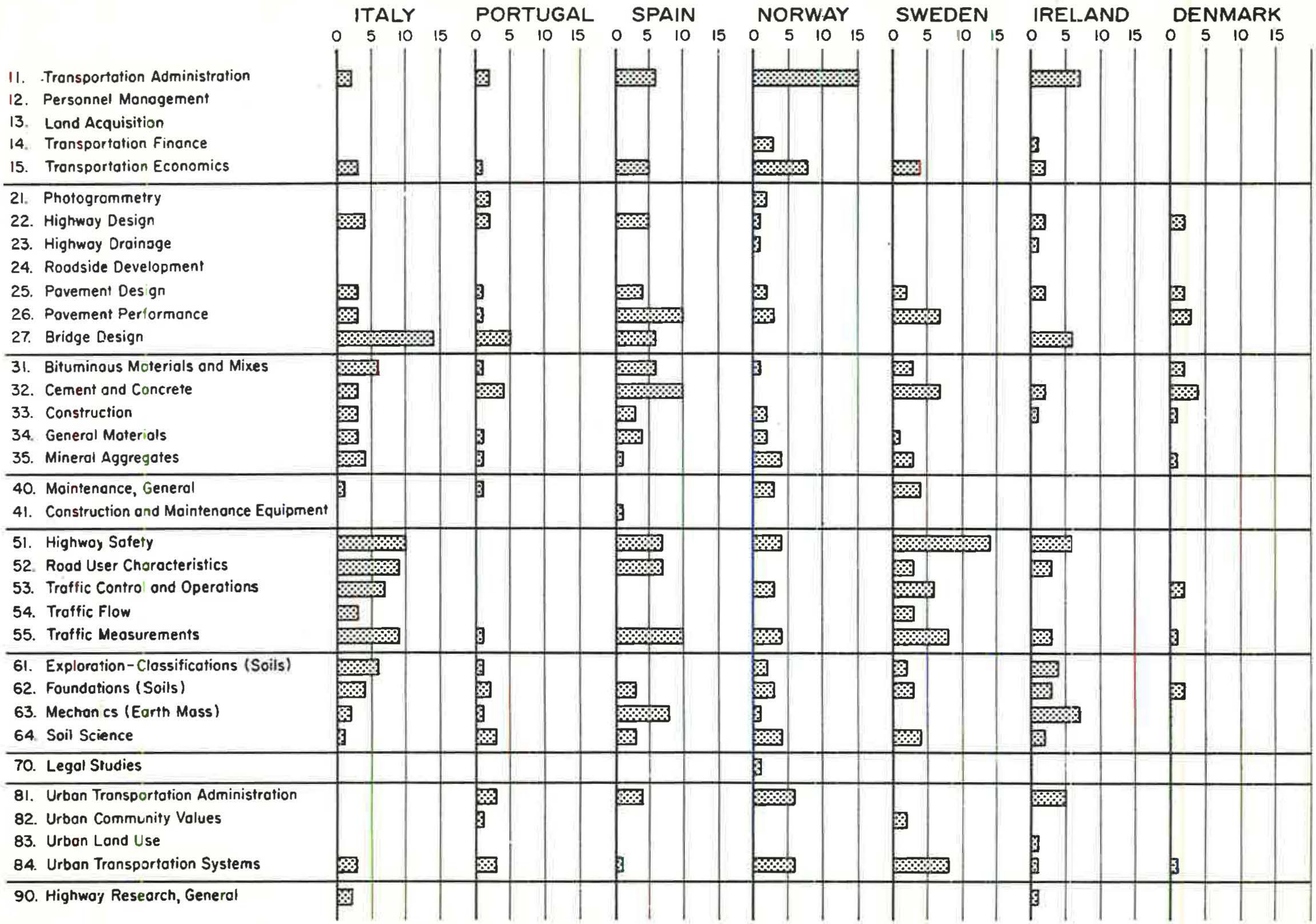

Figure 6. Number of highway research projects by subject areas in smaller European countries, 1964–1965.

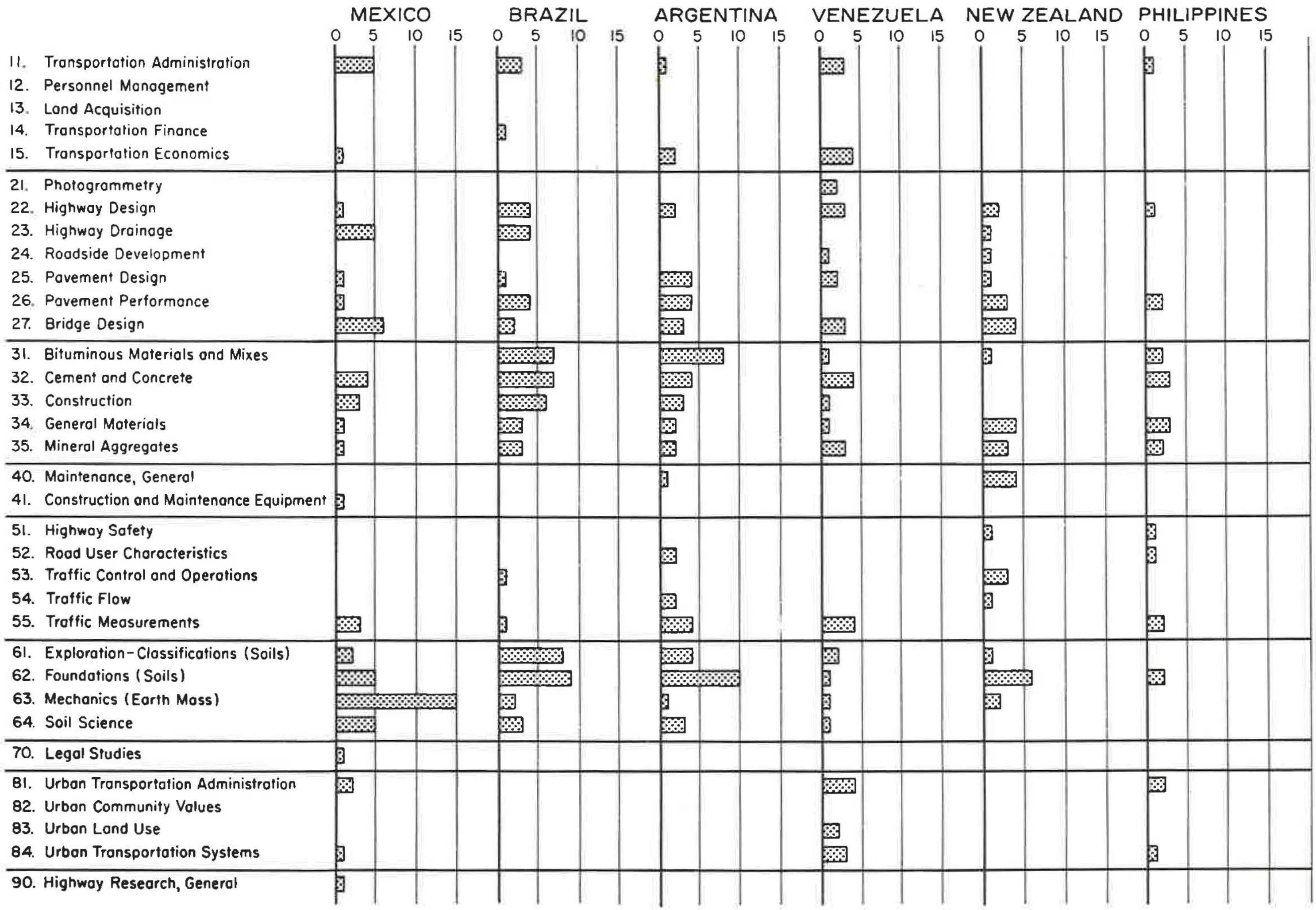

Figure 7. Number of highway research projects by subject areas in Latin American countries, New Zealand and the Philippines, 1965.

As part of the expanded program, too, case histories of particular research projects in other countries have been studied in an attempt to determine how research is developed, the results obtained, and how the results are implemented.

During the past year we have conducted case studies in the United Kingdom and Germany on skid resistance and development of bituminous base construction. In Germany the work was carried out by Mr. James M. Rice, of the Bureau of Public Roads, on temporary assignment to the International Road Federation. Following are some of Mr. Rice's impressions on these two projects in Germany, and one from Mr. G. Grime of the Road Research Laboratory on skid resistance in the United Kingdom.

Regarding skid resistance, the skidding problem appears more severe in West Germany than in the United States due primarily to the driving habits and the general lack of any speed restrictions. On the other hand, the research bearing on the problem has been carried forward rather directly and more coherently than in the United States. For example, the Stuttgart trailer method has been standardized for several years, whereas, although Professor Ralph Moyer laid the foundations of the study of skid resistance in the United States from 1930 on, the similar ASTM procedure, "Skid Resistance of Pavements Using a Two-Wheel Trailer," was proposed as a tentative method only in 1965. It is pertinent to note that the Stuttgart trailer participated in the Tappahannock (Virginia) correlation studies in 1962; therefore, the test results by the two methods may be used interchangeably.

In the area of implementing action with respect to skid resistance of pavement surfaces, guidelines have been prepared which provide minimum values for coefficients of friction for several conditions, and recommendations for remedial action when necessary. These guidelines are being advanced by the Advisory Board for Road Research and may subsequently be adopted by the Ministry of Transport. In contrast, the United States is behind in this respect. Only in the last year has the ASTM Committee on Road and Paving Materials decided to undertake the preparation of specifications for skid resistance of paving materials.

Mr. Grime's case-history study of the skid-resistance research carried out in the United Kingdom also discloses a much more concentrated attack on the problems involved than occurred in the United States.

Studies began in the late twenties and received particular attention because of the wet climate and the large number of accidents involving skidding on wet roads at that time. The studies involved the development of measuring equipment, the comparison of surfaces and the elimination of the more dangerous of these. This was done before World War II.

The classification of stones from the point of view of polishing under traffic followed, together with the collection of statistics of accidents involving skidding, the statistical identification of skidding black-spots, the systematic treatment of black-spots and the recording of the effects of the treatment.

All this led to recommendations for the skid-resistance coefficients in relation to classified road conditions.

In addition, United Kingdom investigations contributed much to knowledge of the importance of tire design and composition. They also included the study of peak coefficients which are reached just before skidding takes place and how to make use of these coefficients by preventing wheels from locking. Texture in relation to skidding at speeds up to 100 mph has been a feature of this work because of the serious nature of accidents occurring on motorways at high speeds. Much of this work was reported to the First International Conference on Skidding held at Charlottesville, Virginia, in 1958.

It appears that the application of the results of research to practice is a more centralized procedure in some ways in the United Kingdom than it is in the United States because of the way the government is organized.

Concerning bituminous base construction, the most remarkable aspect of the development of asphalt base was the rapidity with which it was accepted in Germany without any really conclusive scientific evidence of its merit and without the benefit of any "official" and proven specifications. Although test roads were constructed, the use of asphalt base was well advanced before these tests were fully completed. The real significance of this event can perhaps best be appreciated by a comparison with United States experience. The first uses of hot-mix asphalt base in this country occurred about the turn of the century and its use has continued to some extent since that time. Yet it is only in the last six or seven years that asphalt base has been actively promoted and has become generally recognized as a suitable base for heavy-duty pavements.

It is also notable that the original "technical directions" have generally proven to be quite adequate, and have remained in use without substantial change. This is an attestation to the technical competence of those responsible for their formulation.

Having had time to review and appraise our experience, we are more than ever convinced that the work has been very much worthwhile. We have established a cordial working cooperation in every country visited, we have seen substantial progress made toward the free and convenient exchange of research information among these countries, and our principal concern now is to see that some means are found for keeping the international research inventory up to date.

The continuing value of the IRF inventories cannot be overemphasized. The several countries in which we have conducted a resurvey after only one year have shown how rapidly the research programs can change, as some projects are completed and others initiated. And, of course, a resurvey usually corrects some omissions or errors. The International Road Federation is seeking to provide for a continuous reporting of current research projects from all the countries hitherto visited, and many others. The demand for information exists, and will surely increase with the availability of such information.

Road Research in Canada

GORDON D. CAMPBELL, Director of Technical Services, Canadian Good Roads Association

This paper describes the relationship between road research in Canada and the administration of road systems, the agencies conducting research, the areas of research cooperation and the method of correlating research. During 1966, 366 individual road research projects involving 78 agencies were documented by the Research Correlation Committee of the Canadian Good Roads Association (CGRA). As this inventory of road research in Canada is known to be incomplete, a continuing effort is being made to include all other work as well as to up-date current records.

Current annual expenditures for road research in Canada are estimated at $2.4 million, which is less than two-tenths of one percent of the $1.5 billion spent on road construction, maintenance and administration in 1966. The rate of expenditure for road research in Canada is at least 50 percent less than the rate in the United States. The ten provincial highway departments are the most active and productive road research organizations in Canada.

The summaries of current research as well as summaries of all significant Canadian publications related to roads and road transportation are made available by CGRA to technologists in other nations through the HRB's Highway Research Information Service (HRIS), the International Road Research Documentation (IRRD) program of the Organization for Economic Cooperation and Development and the world survey of road research and development of the International Road Federation. The information on work in other countries received in return for the data contributed by CGRA is invaluable. The need for further international cooperation in road research and documentation is recognized.

A trend toward more research in planning and administrative methodology, particularly in relationship to urban roads, is noted while there appears to be no decrease in the amount of physical research nor in its importance. This paper cites 10 Canadian research subjects which may be of particular interest and value to members of HRB. The paper concludes with a brief description of the means of disseminating current information on road technology in Canada.

•THE organization of road research in Canada is a direct result of the system by which roads are administered and financed.

By Constitution, the provision of roads in Canada is a provincial responsibility. This responsibility was initially delegated by the provincial governments to the municipalities. However, when large numbers of motor vehicles came into use during the second decade of this century, it became necessary for the provincial governments to create highway departments and assume complete responsibility for the construction, maintenance and operation of limited systems of the most important intercity and interregional rural roads. As motor vehicle travel increased, and the dependence of the

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provincial and national economy on reliable, safe and convenient motor vehicle transportation became more pronounced, the activities of the provincial highway departments were expanded and the provincial highway systems were gradually enlarged. In some provinces the administration of all rural roads became a provincial responsibility, while in others, subsidies were paid to municipalities for the construction and maintenance of local rural roads. More recently, the traffic problem became most acute in urban areas and systems of provincial subsidies have been established to help finance street improvements where municipal revenues were inadequate. The relative responsibility of the various levels of government for road administration are given in Table 1.

In Canada the Federal or national government is responsible for roads in the Yukon, Northwest Territories and national parks. In addition it has contributed to the construction of certain important provincial highways under the Trans-Canada Highway Act, the Roads to Resources program, the Railway Grade-Crossing Improvements program, and other special projects of national importance. Federal financial assistance is limited to special projects with terminal completion dates. In Canada there is no long-term federal aid program for highways such as that administered by the Bureau of Public Roads in the United States. However, in 1966, federal aid for special projects amounted to $120, 000, 000 while direct federal expenditures on their own roads amounted to only $30, 000, 000.

RESEARCH ORGANIZATIONS

There is no central road research organization in Canada. More than 100 independent organizations located throughout the country are involved in road research. These organizations include the 10 provincial highway departments, three provincial transport departments, the road departments of major municipalities, certain federal government departments and agencies, universities, associations and major consulting engineering firms and industries. Road research is correlated by the Canadian Good Roads Association (CGRA), and through the committees of that organization cooperative road research projects are undertaken. In this respect CGRA corresponds very closely to the Highway Research Board in the United States. CGRA membership is composed of five federal government agencies, the 10 provincial highway departments, the road departments of approximately 150 major municipalities, 50 associations, 120 consulting engineering firms, 185 contracting organizations, 180 manufacturers and suppliers of road materials and equipment, 70 road transport and related firms, plus representatives of each of the universities. In some respects CGRA is also similar to the American Association of State Highway Officials as the ministers of highways and senior highway administrators in each of the provinces serve on the Board of Directors and Operating Committee. With the large road builder and road user membership, CGRA is also somewhat similar to the American Road Builders' Association and National Highway Users' Conference in the United States.

All major road departments in Canada carry out research as a normal operating function or as special investigations under a separate research branch. Other agencies, such as the universities and municipal road departments, work closely with the provincial departments. The principal organizations involved in road research are given in Table 2. As most road research is carried out by or with the cooperation of the road department engineers, the results, where applicable, are generally implemented immediately.

RESEARCH PROGRAM

The current CGRA research inventory contains 366 separate projects related to roads and road transportation which are now being carried out in Canada and which involve 78 different agencies. However, CGRA is aware that there are other research projects related to roads and road transportation being carried out in Canada at the present time which are not reported in this inventory. Efforts are being made to document this work.

Most of the research projects in Canada have been initiated and undertaken by a single agency, such as a provincial highway department or a university. However,

TABLE 1

GOVERNMENT UNITS IN CANADA WITH ROAD RESPONSIBILITIES

Unit	No.	Roads or Streets (mi)	Expenditures During 1966 Including Subsidies Paid Out ($ million)
Provinces	10	145,000	1,081
Municipalities			
Cities, towns, villages	1,898	40,000	350
Rural	1,187	301,000	
Federal	1	4,500	153
Total	3,096	490,500	1,584

TABLE 2

CANADIAN ORGANIZATIONS ENGAGED IN ROAD RESEARCH

Class	No.	Agencies	Type of Research
Provincial governments	10	Highway departments	All aspects
	3	Transport departments	Safety (vehicle and driver), economics and finance
Municipal governments	24	Major cities	All aspects
	10	Major counties	Materials, maintenance, design
Federal government departments	11	Public Works	Materials, design, construction
		Northern Affairs and National Resources	Maintenance and operations
		Transport	Economics, finance, design, materials
		National Defense	Design and materials
		Forestry	Materials
		National Research Council (Div. of Building Research)	Building materials and foundations
		Dom. Bureau of Statistics	Economics, finance, administration
		Prairie Farm Rehabilitation Administration	Materials
		National Health and Welfare	Safety (traffic accident injuries)
		Can. Gov't. Spec. Board	Safety (vehicle design)
		Nat. Aeronautical Estab.	Safety (crash injury)
Universities	20	Universities in all provinces	Materials, design, traffic, planning
Industry	10	Major consulting eng. firms	Materials, design, traffic, planning
	10	Major industries	Materials and design
Associations	6	CGRA	All aspects
		Western Assoc. of Canadian Highway Officials	Materials, design, construction maintenance, administration
		Can. Highway Safety Council	Safety education
		Traffic Injury Res. Found'n.	Safety (crash injury)
		Can. Automobile Assoc.	Safety
		Can. Trucking Association	Economics and finance
Total	104		

through the committees of the CGRA many cooperative road research projects, each involving a number of agencies located throughout Canada, have been undertaken. The principal items in this cooperative program are given in Table 3. Each of these items involves a long-term cooperative study leading to a committee report or series of technical papers presented by the participants in the project.

In 1965 CGRA published a report on Road Research Needs in Canada. In this document 48 problems were defined. Of these, eight were assigned to the highest priority group, eight to the second priority group, and the remaining 28 to the lowest priority group. By design the cooperative road research projects given in Table 3 reflect the most important needs defined in the 1965 report.

EXPENDITURES FOR ROAD RESEARCH

Most road research in Canada is carried out as part of a routine construction, maintenance, operation or planning project, and the expenditures for research are charged to that project rather than to a separate budget. Hence, it is difficult to estimate total expenditures attributable to research. However, in conjunction with the latest survey of road research in Canada, information was sought on research expenditures. From the data obtained, it is estimated that the total expenditures on research related to roads and road transportation in Canada amounted to $2. 4 million in 1965. It is of interest to note that the comparable figures for 1958 and 1963 were $1 million and $2. 1 million, respectively. Although investments in research are increasing, annual road expenditures have also been rising. Thus, the current rate of investment in road research in Canada still amounts to less than two-tenths of one percent of the total annual expenditures for road construction, maintenance and administration. This rate of expenditure for road research in Canada is probably 50 percent less than the comparable rate in the United States, and substantially less than one-half the rate in Great Britain.

The approximate distribution of 1965 road research expenditures in Canada by types of agencies was as follows:

Agency	Percent
Provincial highway departments	35
Universities and provincial research councils	25
Municipalities	15
Industries and associations	15
Federal government departments and agencies	10

This breakdown indicates that the provincial highway departments are the most active and productive road research organizations, especially when it is recognized that much of the work done by the universities and provincial research councils is initiated and financed by the provincial highway departments.

RESEARCH CORRELATION

In 1962, a research correlation committee was established under the Technical Advisory Council of CGRA for the purpose of: (a) maintaining a complete up-to-date inventory of all road research and development work in Canada; (b) disseminating information on road research to all interested agencies in Canada; (c) establishing road research priorities and encouraging further work on these problems; and (d) insuring that the results of investigations in Canada and abroad are brought to the attention of all highway agencies in Canada and so put into practice where it is practical and economical to do so.

To date the Research Correlation Committee has been composed of twelve members. These members are senior engineers from each of the ten provincial highway departments, a senior engineer from a federal government department, and a secretary from

TABLE 3

COOPERATIVE ROAD RESEARCH PROJECTS IN CANADA

Area	Projects
Bridges and Structures	Bridge loadings Bridge bearings Use of high tensile steel in concrete Settlements at abutments of earth fills Use of unpainted low-alloy high tensile steel Riverbed scour at bridge piers and abutments Aesthetic design of overhead sign supports
Construction and Maintenance	Statistical quality control procedures for construction Pressure spraying Shoulder design General contract conditions Snow and ice control methods
Economics, Finance and Administration	Government-utility liaison in right-of-way use Public liability and property damage claims Uniform classification of road expenditures Motor vehicle operating costs Multi-project scheduling procedures Supply and demand for transportation engineers
Geometric Design	Warrants for speed-change lanes Passing sight distance requirements Warrants for separate turning lanes Turning paths of modern trucks
Pavement Design	Causes, effects and control of transverse cracking in bituminous pavements Structural design criteria for flexible pavements on low traffic volume roads Load-supporting capacity of flexible pavement bases stabilized with cement, lime and asphalt Determination of the effects of non-uniformity in construction on pavement life Seasonal variation in strength and performance of flexible pavements
Soils and Materials	Evaluation of moisture and density changes in subgrades and pavements Collection of pile-driving test data Deterioration of bridge decks and superstructures by deicing chemicals Production, design and performance of asphalt pavement surfaces Prediction of frost depth
Traffic Operations and Safety	Development of uniform rules of the road for Canada Relationships between accident rates and alignment and cross-section features Control of roadside advertising signs adjacent to controlled-access highways Determination of the relationship between permitted right-turn-on-red-signal movements and vehicle accidents, pedestrian accidents and vehicle delays
Transportation Planning	Determination of potential technological changes in transportation systems which should be considered in current planning and design Evaluation of geographical data coding grids for data banks used in transportation and economics studies Relationship between land use and traffic generation Determination of basic parameters required to estimate future urban traffic flows

the CGRA staff. Being small in number, the Committee is able to work effectively and quickly. Each member of the Committee is responsible for keeping informed on research activities in his own province. Each of the members provide the Association with information on agencies involved in research and with detailed information on current projects.

With the assistance of the Research Correlation Committee CGRA has attempted, since 1958, to maintain an up-to-date file on road research in progress in Canada. Complementing this service, the Association issued Technical Publications No. 9, March 1959, and No. 21, January 1964, to make this information available to all members and other interested parties. During 1964 and 1965 a concerted effort was made to improve the quality and reliability of the information on all current research, and to insure that the inventory was as complete as possible. A new listing of projects was issued by the Association as "Road Research in Canada" in December 1966. The results reported in this document were obtained in the following manner.

1. Approximately 400 agencies and individuals in Canada which were considered as possible sponsors of research were contacted by mail. In each case Research Project report forms, designed to obtain specific information on individual studies, were supplied.
2. Each of the agencies was then contacted by the Research Correlation Committee member in that province to insure that the information request and the significance of the undertaking was clear and that they submitted the report form on the projects which they were conducting or sponsoring.
3. All reports returned to CGRA headquarters were screened for duplication and suitability.
4. A representative of CGRA traveled across Canada to visit all principal investigators and verify, correct or supplement, through interview, the information which had been obtained by mail.

This inventory of 366 road research projects will be maintained up-to-date by reviewing each project at least once a year and by adding new projects as they are undertaken. As a result a file of current research in progress should be available at all times.

DOCUMENTATION

With limited resources available for research, one of the principal objectives of CGRA and Canadian road research agencies is to avoid duplicating work being carried out or completed in other countries. As a result CGRA is participating in cooperative programs with the Organization for Economic Cooperation and Development in Paris, the International Road Federation (IRF) and the Highway Research Board (HRB) to exchange information on road research in progress as well as abstracts of all significant articles or books published since January 1, 1965.

Publication abstracts are being indexed and regularly submitted to the International Road Research Documentation (IRRD) program of OECD in return for similar information being contributed by twelve other nations. CGRA has also provided information on Canadian road research in progress for the IRF's survey of current highway research and development. As the IRF required the data to be submitted in a specific format by an early date, they retained a Canadian engineer to work with CGRA in the compilation of its research inventory. In this way, IRF provided CGRA with considerable assistance which is gratefully acknowledged.

CGRA has also entered into an informal bilateral agreement with the HRB, with respect to the selection and preparation of input information for HRIS on Canadian road research and publications. In return for this contribution to the HRIS we hope to benefit from access to the U. S. and foreign information stored in this information retrieval system. To date all of the information on current road research in Canada and abstracts of approximately 250 Canadian publications have been stored in HRIS. The HRB has very generously made available printouts of this Canadian information to CGRA and has offered other technical advice and assistance. CGRA is most appreciative of the cooperation extended by the Board, its Executive Director, Mr. W. N. Carey, Jr., and its Assistant Director for Special Projects, Dr. P. E. Irick.

CGRA has also instituted a coordinate index card information retrieval system in which to store the summaries of publications and research projects documented in Canada and received from abroad through IRRD and HRIS. This CGRA information system is designed to complement our library and provide our members with up-to-date information on current research and development work.

TRENDS IN RESEARCH PROGRAM

Ten years ago practically all road research in Canada was concerned with road and bridge design and the physical characteristics of materials. Very little attention was being given to the development of new techniques in the planning and administrative areas of economics, finance, law, traffic analysis, transportation systems and safety. Research on these non-physical aspects of road technology has steadily increased, both in terms of the numbers of projects and research dollars spent. Between 1963 and 1966 the non-physical content of Canada's road research program has increased from 15 to 25 percent in terms of the number of active projects. In terms of monetary resources the percentage would certainly be greater. These figures represent an underestimate of the shift in emphasis in road research in Canada because some work in this rapidly evolving area of planning techniques has not been reported.

During the past five years, 50 cities in Canada have undertaken or completed comprehensive urban transportation studies. This represents practically every city in Canada with a population in excess of 20, 000 people. During the same period, three provinces have completed rural highway need studies, while four of the proposed 19 area transportation planning studies in Ontario have been completed. As the techniques for conducting these urban and regional transportation studies have not developed to the point where standard procedures are available, the majority of these studies involve an element of research.

Despite the changing content of the road research program in Canada, there has been no decrease in the total amount of physical research. Some of the most serious problems and significant accomplishments continue to be in this area of physical research.

A second significant trend in the research program is the steady increase in the numbers of projects being carried out at the 20 Canadian universities which offer study programs in transportation engineering. The increase in university research may be attributed to the expansion of the graduate study programs in civil engineering. In the past, most Canadian engineers desiring post-graduate training in the highway sciences went to universities in the United States. Today at least five Canadian universities offer comprehensive post-graduate highway engineering programs.

NOTABLE WORK

Specific information on any current Canadian road research project may be obtained from CGRA, the HRB's Highway Research Information Service, or the IRF. All of these projects would be of interest to some technologists in other countries. However, 10 Canadian research subjects which might be of greatest interest to members of the Highway Research Board have been selected for mention. They are (a) the design and evaluation of flexible and rigid pavements; (b) frost action and the insulation of subgrades; (c) soil stabilization with cement, lime and asphalt; (d) determination of the factors affecting temperature cracking of asphaltic concrete surfaces; (e) winter maintenance procedures; (f) the corrosion of motor vehicles by de-icing chemicals; (g) riverbed scour and channel control; (h) development of symbolized traffic signs; (i) traffic generation and assignment models; and (j) the development of automated urban and regional data banks.

DISSEMINATION OF INFORMATION

The results of road research in Canada are exchanged through the 11 technical committees of CGRA. CGRA is also a principal publisher of technical papers on roads and road transportation in Canada. The proceedings of the annual CGRA conventions normally contain close to 50 technical papers and reports. CGRA also issues separate technical publications containing individual papers or committee reports. Special publications of the Association include the Manual of Geometric Design Standards for Canadian Roads and Streets, and the Manual of Uniform Traffic Control Devices for Canada.

Technical papers on roads and road transportation are also published by the provincial highway departments, various trade magazines, the National Research Council, the Engineering Institute of Canada, the Canadian Technical Asphalt Association, and other professional associations. There are approximately 75 sources of technical publications on roads and road transportation in Canada. All of these sources are monitored by CGRA in an attempt to select all significant papers of permanent value for the Canadian Good Roads Association, HRIS and IRRD information retrieval systems.

Canadian road technologists customarily present papers at important international conferences such as those on soil mechanics and foundation engineering, the structural design of asphalt pavements and the IRF World Road Congresses. In addition there are generally 10 to 15 papers by Canadian engineers presented at each HRB annual meeting. Normally close to 100 Canadian engineers attend the HRB annual meetings.

To further disseminate the results of Canadian road research and development, CGRA has a program of exchanging technical publications with corresponding organizations in a number of other countries.

CONCLUSIONS

Traditionally Canada has depended, to a large extent, on research and development in other countries, and particularly that done in the United States. However, the amount of road research in Canada is increasing steadily and some significant results are being produced which should be of value to road technologists in other countries.

The amount of road research being carried out in Canada has been restricted by the shortage of qualified engineers, scientists, economists and other transportation technologists. A very large and increasing construction program in Canada has made it necessary to utilize all available talent for operational purposes, and resources have been allocated only to the most essential research projects. This situation undoubtedly exists in other countries.

As the resources available for road research are limited, it is believed that great benefits can be obtained through international cooperation and the exchange of information. For this reason CGRA has actively cooperated in the HRB's Highway Research Information Service, the IRF World Survey and Road Research and Development, and the cooperative road research programs of the Organization for Economic Cooperation and Development. Further cooperation between nations will result in improved utilization of available resources for research and in accelerated advances in road technology.

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The Road Capacity of City Centers

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•IN September of last year, a paper was presented by the writer at an International Study Week in Barcelona, Spain, on the road capacity of city centers (1). This paper develops aspects of the same subject which were not dealt with in the previous paper. Considering first the numbers of vehicles that can use the roads of a city per unit time under various conditions, it might reasonably be expected that this number would depend on many factors, including the nature of the city and of its road system and on the types of journey that are made there. It is, of course, necessary to consider the matter quantitatively.

THE AREA OF ROAD REQUIRED FOR TRAVEL

Suppose that the capacity of a road of width W is Q vehicles per unit time. Then one may regard each vehicle using the road in unit time as requiring a width of road W/Q. If a vehicle makes a journey of length d on such a road, it may be said to require an area Wd/Q of carriageway. Suppose, in the first instance, that the value of W/Q is the same for all roads in a Central Business District. Then, if N vehicles use the roads of the CBD per unit time, and if the average distance traveled is $\bar{d}$, the total area of carriageway required for these journeys is $NW\bar{d}/Q$. If the fraction of the carriageway area in the CBD used for traffic movement of the type under consideration is J, if f is the fraction of the ground area of the CBD devoted to roads and if A is the total ground area of the CBD, it follows that

$$\frac{N\bar{d}W}{Q} = JfA,$$

and therefore that

$$N = \frac{JQ}{W} \cdot \frac{fA}{\bar{d}}$$

The Value of $\bar{d}$

The value of $\bar{d}$, the average distance traveled, depends on the type of road network, the distribution of origins and destinations, etc. This paper is, however, concerned with the capacity of a road network and therefore mainly with travel at peak travel periods. At such times, journeys are predominantly between points on the outskirts of a CBD and points inside it. It is, therefore, convenient to assume initially that origins are equally distributed among the points at which the roads leading into the CBD meet the boundary of the CBD and that destinations are distributed either uniformly along the sides of the roads of the CBD or uniformly within the area. Under such conditions, it is possible to calculate the average distance traveled on the roads of any given CBD, assuming that journeys are made by the shortest possible route. Approximate calculations have been made for a number of idealized and real road systems, and the results given in Figures 1 to 5.

Figure 1 gives the results for four routing systems in circular CBD's in which it is assumed that roads are infinitely close together and that destinations are distributed uniformly throughout the area. Figures 2, 3 and 4 are for idealized road systems, in

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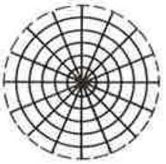
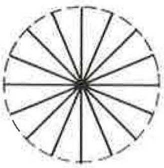
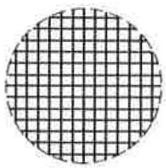
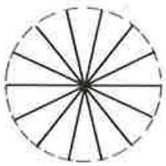
Route	Road network	Average distance
Radial Arc Vehicle travels along the radial through O, the point of arrival at the outskirts of the central area, until it reaches the circular road on which its destination lies, and then along this road until it reaches its destination.		$\frac{1}{3}\left(\frac{1}{\pi^{1/2}}+\pi^{1/2}\right)A^{1/2}=0\cdot78A^{1/2}$
Radial Vehicle travels along radial from O to center of central area and then turns on to radial on which destination lies.		$\frac{5}{3\pi^{1/2}}A^{1/2}=0\cdot94A^{1/2}$
Rectangular Vehicle travels along one of the two roads through point of arrival at outskirts of the central area until it reaches the perpendicular road on which its destination lies and then along this road.		$\frac{128}{9\pi^{2\cdot5}}A^{1/2}=0\cdot81A^{1/2}$
Ring Vehicle travels along a ring road on the outskirts of the central area until it reaches the radial on which its destination lies, and then along this radial.		$\left(\frac{\pi^{1/2}}{2}+\frac{1}{3\pi^{1/2}}\right)A^{1/2}=1\cdot07A^{1/2}$

Figure 1. Effect of road and routing system on average distance traveled—vehicles assumed to travel from random points on the outskirts of a circular central area to random points inside circle (roads assumed to exist at all origins and all destinations).

which it is assumed that destinations are uniformly distributed along the roads and that the road network consists of two sets of parallel roads, one set being perpendicular to the other. Figure 5 gives the results for a number of actual road networks in England and it is again assumed that destinations are uniformly distributed along the sides of the roads.

Examination of the results shows that, despite the wide range of kinds of road network and of shapes of central area, the average distance traveled varies only from $0.62A^{1/2}$ to $1.07A^{1/2}$, the more realistic cases varying from 0.77 to $1.07A^{1/2}$. All the results obtained are within 30 percent of the mean value $0.85A^{1/2}$, while 88 percent of the results are within 12 percent of $0.87A^{1/2}$. It seems likely, therefore, that if we substitute $0.87A^{1/2}$ for $\bar{d}$, the result will, in practice, not usually be subject to large error.

The Capacity per Unit Width of Road

A number of investigations have been carried out in various countries to find the road capacity of city streets. The recently published Highway Capacity Manual (2) devotes some attention to it and gives graphs showing that, in the absence of parking, and for apporach widths larger than a certain amount, the number of vehicles that can pass through a single-controlled intersection per hour of green time is approximately

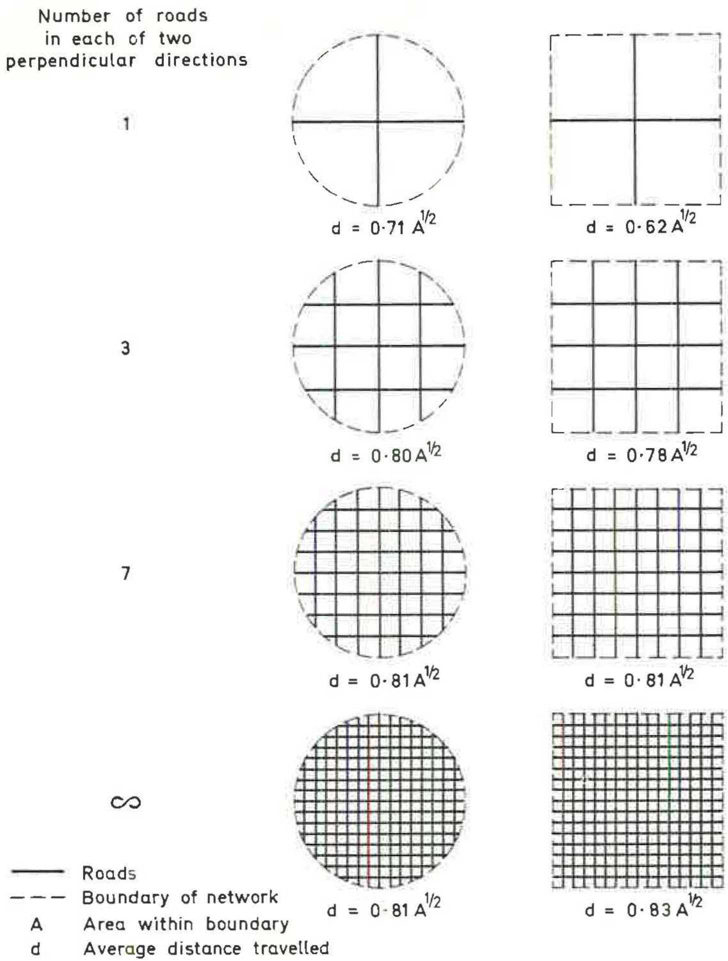


Figure 2. Effect of density of roads on average distance traveled assuming uniform density of destinations per unit length of road (rectangular routing).

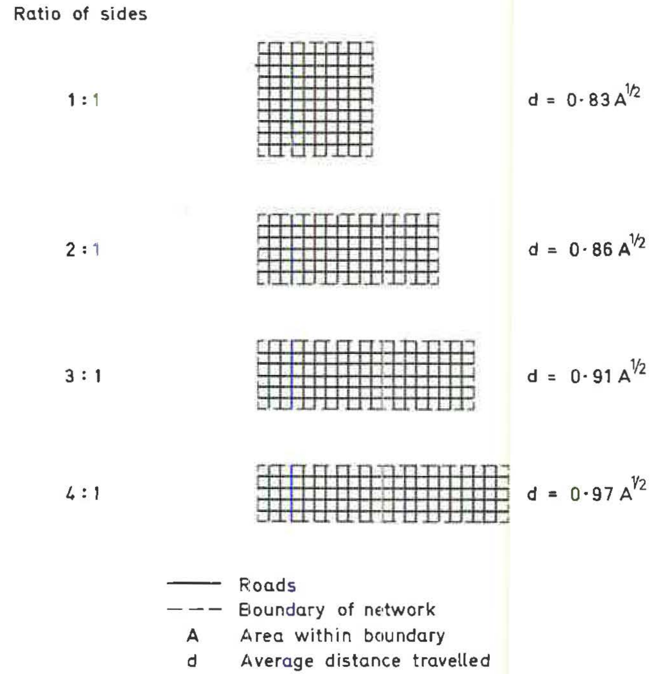


Figure 3. Effect of length/breadth ratio on average distance traveled in a rectangular-shaped CBD (roads infinitely close together and parallel to sides of CBD).

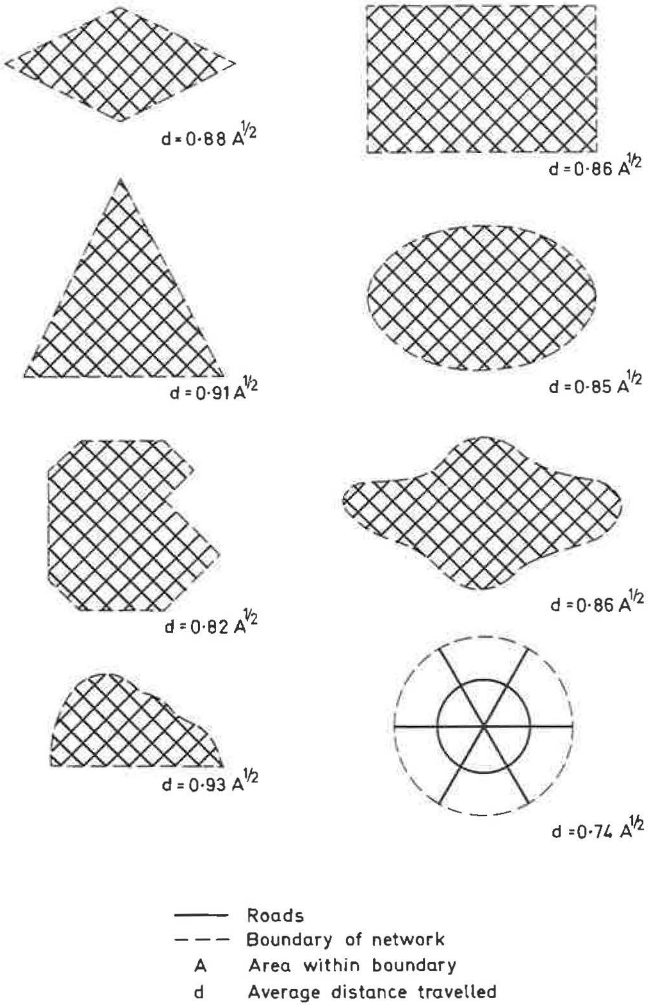


Figure 4. Average distance traveled on some miscellaneous imaginary networks (number of destinations per unit length of road uniform).

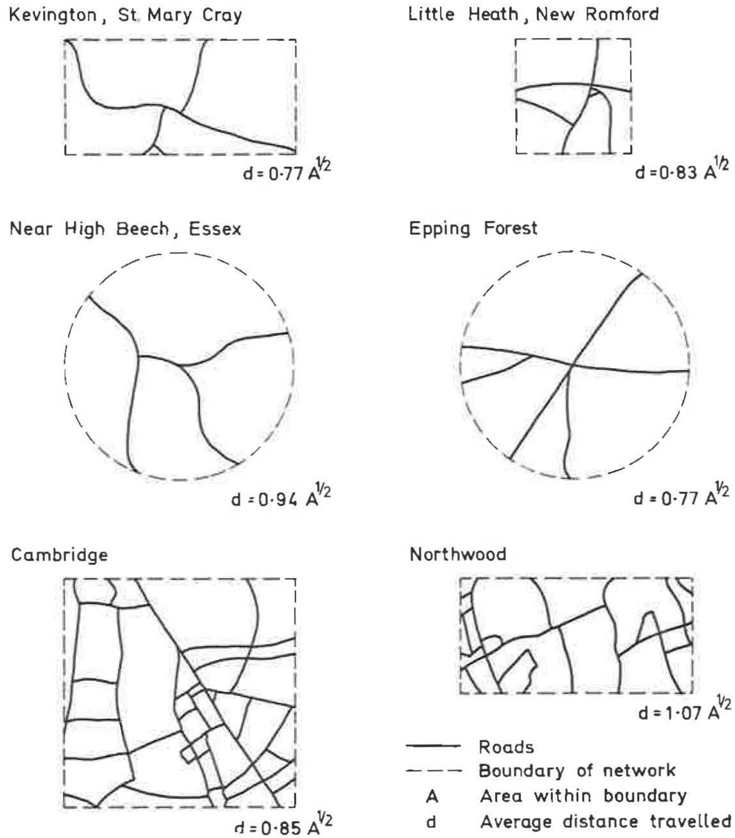


Figure 5. Average distance traveled on some real road networks (number of destinations per unit length of road assumed constant).

proportional to the approach width. A similar result has been obtained in Great Britain (3). Since the intersections are, in general, the factors limiting the capacity of urban streets, it follows that the capacity of urban streets is approximately proportional to their widths, as was assumed above. The factor of proportionality is perhaps best obtained from an investigation carried out in Great Britain, where a relationship has been obtained between the average speed of traffic and its amount for roads of given width. In an earlier paper (1) this relationship was put into algebraic form, and it was found that, provided the average speed is not too small, more than 4 mph, say, the capacity per unit width per hour, Q/W, is given approximately by

$$\frac{Q}{W} = 58 - 0.0052v^3$$

where v is the average journey speed in miles per hour and capacity is measured in pcu's, i.e., passenger car units. According to "Research on Road Traffic" (3), the pcu values appropriate to urban streets are

Cars and light vans	1.0
Medium commercial vehicles	1.75
Heavy commercial vehicles	2.5
Buses and coaches	3.0
Motorcycles	0.75
Bicycles	0.33

The Value of J

The value of J, the effective proportion of the total carriageway used during peak travel periods, depends mainly on the proportion of the total carriageway suitable for general movement during such periods and on the extent to which both sides of the roads are in use. Since in many towns large areas of carriageway are only suitable for serving neighboring buildings, and because travel is predominantly in one direction in peak periods, a value of J considerably less than unity and perhaps between ⅓ and ½ is generally to be expected. Further investigation is required on this point, but the effect on road space required of travel being predominantly in one direction was examined (4) for some cases of idealized towns. The results of calculations given (4) show that, for circular towns and for ring, radial-arc and rectangular routing, as defined in Figure 1, the proportions of through carriageway fully used during peak periods were 85, 81, 83 and 77 percent respectively.

An Approximate Theoretical Formula for the Road Capacity of City Centers

It has been found that:

1. $N = \frac{JQ}{W} \cdot \frac{fA}{\bar{d}}$
2. $\bar{d} = 0.87A^{1/2}$, approximately, for a wide range of cases.
3. $Q/W = 58 - 0.0052v^3$, provided that Q/W is measured in passenger car units per hour and per foot width of carriageway and that v is measured in miles per hour.

It follows that

$$N = (58 - 0.0052v^3)\, fA^{1/2}/0.87 = J(67 - 0.0060v^3)\, fA^{1/2}$$

approximately, for a wide range of cases, provided that N and v are expressed in the above units and A in square feet.

Assuming J to be between ½ and ⅓, the analysis therefore suggests that the maximum number of vehicles that can usefully circulate per hour in a CBD with a normal

TABLE 1

VALUES FOR $N/fA^{1/2}$ FOR VARIOUS CBD'S

N = pcu's per hour, one way
A = Area of CBD (sq ft)

$$f = \frac{\text{carriageway area}}{\text{total area}}$$

Towns of Great Britain	
Edinburgh	12
Bradford	14
Maidenhead	15
Darlington	15
Liverpool	17
Hull	19
Nottingham	19
Leeds	21
Sheffield	21
Cardiff	24
Birmingham	24
Coventry	25
Watford	25
Bristol	25
Reading	25
Leicester	25
Maidstone	27
London	29
Towns Outside Great Britain	
Salisbury, S. Rhodesia	11
Dublin, Eire	12
Hamburg, Germany	14
Lisbon, Portugal	14
Tel Aviv, Israel	14
Denver, U. S. A.	17
Stockholm, Sweden	18
Goteborg, Sweden	24
Washington, U. S. A.	26
The Hague, Netherlands	28
Copenhagen, Denmark	29
Los Angeles, U. S. A.	30

type of road network is between $20fA^{1/2}$ and $30fA^{1/2}$ if the speed is 10 mph and between $22fA^{1/2}$ and $33fA^{1/2}$ if the speed is 5 mph or less. If the speed of traffic is higher, the numbers of vehicles that can circulate would be expected to be less. If the speed is 15 mph, the number would be expected to be between, say, $15fA^{1/2}$ and $23fA^{1/2}$, and at 20 mph, between $6fA^{1/2}$ and $9fA^{1/2}$.

Summing up, it would appear that the number of vehicles (expressed pcu's) that can usefully circulate per hour in a central business district would be expected to be very roughly $(33 - 0.003v^3)fA^{1/2}$ or, as v is usually in the range of 5 to 20 mph, between $6fA^{1/2}$ and $33fA^{1/2}$.

A number of authorities have kindly supplied data on the numbers of vehicles of various types entering particular CBD's during peak travel periods, on the total area and on the area of carriageway within the CBD's. Other data have been collected from various sources. All the complete sets of data for CBD's available at the time of writing this paper are summarized in the Appendix to this paper. From these data, the values of $N/fA^{1/2}$ have been calculated and are given in Table 1. (Some data given in Ref. 1 have been omitted, because they include large areas outside the CBD's, or because full details of the types of vehicles were not available or, as in the case of some United States cities, because only estimates were available for the value of f. There are some differences between the data in Table 1 and those given in Ref. 1 because other sets of data were subsequently obtained, sometimes with different definitions of CBD's, and because rather different pcu values were used.)

The theoretical analysis suggests that the number of vehicles (pcu's) that can usefully enter a town center would lie between 6 and 33 $fA^{1/2}$. The data in Table 1 for the 30 towns for which information is available suggest that the number of vehicles (pcu's) that actually enter lies between 12 and 30 $fA^{1/2}$. All of the data available are consistent with the theoretical analysis made above. This suggests that the formula obtained for the capacity of a CBD network has some value, but it does not prove the complete validity of the formula. For this, values of J, v and $\bar{d}$ must be obtained for a number of towns, and the results analyzed.

FURTHER INVESTIGATIONS REQUIRED

Sufficient evidence is given to make it possible to draw the conclusion that, for a number of towns, the numbers of vehicles that enter (or leave) the CBD's per hour is given, very approximately, by the formula

$$N = (33 - 0.003v^3)\, fA^{1/2}$$

It is likely, however, that the formula can be improved and more exact conditions under which it is likely to apply specified. The subject to which the formula applies is important and the further research needed requires information from many towns. The information primarily required for any CBD is:

1. The numbers of vehicles of various kinds entering or leaving the CBD per hour during peak travel periods.
2. The area of the CBD.
3. The area of carriageway within the CBD.
4. The area of carriageway carrying very little traffic, e. g., cul-de-sacs.
5. The average speed of the traffic.
6. The average distance traveled by the vehicles within the CBD.

Many highway authorities and others throughout the world have a great deal of this information and it would be very difficult for any single researcher to obtain it independently. The author of this paper would be very grateful if anyone having relevant information would send it to him even if, as will generally be the case, they have only a part of the information required.

Some Limitations on the Applicability of the Formula

Care should, of course, be taken not to use the expression for the range of possible capacities of a CBD for circumstances in which it would not reasonably be expected to apply. For example, if the policy of widening the intersections in a CBD were adopted, the capacity of the intersections could be made more nearly equal to the capacity of the roads leading into them, and the capacity of the whole network would be greater than that indicated by the formula. Again, if there were a ring road of adequate capacity around the CBD with adequate intersection capacity, the formula would have to be materially modified if the area of the ring road were not included as part of the CBD. The formula would also not apply if a high proportion of the carriageway area were high-capacity roads, such as freeways.

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Appendix

COMPLETE CBD DATA

Town	Area Within Cordon (10^6 sq ft) (A)	Proportion of Carriageway (f)	Vehicles Crossing Cordon During Peak Hour, One Way: Cars, Taxis, Light Goods	Heavy Commercial	Medium and Heavy Commercial	All Goods	P.S.V.'s	Motorcycles	Bicycles	Total pcu's (N)	$\frac{N}{fA^{1/2}}$
Great Britain											
Edinburgh	43.6	.19	9,781		679		934	1,044	1,102	15,091	12
Bradford	14.3	.20	7,263		532		547	509		10,349	14
Maidenhead	3.1	.14	2,695		95		75	235	800	3,553	15
Darlington	3.6	.19								5,375	15
Liverpool	31.2	.18	10,260		1,550		800	1,675		17,010	17
Hull	8.4	.17	5,814		532		333	1,105	2,036	9,384	19
Nottingham	19.6	.17	7,200			2,800	1,000			14,400	19
Leeds	12.8	.21	10,855		745		1,060	500	140	15,947	21
Sheffield	44.8	.12	11,664		879		748	1,272	478	16,779	21
Cardiff	9.2	.12	5,338			707	472	684	1,784	8,922	24
Birmingham	10.2	.15								11,750	24
Coventry	11.5	.17	10,837		1,279		165			13,890	25
Leicester	30.3	.11								15,100	25
Watford	4.74	.096	3,980		160		125	530	585	5,267	25
Bristol	85.1	.11	18,220		1,978		925	2,262		26,647	25
Reading	4.2	.15	5,610		255		255	725	1,340	7,875	25
Maidstone	2.4	.12	3,902	174			144	512		5,153	27
London	348	.15	55,675		5,445		2,025	7,880	3,305	79,652	29
Rest of World											
Salisbury, Rhodesia	13.6	.38								15,000	11
Dublin, Ireland	14.5	.12	10,000		1,000		675	2,000	6,500	17,700	12
Hamburg, Germany	46.3	.19								17,900	14
Lisbon, Portugal	10.8	.20	5,765			651	772	514		9,300	14
Tel Aviv, Israel	64.6	.12	7,893		584		787	2,289	1,839	13,750	14
Denver, Colo., U. S. A.	10.1	.26								14,200	17
Stockholm, Sweden	36.6	.12	10,500			1,000	300			12,900	18
Goteborg, Sweden	9.7	.18								13,445	24
Washington, D. C., U. S. A.	44.6	.24								41,152	26
The Hague, Holland	22.1	.16	9,980			1,274	198	813	23,387	20,890	28
Copenhagen, Denmark	61.4	.13	19,409		1,099		1,197	4,457	4,558	30,059	29
Los Angeles, Calif., U. S. A.	34.8	.23								40,000	30

Urban Development and Expressways in Tokyo

MASAO YAMADA, Director, Bureau of Capital City Development,
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•JAPAN consists mainly of four islands, Hokkaido, Honshu, Kyushu and Shikoku. Tokyo is situated near the middle of Honshu Island, bordering Tokyo Bay and occupying the major part of what planners call the Tokyo Metropolitan Region (Fig. 1).

In terms of local government units in Japan, Tokyo-to (Metropolis) is a top-tier authority, embracing as its second tier authorities 23 wards with a total area of 569. 5 square kilometers and a population of 8, 810, 000 in 14 cities and 26 towns and villages. The total area of its jurisdiction is approximately 2, 027 square kilometers and the total population is 10, 660, 000 as of January 1966.

The name Edo was changed to Tokyo in 1868 when the Meiji Restoration put an end to the Shogunate Regime and Tokyo became the capital of Japan, then emerging as a modern state.

Today, Tokyo is the center of policy, economy, education, and culture and occupies an important international position.

During the city's development, there were two great occasions for city planning. On September 1, 1923, an earthquake struck the entire Kanto Region, causing most of central and downtown Tokyo to be burnt to ashes. Land readjustment schemes were effected for those damaged districts, with the result that blocks and streets were improved on a grand scale. The major part of the urban structure in the central and downtown area of today was formed by the city planning scheme of that time.

During World War II, Tokyo was hit by a series of air raids and the war-damaged area totaled 160. 7 square kilometers.

The postwar Japanese economy, which has grown at a fast pace through several chaotic years, has accompanied the concentration of population and industry in large cities. The population increase in Tokyo has been especially noteworthy, as is seen in Table 1. As the result of a 200, 000 annual population increase repeated for several years, the population of Tokyo broke 10 million in 1965 and at present it has reached 11 million, the largest city in the world.

The number of vehicles in Japan is also increasing rapidly, corresponding to the economic growth of Japan. Vehicle type has changed though, with passenger cars enlarging their share. Table 2 shows the changes in the number of registered vehicles in Tokyo. Comparing the number of registered vehicles with the population, it is clear that whereas the population of Tokyo is 10 percent of the total population of Japan, on the other hand the number of registered vehicles amounts to 15 percent of the total number of registered vehicles in Japan. From this situation we realize the trend toward centralization of vehicles in large cities.

However, roads are not highly developed. The ratio of road area to total area in the Ward Area of Tokyo is 11 percent, and outside of the Ward Area the ratio is lower than that, such that the increase of traffic volume cannot be coped with. Therefore peak hour traffic congestion is gradually spreading out from the central part of Tokyo to the suburbs, and traffic accidents are also increasing.

PLANNING POLICY FOR THE RENEWAL OF TOKYO

In the Tokyo area, the location of housing, factories, transportation, and commuting, as well as the population increase, all indicate that the social and economic

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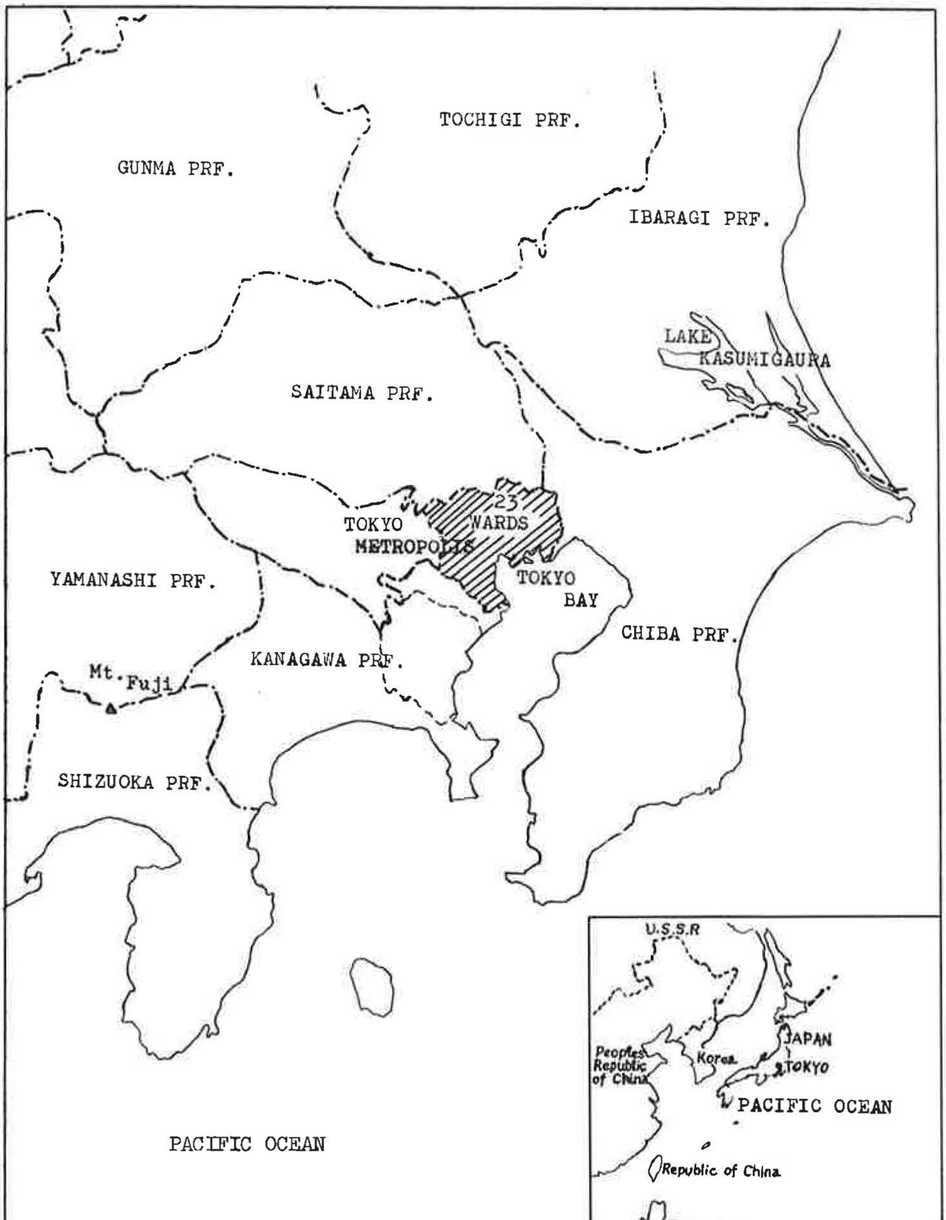


Figure 1. Tokyo Metropolitan Region.

development of the Tokyo Metropolitan Region, where urban activities are performed as a unit city, extends to a 50-kilometer distance from the center.

The Tokyo Metropolitan Region consists of major parts of Metropolis of Tokyo, Prefecture of Kanagawa, Prefecture of Saitama, and Prefecture of Chiba. This region occupies only 2 percent of the total national area but has 20 percent of the nation's population. The population of the Tokyo Metropolitan Region is approximately 19 million and is increasing by 500, 000 to 600, 000 annually, half of the nation's population increase.

TABLE 1

GROWTH OF POPULATION OF TOKYO

Year	Population
1930	5,402,936
1935	6,363,190
1940	7,347,610
1945	3,488,284
1950	6,277,500
1955	8,037,084
1960	9,683,802
1965	10,869,244

The population of Japan will reach its peak between 1985 and 2000 at an estimated 120,000,000. The population in the capital region will level out between 28,000,000 and 30,000,000.

To cope with this situation, it is necessary that the nationwide land development plan, regional plan and city plan be coordinated effectively and executed strongly.

Necessarily much attention was paid to the development of the capital region. The Capital City Construction Law was enacted in 1950, by which the national government would extend financial assistance to develop Tokyo. However, this legislation could not bring about a basic solution to the population problems and Tokyo's other needs, which required a regional planning approach. The planning area was confined to the administrative area of the Tokyo Metropolitan Government, and financial resources of both the national government and Tokyo Metropolitan Government were insufficient to meet the financial requirements of the plan's execution in war-devastated Tokyo.

The Capital City Construction Law was replaced by the Capital Region Development Law in 1956. The basic idea of the latter was to meet the increasing problems of excessive urban growth and the resultant inadequacy of public service by a regional planning approach. A broadly defined "Capital Region" with a radius of approximately 100 kilometers from Tokyo Central Station was established for planning purposes. The region is divided into three concentric rings: Inner Urban Area, Greenbelt Area and Peripheral Area. A number of industrial satellite cities have been planned in the peripheral area to absorb industry and population which would otherwise be attached to Tokyo or move into Tokyo or which might be decentralized from the central city. The Greenbelt Area was envisioned at the outskirts of the built-up area to prevent the further sprawl of the Inner Urban Area. This plan was worked out after study of a regional planning pattern which was adopted for London on the basis of the Greater London Plan.

Nearly ten years have passed since the Capital Region Development Law was put into force. However, in view of its limited effectiveness in controlling the overgrowth of Tokyo, it was not powerful enough to encourage the development of industrial satellite cities. The greenbelt proposal has been frustrated because the difference

TABLE 2

GROWTH OF NUMBER OF REGISTERED VEHICLES IN TOKYO

Year	Number of Registered Vehicles	Population per Registered Vehicle
1958	403,023	22
1959	490,306	19
1960	608,392	16
1961	726,420	14
1962	814,841	13
1963	924,816	11
1964	1,063,199	10
1965	1,181,010	9

in actual situation of land ownership and land use between the greenbelt area around London and the proposed greenbelt area surrounding Tokyo was not recognized. In addition, the proposal in Tokyo is denounced as lacking an understanding of the growth potential of a giant city like Tokyo. Consequently much land in the area scheduled to be designated as the greenbelt area has been occupied by unplanned industrial plants and housing, resulting in continued urban sprawl and commuter congestion during the morning and evening rush hours. This area should have been developed with positive planning suited for its growth potential.

In June 1965, in order to establish comprehensive planning for the metropolitan region, the Capital Region Development Law was amended to revise greenbelt control and to plan the Tokyo Metropolitan Region consisting of the Built-Up Area and Suburban Development Area. At present, studies are being conducted to revise the regional development plan according to the amendment of the law. The Capital Region Development plan will officially start again within a year, drastically converting its negative enforcement into positive implementation, from control to induction, to adapt the Tokyo Metropolitan Region to the economic growth of Japan.

What must be the nature of the future metropolitan region?

Satellite cities, larger in size and more attractive, to absorb industry and population, should be fostered in the 50- to 100-kilometer area in smaller number, instead of the existing small-sized cities in large number. In the 50-kilometer area, it is necessary to reorganize the urban structure through a rational introduction of industrial plants, business offices and housing in an orderly fashion. This area should be called the Tokyo Metropolitan Region.

The fundamental items required for putting forward a rational plan for the 50-kilometer area of the Tokyo Metropolitan Region are as follows.

First, the proposed greenbelt in the shape of a concentric ring should be abolished. Instead a comprehensive planning pattern should be established for the 50-kilometer area as a whole with the existing proposed greenbelt, industrial satellite cities and Inner Urban Area (Built-Up Area) combined together. A planned development within the 15-kilometer area and planned development in the 15- to 50-kilometer area should be promoted in their organic relationships with each other.

Second, to reorganize the 50-kilometer area into a more efficient urban structure, it is necessary to reorganize the urban structure from the existing single-focus structure into a multi-focus structure. A number of measures which would be effective for bringing about a multi-focus urban structure are listed below.

1. An efficient network of transportation, especially a rational relocation of road transportation facilities, should be established. Urban expressways will be extended and an outer-ring expressway will be constructed on the outer fringe of the Ward Area of Tokyo to connect inter-city freeways organically. Bus terminals and parking facilities will be located at suitable points, which will be accompanied by redevelopments.

2. It is necessary to push forward urban redevelopment schemes around the city center and subcenter district, to attract business firms to the subcenter so that central functions may be distributed and to induce planned development of industry and housing in the surrounding areas, and to develop a number of auxiliary centers like the synthetic center for distribution and others along the arterial routes of transportation. Actually large redevelopment projects are under way; one is at Shinjuku utilizing the vacated land of the Yodobashi Water Purification Plant and another is at Ikebukuro utilizing the vacated land of Sugamo Prison. Also, synthetic centers for distribution which include truck terminals, wholesale markets and warehouses will be constructed along the outer-ring expressway.

3. Construction and expansion of factories in the Built-Up Area is limited by the Law for Controlling Industry and Other Activity Within the Inner Urban Area, whereby vacated lands of factories are acquired and redeveloped to promote the decentralization of industry.

4. Designation of bulk control will maintain the equilibrium between bulk of buildings and transportation facilities. Besides that, bulk control will protect living and working conditions in the city.

PROPOSED ARTERIAL ROADS OF TOKYO

The present highway system for Tokyo has an 80-year history. However, current traffic problems make the former two-dimensional highway plan inadequate. Construction of new roads or widening of existing roads can no longer be a countermeasure against the increasing traffic demand, from the point of economy as well as time. Therefore an economic and effective highway system has been designed to cope with present and future traffic problems, on the basis of a ten-year study.

According to this plan traffic demand in 1985, which is estimated through analysis of an origin-and-destination traffic survey conducted in 1962, will be met by arterial roads and urban expressways (Fig. 2).

The arterial road network has a combined ring and radial pattern. The intention to reorganize the present urban structure of Tokyo into a multi-focus pattern is included. The physical structure of the urban area of Tokyo is featured by fragmented blocks and numerous traffic intersections. For this reason, from the standpoint of traffic engineering, the most important point in road improvement in Tokyo is how to bring about continuous grade separations at the intersections rather than mere widening of roads. The problem is how to obtain the maximum traffic capacity at a minimum cost.

Total length of the proposed roads in the Ward Area of Tokyo is more than 1, 500 kilometers, consisting of trunk roads totaling approximately 600 kilometers and auxiliary roads.

Grade separations are proposed at about 330 existing intersections. Some have already been completed. On Showa-dori Street in the central city, grade separations were made at five major intersections for a continuous distance of 2. 8 kilometers. On Ring Road No. 7, continuous grade separation at 67 traffic intersections was proposed and grade separation is finished at 25 intersections. A lane of the grade separation on Showa-dori Street allowed more than 1, 500 vehicles to pass in an hour. The number of vehicles proves the effectiveness of the continuous grade separation.

Because it is expected that the present increasing demand for traffic facilities will reach its summit sometime in the next 20 or 30 years, it is hoped that all of the proposals will have been finished by that time. A total of 5. 56 billion dollars (2, 000 billion yen) is required for the completion of all the proposed arterial roads.

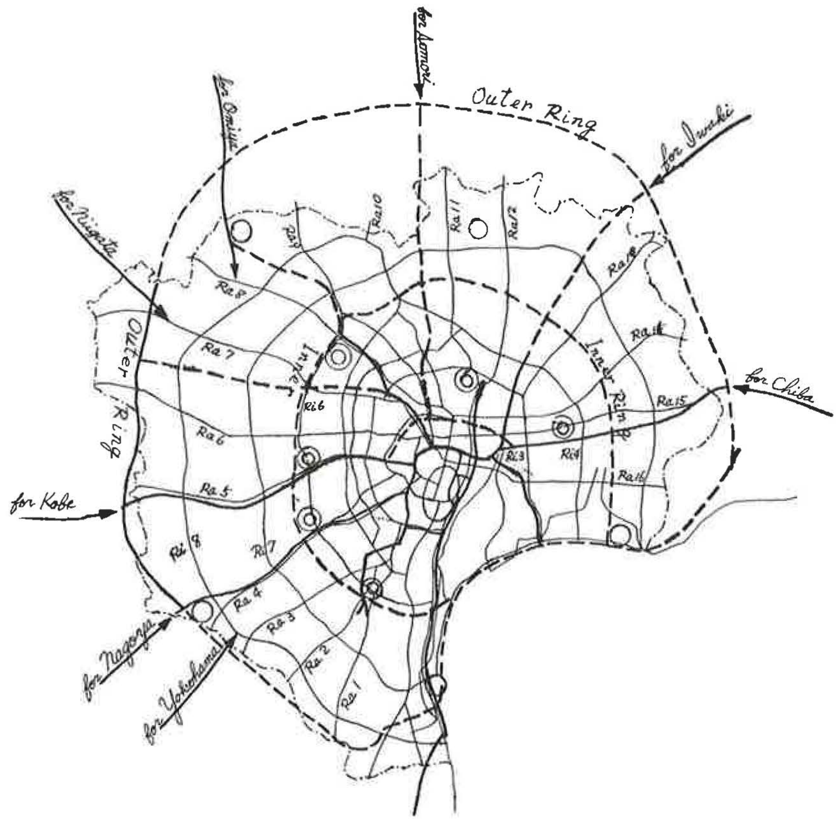
THE BIRTH OF URBAN EXPRESSWAYS

Generally speaking, the following are considered as the means of resolving the traffic congestion in a city: the improvement of ordinary roads, the construction of grade-separated intersections, traffic regulations such as one-way control, etc. But none of these is a decisive solution. For the highly agglomerated areas in Tokyo the difficulties of expropriation and continuously rising land prices require a number of years of construction and tremendous investments.

Thus, to make the traffic flow smooth in a city, roads exclusively for cars, separated from ordinary roads and intersections, were proposed. From this proposal developed the theory of successive grade-separated intersections—the Urban Expressways in Tokyo.

The primary object of urban expressways, therefore, is to attain efficient traffic flow; the increase of running speed is merely a secondary aim. In this sense they have quite different characteristics from the long-distance expressways, whose object is to connect cities in a shorter time.

The concept of urban expressways in Tokyo was born in about 1950. After extensive research and examination, such as O-D surveys, traffic volume counts, projection of vehicle numbers in the future, etc., the network of urban expressways with a total length of about 70 kilometers was decided upon in 1959. Several routes having been added afterward, the total length amounts to 103 kilometers at the present time. Construction is being carried out by the Tokyo Expressway Corporation. The completion of the important routes on the eve of the XVIIIth Tokyo Olympiad was especially remarkable. As the result, a 32-kilometer section of the expressway from Haneda



Legend

Administrative Boundary of Ward Area

Arterial Roads: Ra = Radial Roads; Ri = Ring Roads

Planned Urban Expressway (Authorized)

Extension of Planned Urban Expressway (In Study)

Inter-City Freeway

Center of City

Subcenter

Synthetic Center for Distribution

Figure 2.

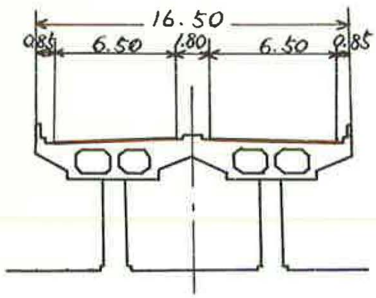


Figure 3. Cross section (units are meters).

Airport to Shinjuku via the central district has been put to use. The fee is 80 cents for trucks and buses, 40 cents for ordinary cars.

Permitting automobiles to travel at high speed is not their primary aim, so the standard speed of automobiles has been set at 60 kilometers per hour and the structure is also designed with a fairly low average.

Figure 3 shows the standard cross section. The width of 16. 5 meters with four lanes may be considered narrow for an expressway. On the other hand, as the land cost is extraordinarily high in Tokyo, it has the advantage of lower cost of construction and easier choice of routes. The structure is mainly viaduct form, and in part takes the form of open-cut or underground.

URBAN EXPRESSWAY PLANNING FOR TOKYO

As mentioned before, one aim of the development of the Tokyo Metropolitan Region is to achieve the multi-focus urban structure, and now is the time when we have to make every effort to realize this plan. To induce relocation of urban functions, it is indispensable to develop the traffic facilities, including urban expressways, which will be the framework of the highway network of Tokyo.

In the built-up area, some urban expressways which connect the city center and subcenter districts have already been constructed. Tokyo also has other planned urban expressways, but those urban expressways, both completed and planned, will not be enough to cope with the future traffic demand. On the other hand, in the outer districts of the Ward Area, a number of inter-city freeways which run through the country have been proposed and are partly under construction. However, inter-city freeways run merely in radial directions out into the outer fringe of the Ward Area. To distribute long-distance traffic on the inter-city freeways into the Ward Area smoothly and to realize the multi-focus urban structure, existing urban expressway planning must be improved, so that the urban expressway network may connect each district organically.

Figure 2 shows the future plan. First, the Outer Ring Expressway is planned on the outer fringe of the Ward Area, nearly 15 kilometers from the center, to connect the inter-city freeways. An Inner Ring Expressway will be planned on a circle of approximately 8 kilometers as a coupler of subcenters. All radial expressways which end at the subcenters will be extended to the Outer Ring Expressway. Thus, the urban expressway network including the Outer Ring Expressway will total 340 kilometers, and most of the proposed expressways are expected to be finished in 10 years.

The nature of traffic in Tokyo is more intensely centralized than that of New York and Chicago because of its urban structure. Although the economic value of the Outer Ring Expressway would be low, it should be utilized for bringing about a reorganization of the urban structure of Tokyo by locating subcenters, auxiliary subcenters and synthetic centers for distribution along its route.