

REPORT OF COMMITTEE ON COORDINATION AND PROGRAM

R W CROWM, *Chairman*

A PROGRAM OF HIGHWAY RESEARCH

Since the advent of the motor vehicle and the extraordinary development of its use, traffic conditions have been changing so rapidly, that new problems and new aspects of old problems are constantly arising.

The result has been, and no doubt the condition will continue, that traffic needs must be cared for as well as possible with what knowledge is available at the same time that correct principles are being developed for future use.

Highway Research has already contributed materially toward meeting modern conditions of highway transportation. However, many important questions are yet unanswered and much thorough and painstaking research will be needed for their solution.

It is the purpose of the Highway Research Board to set up a comprehensive program looking toward the solution of these problems. Such a program will be subject to continual change. Final answers will be reached at times, new projects must be frequently added and changing conditions will no doubt render some work valueless even before it is completed. Having a program outlined it is our hope to keep it up to date continuously.

Such a research program as this will not be of much value unless the necessary experimental work is accomplished, the results thoroughly studied and sound conclusions drawn and put into practice. The Highway Research Board therefore plans to do much more than merely outline a research program. The plan of activity may be briefly stated as follows:

1. To draw up a comprehensive program of highway research.
2. To compile and have available for dissemination, information and references on the existing status of knowledge of the various projects.
3. To compile and keep up to date lists of the current research projects throughout the United States.
4. To promote with the various research agencies the carrying on of the experimental work recommended in the program.

5. To conduct special investigations of national scope.
6. To correlate the work of the various investigators, to study the results of research work as they become available, and to draw sound and usable conclusions wherever possible.
7. To disseminate research information.

To accomplish these objectives will require the co-ordinated efforts of the officers and staff of the Board, technical committees of unquestioned standing and contact men with all of the research agencies and highway departments.

We are presenting herewith statements and analyses of the highway problems as they exist today with suggestions as to needed research in their solution. It is not intended that the items of needed research listed shall be exhaustive, but rather that they shall be indicative of the field that should be covered, and that they may serve as a starting point for extension and sub-division by the various committees of the Board. It is expected that the various committees will expand this outline into complete research programs covering their various interests.

OUTLINE FOR A PROGRAM OF HIGHWAY RESEARCH

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I. HIGHWAY ADMINISTRATION AND FINANCE

ADMINISTRATION

The problems of highway administration have to do principally with the allocation of the available funds, decision as to priority in road improvement programs and location as respects termini and general route. Administration includes matters of policy in handling the funds available for road work.

There are forty-eight systems of state highway administration in the United States, each differing from all of the others in many important particulars. The administration of the secondary road funds by smaller governmental units also varies widely in method.

Published data are not available upon which decision could be based as to the method of highway administration likely to be most efficient in any given case.

Although state highway administrative organizations all differ in detail, they may be grouped into three general systems.

1. An appointive commission, with an executive officer appointed by the commission. The chief engineer is sometimes the principal executive officer.
2. A director or superintendent appointed by the governor, who handles both matters of policy and executive direction.
3. A director or superintendent elected by the people, who handles both matters of policy and executive direction.

The success of any administrative organization depends upon the abilities and personalities of the men at its head, and there are outstanding samples of well managed state highway departments under each of these categories. However, it is possible that thorough inquiry might reveal some inherent advantages or defects in one or more of these systems. Although such an investigation would be costly and difficult to make, it should be included in a comprehensive program of highway research. The fruits of such an inquiry would be of great value to highway officials in dealing with legislative bodies, and to progressive legislators themselves in framing adequate highway laws.

FINANCE

The general problem is the equitable distribution of the cost of providing highway service in proportion to the benefits derived therefrom. It may be assumed that benefits accrue in four ways, (1) National benefit by providing for free flow of traffic between states and

by provision for national defence, (2) General benefit to community life, (3) Special benefit to abutting property, and (4) Benefit to the individual user of the roads. Revenues should be raised from each of these four sources, the unanswered questions being: What portion should each source contribute, and in what ratio should the funds be allocated among—the through traffic highways, the community roads, the purely local roads, and municipal streets?

1. FEDERAL AID

The principle of federal aid for the improvement of roads of national importance is firmly established on a sound basis. The amounts and allocation provided by acts of Congress have had a stimulating effect on road improvements, and a profound beneficial effect upon the standards of road construction. Federal aid should be in proportion to the national benefit derived from adequate road systems.

2. GENERAL TAXATION

To what extent should the general public contribute through property taxes, and what proportion should be expended upon each of the three classes of roads . . . (a) through traffic highways, (b) community roads, (c) purely local roads? In other words to what extent should property taxes be levied in the interests of each of the three classes of roads? On the one extreme we have the local road of importance only to the residents along the road, used only by them or by those who seek access to them. On the other extreme we have the through highway used by everyone in the community as well as by others from outside passing through. To what extent does the improvement of each of the three classes of roads benefit the entire community irrespective of the actual use of the roads?

3. ASSESSMENT AGAINST ABUTTING PROPERTY

Agricultural property is undoubtedly benefited by proximity to a good road over which its produce can be marketed and also to some degree by the effect of the road improvement on its desirability as a home site. The question is, at what stage in road improvement does the special benefit cease to increase? These benefits can be measured by the increase in selling price of the land caused by the road improvement, and in the absence of such cost data by farm records as to cost of marketing and savings due to timeliness in marketing.

4. MOTOR VEHICLE TAXES

Taxes imposed upon vehicles are of three kinds at the present time: (1) General property taxes; (2) license and registration fees; and (3) taxes on gasoline. It may be assumed that the most equitable taxes on the vehicle are those based upon the amount of use of the road and upon the destructive effect of the vehicle upon the road. The tax on gasoline is the best measure yet proposed for a tax based upon use of the road. The destructive effects of different types of vehicles have not yet been evaluated. Information is needed as to the costs of vehicle operation and as to the costs of providing highway service adequate for different classes of traffic. For instance, a 6-inch concrete slab might be heavy enough for a large part of the traffic on a certain highway, but the presence of bus and truck traffic might make necessary an 8-inch slab. In such a case a tax rate based on mileage alone might not distribute the burden equitably. On the other hand it might not be equitable to saddle all of the cost of the extra two inches of concrete upon the busses and trucks because the general public benefits from the ability of the busses and trucks to operate over the road.

Another problem of immediate importance is the distribution of the proceeds of gas or other vehicle taxes, as between the various classes of rural roads and city streets. If such taxes are a measure of road use by the vehicles, all of the roads used have some claim upon the proceeds of the tax, but as yet no data are available showing what the relative amounts should be. The proportion of a gasoline tax, for instance, that should go to the various classes of roads, and to the city streets will depend upon the relative amount of traffic and upon the proportion of the cost of each class that should be borne by the road user.

5. USE OF CREDIT

If roads are constructed by means of bond issues, they can be put into service sooner, but the earlier expenditure of capital will mean additional interest charges which will increase the net annual cost of providing the highway service. The question is whether or not the savings in total highway transportation costs during the extra years of service will compensate for the additional roadway cost. The ability to find the answer in any given case will depend upon the available knowledge of costs of transportation over various types of road surfaces and upon the amount of traffic.

NEEDED RESEARCH
ADMINISTRATION AND FINANCE
ADMINISTRATION

1. A critical study of results secured under various methods of state highway administration
2. A critical study of results secured under various methods of administering secondary road funds by counties and townships
3. A critical study of results secured under various methods of municipal highway administration.

FEDERAL AID

1. Study of trends in inter-state highway traffic

GENERAL TAXATION

1. Studies of economic changes in typical communities to show the benefit of road development in the life of the community
2. Studies in typical communities to show the stage of road improvement at which the benefits to the road user begin to over-shadow the general benefits. For instance, a low type of surfacing might be sufficient for general community needs, although a high type may be needed to care for the traffic adequately.

ASSESSMENT AGAINST BENEFITED PROPERTY

1. Studies in a number of scattered communities of the effects of different types of road improvement upon land values and marketing conditions, and the effect which distance from marketing centers has upon land values, and upon the type of road necessary for farm to market service.

MOTOR VEHICLE TAXES

1. Vehicle operating costs, for various types of vehicles, on various kinds of road surfaces.
2. Costs of providing highway service for various kinds of traffic.

(NOTE—These (1 and 2) will be further discussed under Highway Transportation Costs)

3. Relative use of different classes of roads—Traffic surveys on all classes.
4. Under what conditions are toll roads and bridges justified?

USE OF CREDIT

1. Data on highway transportation costs.

(NOTE—To be further discussed under Highway Transportation Costs)

2. Several states have already expended the proceeds of large bond issues for road improvements. Studies of economic conditions in those states as related to highway transportation should go far to answer the question as to the practical value of thus speeding up the road building program.

II. HIGHWAY TRANSPORTATION
COSTS

The annual cost of transportation over any length of highway consists of the yearly cost of providing the roadway ready for service plus the cost of operation of all vehicles while using that particular road during the year.

A knowledge of all of the factors entering into this total cost is needed to furnish a basis, for equitable taxation of vehicles, for the proper layout of highway improvement programs, and for the economic design of the roads. In other words, *highway transportation cost* is a dominant factor in the solution of all of the major highway problems.

If the vehicle owners are to be expected to pay a large part of the highway service bill, they should be taxed in proportion to the extent to which each uses the roads, and in proportion to the effect of his vehicle upon the annual cost of providing the highway. The class of road service to be provided to the user should also be taken into account in fixing the tax rate, for the user can afford to pay more for the use of a good road providing a free flow for traffic, than for the use of a poor road with frequent constrictions. Methods for accurate determination of these factors depend upon further study of costs.

Vehicle operating costs are affected by the type of road surface. In planning an improvement program the type of improvement should be used for which the annual transportation cost will be the lowest at which the expected traffic can be adequately served.

In designing the road itself, consideration should be given to the effects of such features as grade, alignment, cross section and prospective increased use upon the total transportation cost. Knowledge of the effects of such features upon such items as gasoline and oil consumption, tractive resistance, and upon schedule speeds is needed for economical designing.

The principal elements of highway transportation costs are as follows:

1. Roadway costs
 - A. Capital costs, consisting of interest on the following investment items.
 1. Right-of-way.
 2. Primary construction.
 3. Surfacing.
 4. Engineering and supervision.
 - B. Upkeep costs, consisting of the costs of the following items plus interest thereon.
 1. Maintenance of road surface
 2. Maintenance of right-of-way.
 3. Administration.

The principal elements upon which data are lacking in connection with roadway costs are the effects of quantity and kind of traffic upon maintenance costs, and the rate of depreciation and salvage value of various types of roads under various conditions.

2. Vehicle operating cost.
 - A. Capital costs.
 1. Interest on initial cost minus cost of tires and tubes.
 2. Depreciation.
 - B. Operation Costs.
 1. Tires and tubes.
 2. Gasoline and oil.
 3. Maintenance.
 4. Driver's pay.
 5. Depreciation (one-half considered an operating cost).
 6. License fee.
 7. Garage
 8. Gasoline tax
 9. Insurance.

More data are needed on all of the items of vehicle costs that are affected by mileage, for those are the items that are also affected by the roadway characteristics. Also data are needed on the cost of such items as waiting on traffic lights, and slow speed due to congestion, especially in the case of commercial transport vehicles.

UTILIZATION OF HIGHWAYS

A most important factor in the proper development of highway systems is the extent of productive use of the highways. The extent of movement of people and commodities over the highways has important bearings, not only upon the economic development of the highways, but upon the future of other forms of transportation as well. Certainly continuing study should be made of the trends in highway utilization. One problem is to determine the conditions under which it is economical to move passengers and commodities over the highways. Its solution will involve detailed investigation of such matters as transportation cost per item moved, time saved or lost, condition of shipments, convenience of terminals, etc.

NEEDED RESEARCH

TRANSPORTATION

ROADWAY COSTS

1. Collection of data on relation of maintenance costs to traffic for all types of surfaces. Promotion of the use of uniform records of cost and traffic.
2. Collection of data on cost of resurfacing and on salvage value.
3. Study of rates of depreciation.

VEHICLE OPERATING COSTS

1. Collection of data on vehicle operating costs, especially on busses and trucks
2. Study of factors, outside of vehicle design that affect operating costs.
 - (a) Road surface (tractive resistance)
 - (b) Grade and alignment.
 - (c) Tire wear.
 - (d) Car maintenance (mechanical depreciation).
 - (e) Effect of time lost, due to enforced waits and congestion

UTILIZATION OF HIGHWAYS

1. Collection and study of data on amount of commercial transportation of passengers and commodities over highways.
2. Study of movement of agricultural produce and live stock to market centers by highway, including costs, condition, convenience, time factor, etc.

- 3 Study of movement of manufactured articles and raw materials by highways, including costs, condition, convenience, time factor, etc.

III. HIGHWAY DESIGN

The design of the highway includes roadway, drainage structures and surface. The general problem is, how best to build for maximum economy and safety. The principal consideration in dealing with each item, outside of safety, is that of cost. By cost is meant the total transportation cost based on both roadway and vehicle operating costs. Traffic has now become so great that sound economic designs can no longer be based on roadway costs alone. Costs of vehicle operation, and savings to the user by providing for unrestricted flow of traffic must be taken into account. In fact, on heavy traveled roads the vehicular costs entirely overshadow the mere cost of building the roadway.

ROADWAY

Location, grades, alignment and width have a large effect upon transportation costs, traffic capacity, and safety. Their effects upon vehicle costs are measured by tractive resistance, both rolling and wind resistance, fuel consumption, mileage, ability to maintain schedule speeds, and traffic capacity. Their effects upon safety must be evaluated from accident statistics. Their effects on roadway costs, outside of construction, are measured by the cost of maintenance.

The principal determining factors in establishing these features of a highway are, quantity and kind of traffic and considerations of public safety. Unusual conditions caused by such phenomena as landslides, subsistence, etc., are troublesome in some regions.

DRAINAGE STRUCTURES

Bridges and culverts do not affect the cost of vehicle operation unless they are restricted in width and their cost is not ordinarily a large proportion of the roadway cost. Therefore, on heavily traveled roads, where the vehicular costs are the principal item, any reasonable expenditure to secure attractive structures that are adequate, durable and safe can be justified. The general problem is to build in each location the structure that will adequately meet the needs of the situation from both utilitarian and æsthetic standpoints.

BRIDGES

Probably the most difficult problems in bridge design are the selection of type and size. Type depends upon relative economy and upon appearance. The size of waterway depends upon the size and character of drainage area, and rainfall to be expected. Detail design depends upon static and impact loads and upon the strength of materials. With respect to type and size the principal field for research work lies in the study of relative economy and durability of different materials, and in collecting run-off data.

With respect to detail design the field for research is in the development of new materials and new combinations of materials, and further studies of loads due to impact

CULVERTS

The selection of type of culvert depends upon relative economy. Detail design depends upon the size of waterway needed and upon the loads to be supported. The relative durability of different types of culverts for a given set of conditions should be evaluated by the annual cost, taking into account interest on investment, maintenance, depreciation and salvage value. Information is lacking at the present time on depreciation and salvage values. The effects of loads on culvert pipe have been extensively studied, and general principles are well developed.

SUB-DRAINS AND ACCESSORIES

Attempted stabilization of roadways by under drainage has long been practiced, but without any very definite guiding principle as to the conditions under which it is effective and worth the cost.

SURFACE—SUBGRADE, BASE COURSE, WEARING COURSE

As in most other phases of highway work, the general problem is to provide the surface that will take care of the traffic satisfactorily at the least cost for highway transportation. The choice of type and design of surface are affected by the character of the subgrade, the amount and kind of traffic, climate and topography, the annual cost of various types of surface and safety precautions.

The following introduction to an article by Hogentogler and Terzaghi on "Inter-relationships of Load, Road, and Subgrade" in *Public Roads*, May, 1929, may well serve also as to statement of objectives in research on design of road surfaces.

“ It is intended to point out how a knowledge of the primary subgrade soil characteristics considered with that of the different pavement properties may prevent the engineer from specifying one type of pavement when conditions will not permit of its adequate construction or operation; from increasing pavement thickness in an attempt to eliminate troubles not caused by lack of thickness; from attempting to cure structural defects by improving the wearing course; from attempting to prevent abrasive troubles by improving the structural resistance; from attempting to estimate the comparable service values of rigid and non-rigid pavements for conditions which clearly indicate the necessity for pavements furnishing high load distribution; from supplying only cohesion when friction is also required and vice versa; and from improving the subgrade to prevent troubles resulting from improper design, construction or maintenance of the pavement.”

Subgrade—Effects on Design of Surface

The factors, according to Hogentogler and Terzaghi, involved in the study of the relationship between subgrade soil and pavements are as follows:

“ Subgrade properties due primarily to the raw constituents of the soil, also those due to the field conditions under which the soil exists; pavement conditions caused entirely by the subgrade support, and conditions only partially caused by the characteristics of the subgrade; individual conditions of subgrade support which produce particular conditions in the pavement, the relative influence which similar subgrade conditions exert upon pavements different in type; the soil characteristics disclosed by a particular group of laboratory test results; the individual raw constituents which cause the soil to exhibit particular physical properties, the relative influence which the arbitrary test procedure and the physical characteristics of the raw constituents of soils exert upon the results furnished by laboratory tests; and the extent to which the physical manifestations disclosed by the laboratory tests serve to explain the behavior of soils when subjected to field conditions.

“ Pavement behavior may depend upon the character of the subgrade soil material (raw constituents), upon the structure of the soil in its natural state (dense or loose, homogeneous or full of cracks and root holes), upon the soil profile (variation in depth of the different soil zones and the relative occurrence of permeable and impermeable strata), upon adjacent topography (through its influence upon the

occurrence of surface and underground water), upon climatic conditions (well distributed or intermittent occurrence of rainfall and presence or absence of frost action), or upon any combination of these variables.”

Traffic—Effects on Design of Surface

The effects of the quantity, kind and weight of traffic are the dominant factors in the design of the road surface since the only reason for building the road is to serve the vehicles that use it. The type of surface should be the one which will accommodate the expected traffic at the least transportation cost. For instance, a low cost road with high maintenance costs may be more economical for a light traffic road than a more expensive but more durable type, because in such a case the total saving in operating costs to the small number of vehicles using the road, by having a higher type road would not be large enough to overcome the high annual charge for interest due to the greater first cost of the high type road, and conversely, a high type will usually be found to be more economical for the use of heavy traffic.

The physical effects of the traffic upon the surface are caused by speed, weight, and impact, and are ultimately measured in terms of cost of upkeep.

A difficult problem in each specific case is the determination of the controlling weight of traffic unit upon which to base the design. Information as to the frequency of use by the heavier vehicles is important.

Climate and Topography—Effects on Design of Surface

Some road surface deterioration is caused by action of the elements. Rainfall and extremes of temperature in some parts of the country are determining factors in design. The principal effect of ordinary topographical conditions upon structural design is the provision that must be made for surface water run off.

Road Surface Types

Road surfaces may be classified as high, intermediate, and low type according to their suitability for heavy traffic main thoroughfares, medium traffic thoroughfares and community roads, and light traffic local roads. The principal problems in connection with all of

them, have to do with the development of the necessary characteristics to handle the traffic satisfactorily at minimum transportation cost.

The high types at present of importance on rural highways are concrete, asphalt, and brick.

High Type Surfaces. (a) *Concrete and Concrete Bases.* The problems involved are the determination of stresses caused by static loads, impact loads, volume change and fatigue, and methods of rational design to withstand the stresses economically.

Problems concerned with the quality of concrete will be considered under materials.

(b) *Sheet Asphalt and Asphaltic Concrete Surfaces.* The problem is to construct durable surfaces economically, that will not be displaced under traffic.

(c) *Brick Surfaces.* The principal remaining problems have to do with the size of the brick and the character of the joint filler to meet conditions in various parts of the country.

Intermediate Type Surfaces. The intermediate types of surfaces include: Waterbound macadam, traffic bound surfaces of various materials, bituminous macadam and bituminous bound surfaces. The problem is largely one of economy as the principal objective is to build roads that can be maintained in a satisfactory condition at reasonable cost for highway transportation. The relation between amount and kind of traffic and maintenance cost is especially important on these roads. From a structural standpoint the problems have to do with the effects of climate, and traffic upon durability. Much of the needed research has to do with the materials, which will be considered in another section.

Development of road surfaces of this class will be largely a matter of experimentation in service. More detailed reports of such experiments should be made.

Low Type Surfaces. The low type surfaces include dirt, top soil, sand-clay, etc. The problem is to provide a road at very slight cost that will furnish approximately all weather service for light traffic. Top soil and sand-clay where available have been found reasonably satisfactory. The problem is very pressing in the great agricultural regions where the cost of hauling surfacing material is prohibitive for these roads.

“While this problem is so simply stated, this statement does not itself carry evidence of its importance. There is probably no other

single investigation that can be defined that is of as much importance in the highway research field. What is sought is the development of some now unknown method of soil treatment that will result in effective and very low cost improvement of the thousands of miles of earth roads."

NEEDED RESEARCH

DESIGN

ROADWAY

For suggested researches bearing upon roadway see Transportation—Maintenance—and Traffic.

1. Data on landslides.
2. Data on subsistence.
3. Method for building fills in marshes.
4. Relationships between highway design and speed, safety and traffic capacity.
5. Relation of width, crown, curvature, sight distance, ditches, shoulders, etc , to accidents
6. Relation of curvature, super-elevation, width, to speed and traffic capacity.
7. Effect of constrictions on capacity and accidents.
8. Effect of road condition, visibility distances, etc., on formation of "cues," and possible means for their elimination.

DRAINAGE STRUCTURES

Bridges

1. Conditions required for durability of concrete structures
2. Protection of steel work to secure maximum durability.
3. Collection of run-off data.
4. Measurement of stresses due to impact.
5. Allowable unit stresses in concrete and reinforcing steel.
6. Suitability of various materials and designs for floors.

Culverts

1. Development of methods for determining the economic value of various types of small drainage structures The principal unknown items are rate of depreciation and salvage value.

2. Determination of economic value of various types of culverts under various conditions of use, such as height of embankment, character of soil, erosive and corrosive effects of water carried, etc.

Sub-Drains

1. Further study of the interrelationships between soil characteristics, climate, topography, under drains and road characteristics.

SURFACE

Subgrade

1. Continued development of laboratory tests to aid in classification and identification of soils.
2. Relationships between laboratory tests and properties and behavior of soils in roads.
3. Study of the behavior of soils under various moisture conditions.
4. Effects of surface treatments of subgrades.
5. Effects of subgrade treatments on supporting quality.
6. Surveys of relationships between soil characteristics and road surfacing behavior.

Effects of Traffic on Design of Surface

1. Wheel load intensities.
2. Distribution of wheel loads through various surfaces.
3. Effect of volume and weight of traffic on maintenance costs of various surface types.
4. Effect of speed on road surfaces

Effects of Climate and Topography

1. Data on run-off on various grades under various intensities of rainfall.

Concrete Surfaces and Bases

1. Study of fatigue of concrete.
2. Study of the balance of various thickened-edge cross-sectional designs.
3. Study of longitudinal joints, with reference to edge strengthening.

4. Causes for blow-ups.
5. Theoretical study of various influences upon stresses.
6. Experiments to determine values of the modulus of subgrade reaction.
7. Study of volume changes under various conditions. Effects of moisture and temperature on volume changes.
8. Methods for constructing joints and planes of weakness
9. Effect of reinforcement
10. Strength of concrete and thickness necessary in bases for use with asphalt and brick wearing surfaces

Sheet Asphalt and Asphaltic Concrete Surfaces

1. Methods of maintenance to renew volatile constituents.
2. Study of conditions affecting stability
3. Development of test for stability of mixtures containing coarse aggregate.
4. Study of finishing methods to provide smooth surfaces
5. Study of suitability of flexible bases.

Brick Surfaces

1. Service tests of various thicknesses of brick
2. Characteristics of filler under various climatic conditions

Intermediate Type Surfaces

1. Data on effects of weather and climate on various combinations of materials.
2. Data on effects of traffic
3. Rate of wear of waterbound and traffic bound roads and effect of dust prevention measures thereon.
4. Salvage value of such surfaces in connection with change to higher type.
5. Critical study of various types of surfaces now in use
6. Design of cross section for bituminous macadam.

Low Type Surfaces

1. Investigation of possible methods of stabilizing soil to form a road surface.

IV MATERIALS AND CONSTRUCTION

MATERIALS

The two factors that are of most importance are the effects of the characteristics of materials upon results and the identification of characteristics by test methods. Knowledge of both is necessary for proper design and use. The general problem with respect to materials is the use of the most economically available material in proper combinations to yield the result expected by the designer of the pavement or structure. Conversely good engineering requires the design of structures in such a way as to utilize with economy the most economically available materials. There are yet many factors as respects highway materials that need investigation.

CONSTRUCTION

Construction methods and appliances are usually developed as the result of trial, rather than by premeditated research. However, research often becomes necessary to evaluate the results secured by new methods or appliances, in cases where the quality of result is not obvious. It is not possible to lay out in advance a program of such research work. A place on the program should be provided for the inclusion of such projects whenever they appear.

NEEDED RESEARCH

MATERIALS AND CONSTRUCTION

MATERIALS

Concrete Materials.

Cement.

1. Development of more determinative tests than are now available.
2. Possibilities of high early strength cement.

Aggregates.

1. Method of test for concrete making quality of fine aggregate to replace the mortar strength test.
2. Studies of effects of such characteristics as shape and size of particle, surface texture, hardness, mineralogical composition, abrasion, quality, porosity, etc., upon strength (particularly flexural strength) and durability of concrete.

3. Method of test for durability of aggregate.
4. Method of test to indicate directly the quality of aggregates for concrete.
5. Studies of economy in the use of different combinations of aggregates.

Concrete.

1. Method of test for workability of concrete that will be indicative of workability on concrete pavement construction.
2. Effects of admixtures.
3. Curing methods.
4. Method of test for durability of concrete.
5. Study of mixing process.

Bituminous Materials and Mixtures with Mineral Aggregates

1. The development of tests for determining suitability, proportions and characteristics of aggregates for mixed-in-place bituminous surfaces and for premixed laid cold bituminous surfaces.
2. Bituminous emulsions suitable for cold surface treatments.
3. Determination and classification of the important characteristics of bitumens for use in surface applications, mixed-in-place surfaces, etc.
4. Methods of test.

Steel.

1. Use of rail steel bars for reinforcing.
2. Use of plain vs. deformed bars, bond effect.

Miscellaneous Materials, Paints, Oil, Fence Posts, etc.

1. Characteristics of paints for traffic marking.
2. Determinative tests for lubricating oil.
3. Economic study of various preservative treatments of guard fence posts.

CONSTRUCTION

1. Effects of various degrees of surface manipulation in finishing concrete pavements.
2. Critical studies of developments in construction methods and appliances as they appear.

V. MAINTENANCE

The problem of the maintenance engineer is that of keeping the roads as nearly as possible up to their original condition at reasonable cost. His experiments have been directed toward the improvement

of maintenance methods, and the lowering of costs. Improvements in maintenance equipment have come about largely through trial on the roads, and will no doubt continue to come in this way as inventive genius does not wait on organized research projects. Keeping abreast with the improvements in methods and equipment is itself a research project.

Many economic questions depend upon the relation between amount and kind of traffic and maintenance costs as discussed under Transportation Costs. A large feature of the work of the Highway Research Board in this field is the collection and dissemination of information on improved methods and equipment as they are developed in the various states.

NEEDED RESEARCH

MAINTENANCE

1. Maintenance of cracks and joints in concrete pavements. Characteristics of crack fillers
2. Resurfacing of concrete, brick and asphalt pavements.
3. Effects of increasing traffic on maintenance methods and costs.
4. Data on reduction in loss of material on waterbound and traffic-bound surfaces, due to use of dust palliatives.
5. Method of testing quality of cutting edges of grader blades.
6. Specifications for quality of cutting edges of grader blades.
7. Methods for resmoothing surfaces of bituminous surfaces and pavements.
8. Methods for snow removal, drift prevention, and treatment of icy pavements.
9. Operation and care of maintenance equipment.

VI. TRAFFIC

The sole purpose in building and maintaining highways is to provide service for the traffic and the principal highway effort is to provide such roadways that the combined costs of building, maintaining and using them safely will be as low as possible. To reach this desired end, adequate service must be provided, and vehicles must use the roads in an efficient manner. In order to design highways and formulate regulations for their use, information about the amount and behavior of the traffic is necessary. Vehicles should be able to get over the roads expeditiously, economically and safely. To these ends four factors must contribute: Improvement programs, road design, traffic regulations and education

In order to properly evaluate each of these factors in planning regional or state improvement programs, highway transport surveys, including not only counts of present traffic but study of transportation trends and influences for estimation of future traffic, are necessary. Research work in connection with the use of highways consists largely in search for possible betterments by study of the information collected through transport surveys, traffic counts and accident reports and statistics.

Improvement Programs and Design of Roads as Affected by Traffic. The objectives are the building of highway systems that will be adequate to care for the traffic during the life of the improvements.

Traffic Regulation and Safety. The object in regulating traffic is to expedite movement of vehicles with safety. Most regulatory methods in use today have the effect of restricting rather than expediting traffic. There is a real need for research that will divorce itself from present regulations and conditions, and develop the fundamental mechanical and psychological principles upon which practice that will expedite traffic movement with safety can be based. For instance clear conception is needed as to the inherent and legal rights of each vehicle in its use of the road and in its relation to other vehicles. Also more definite ideas as to what traffic regulation should accomplish are needed. The principal problem in traffic regulation is the acquisition of basic facts upon which regulatory measures can be based so that the results will not be merely matters of opinion. The principal problem with respect to safety is how to inculcate vehicle drivers and pedestrians with safe traffic habits. The concern of the highway engineer is in so far as possible to eliminate physical hazards.

NEEDED RESEARCH

TRAFFIC

IMPROVEMENT PROGRAMS AND DESIGN OF ROADS AS AFFECTED BY TRAFFIC

1. Standardization of traffic survey methods
2. Methods for measurements of traffic congestion
3. Methods for traffic classification of highways with reference to type, width and design of roadway and width of right of way
4. Capacity and width of traffic lanes for various volumes and types of traffic.

5. Required right of way width for various roadways and most economical method of acquiring right of way.
6. Study of highway intersections as respects design.
7. Provision for parking.
8. Study of highway facilities in the vicinity of airports.
9. Study of justification for toll roads and bridges.
10. Studies of possibilities of increasing highway capacity and relieving congestion by (a) widening, (b) additional roads, (c) segregation of high and low speed traffic, (d) by-pass routes, (e) elimination of railway grade crossings, (f) elimination of highway grade crossings.
11. Basis for determination of grade crossing separation and division of cost.

REGULATION OF TRAFFIC

1. Study of rights of vehicles in relation to other vehicles and pedestrians.
2. Study of objectives in traffic control.
3. Relative efficiency and cost of methods of regulating flow of traffic through intersections, traffic police, stop and go signals, free movement.
4. Study of the importance of eliminating grade crossings.
5. Study of efficiency of speed laws.
6. Provisions for pedestrian safety.
7. Study of efficiency of signs.

SAFETY

1. Study of relation between accidents and highway hazards.
2. Study of relation between accidents and vehicle condition and characteristics
3. Study of relation between accidents and speed of operation.
4. Study of the personal factor in highway accidents.
5. Results obtained by examination and licensing of drivers.
6. Results of different systems of highway traffic control, state police, county, local, etc.
7. Hazards of night driving. Lighting.
8. Standardization of accident reports
9. Study of results of educational campaigns.
10. Relation between surface characteristics and skidding.

DISCUSSION
ON
REPORT OF COMMITTEE ON COORDINATION AND
PROGRAM

MR A J BROSSAU, *President, Mack Trucks, Inc* I have gone over, very carefully, the outline of the program of Highway Research

Somebody has evidently given a good deal of time to its preparation as it is a very thorough and comprehensive piece of work.

Some details appear to be omitted, although they are probably in the mind of the man who made the outline.

For instance, with respect to highway administration, where minor political units are mentioned, it is assumed that the metropolitan area is under consideration along with counties.

As long as we are getting into the question of commercial vehicle taxation in the industry, I think it would be worthwhile to inject this as a special feature in the subject of highway finance as outlined for discussion. Of course, the subject must come up under the question of highway transportation costs and it might be well to give it more emphasis.

I notice that highway administration is mentioned first. I don't know whether this is done deliberately or not, but I think that in the light of the various drives that are now being made for diffusion of funds that it becomes probably the outstanding question in highway development and one which should be given most thorough consideration.

Between the express highway plans on the one side and secondary roads on the other, the state units are being faced with a drive which might easily result in unsound diffusion of funds.

Whatever facts research can contribute to the solution of this problem should be available when discussion of it reaches those authorities who must make decisions.

There is nothing in the whole program which goes to the question of the relationships between the various types of transportation, and yet there are many questions still unanswered in this field.

The problem of traffic congestion is not stated in so many words, but I presume that it is in mind.

MR. ALFRED E. FLINN, *Director, Engineering Foundation.* In carrying on the research work of the Highway Research Board and of the experimental bureaus and the associations with which it is

influential, it should be urged that all possible use be made of all published and unpublished information on highway research and experience, and from all other fields of science and engineering, even some which may not seem related. Engineering Societies Library and possibly a few others are equipped to make searches, copies, bibliographies and translations. A critical review of all worth-while literature should lead to economies in research effort and in making available for immediate use some information which is now hidden and used by few, if any, persons in active highway practise. This review of literature might well lead to one or more helpful manuals which might be sold. Of course, substantial financing would be necessary to do this work rightly.

Many of the topics suggested for research are old, some of them more than one generation. Doubtless the explanation is that some words continue to describe briefly the needs under changing conditions for more and better and more precise determinations. However, there appears to me some indication of lack of collection of knowledge gained in days gone by, of its dissemination and of its use by many who might be profiting from it. Strengthening of the Highway Board's endeavors to coordinate and stimulate efforts all over the country would probably help this situation.