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COVER:

U.S. 550 south of Silverton, Colo. (Photo courtesy of the American Snowblast Corporation, Denver, Colo.)

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Highway Design for Motor Vehicles— A Historical Review

by Frederick W. Cron

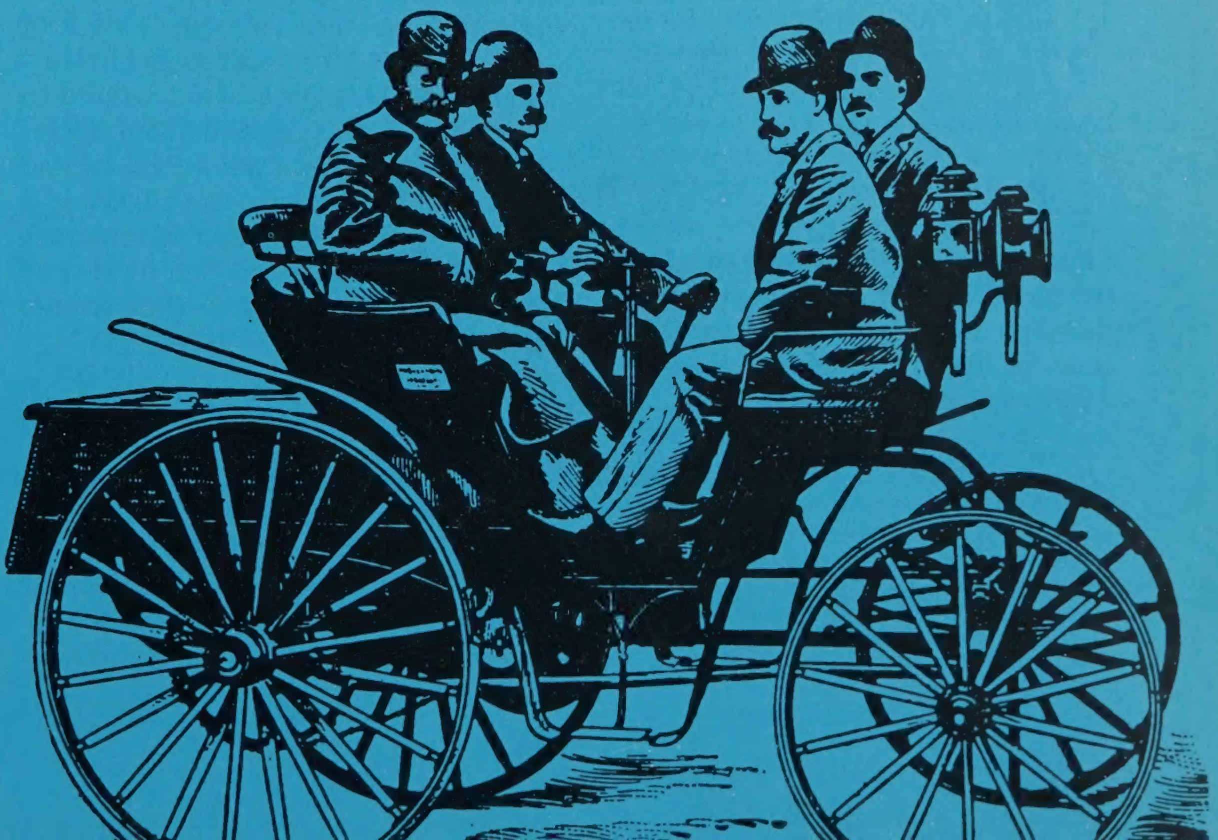
Beginning with this issue and continuing in several succeeding issues, a series of historical articles will be published which will trace the evolution of present highway design practices and standards in the United States.

This series will consist of the following eight parts:

- **Introduction and Part 1**—The Beginnings of Traffic Measurement (in this issue)
- **Part 2**—The Beginnings of Traffic Research
- **Part 3**—The Interaction of the Driver, the Vehicle, and the Highway
- **Part 4**—The Vehicle-Carrying Capacity of the Highway
- **Part 5**—The Dynamics of Highway Curvature
- **Part 6**—Development of a Rational System of Geometric Design
- **Part 7**—The Evolution of Highway Grade Design
- **Part 8**—The Evolution of Highway Standards

Introduction

World War I was a turning point in the history of highway design in the United States. In 1917, despite a decade of astonishing traffic motorization, roads were still being built essentially according to rules laid down by Trésaguet, Telford, and McAdam more than a century earlier. Actually, the theory and art of



roadbuilding retrogressed in that century, since highways were generally being built thinner and narrower in 1916 than in 1806.[1]

From 1907 to 1917 practically the only concessions by roadbuilders to the motor vehicle were the bituminization of the heaviest-trafficked roads to forestall disintegration by dusting, and the introduction of brick and cement concrete surfaces on a very limited scale. During this decade motor vehicle traffic increased from about 30 percent of the total to more than 90 percent. More importantly, heavy trucks—5 tons or more—increased from zero percent of total traffic in 1907 to 7 percent in 1917. It was these heavy vehicles that precipitated the highway crisis that confronted the country in 1918.

Following the outbreak of war in 1917 the mobilization of industry and resources for the war effort preempted most of the capacity of the railroad system, and greatly reduced rail service for the normal supply of the civilian population. To fill the gap the United States turned to its highways:

> Single light units expanded into great fleets, then grew into heavier units that, in turn, developed into long trains. From horse-drawn vehicles with concentrated load of probably 3 tons at most, traveling at the rate of 4 miles an hour, sprung almost overnight the heavy motor truck with a concentrated load of from 8 to 12 tons, thundering along at a speed of 20 miles an hour. The result? The worn and broken threads that bind our communities together *(1)*.[2]

This tremendous highway burden reached its peak at the worst possible time: during the spring thaw of 1918. The results were catastrophic. In Delaware, the Philadelphia Pike was reduced from a good bituminous macadam road to a rutted quagmire by the passage of a single 100-truck convoy. In the Midwest, supposedly high-type roads of brick on concrete bases or bituminous concrete on macadam bases also warped and crumbled. By the end of the war, thousands of miles of roads were barely passable despite skyrocketing maintenance expenditures.

In 1919 Congress, responding to popular pressure, appropriated $200 million for Federal aid to the State highways. This Federal aid, added to the largely unexpended $75 million provided by the original Federal Aid Road Act of 1916 and the States' matching money, placed an immense sum at the disposal of the highway builders—far more than they were prepared to spend wisely.

Scarcity of Basic Information

One of the main obstacles facing the States and the Federal Government was a scarcity of basic information on how highways should be developed to adapt motor vehicle traffic to economic and social needs, and how they should be constructed to stand up under ever-increasing traffic loads. At this time, the most experienced highway research organization in the United States was the Office of Public Roads and Rural Engineering (OPR and RE) of the U.S. Department of Agriculture (USDA). Over the years, Logan W. Page, Director of the Office and a scientist himself, had built a small nucleus of highway engineers, chemists, and research scientists who, since 1912, had been working on experimental and demonstration roads in various parts of the country. The group worked principally on improving materials and methods of construction and disseminating information about roadbuilding.

In 1916 the OPR and RE ascertained by a canvass that less than half of the States had proper facilities for testing their materials and some had no facilities at all. To correct this deficiency, Page invited States with highway departments to send representatives to Washington, D.C., to attend a conference on highway materials. Twenty-one States sent representatives to this

[1]The National Road authorized by Congress in 1806 had a broken stone surface 20 feet wide and 12 inches thick. In 1916 a common design for main roads was 16 feet of macadam 6 inches thick.

[2]Italic numbers in parentheses identify the references on page 95.

First Conference of State Highway Testing Engineers and Chemists in February 1917. The purposes of the Conference were to promote the establishment of well-equipped highway laboratories in every State and to adopt standard specifications for road materials, a comprehensive set of standard tests for such materials, and standard methods of sampling, inspecting, and reporting results. The sponsors also hoped the Conference would encourage cooperative research among the States on the properties of materials and would enhance the usefulness of testing laboratories to highway engineers in the field *(2)*.

Although this conference did not accomplish all that was hoped for, it did focus attention on the need for a coordinated approach to research in the highway field. Of perhaps more immediate importance, it led to the activation later in 1917 of the Committee on Tests and Investigations of the American Association of State Highway Officials (AASHO) under the chairmanship of Thomas R. Agg, Testing Engineer of the Iowa State Highway Commission. Agg organized a later conference which led to important accomplishments in materials testing and control.

Bureau of Public Roads Urged to Assume Leadership of National Research Effort

After the Federal Aid Road Act was approved on July 11, 1916, the staff of the Office of Public Roads and Rural Engineering was enlarged and its name changed to the Bureau of Public Roads (BPR). The death of Logan W. Page in December 1918 deprived the Bureau of leadership at a critical time. For 5 months the Bureau was without a director; then on May 3, 1919, President Wilson appointed Thomas H. MacDonald, Chief Engineer of the Iowa State Highway Commission, to fill the position.

At this time MacDonald, whose appointment had been strongly endorsed by AASHO, was the best qualified of the younger State highway executive officers. His influence on the highway movement in the United States was immediate and profound, but nowhere more pervasive than in the field of research. A scientist and research engineer by preference and an administrator by necessity, he gave a tremendous impetus not only to the BPR's research program but to the national program as well. He was also involved in the formation of the Highway Research Board (HRB).

In August 1919, Thomas R. Agg forcefully summarized the status of highway engineering in the United States in an article in *Public Roads* magazine:

> The situation then is this: The United States is entering upon a very extensive highway construction program without an adequate, acceptable economic theory or group of theories upon which to base design, selection of routes, and types of construction. Knowledge of tests and properties of materials have not advanced to the extent necessary to enable highway engineers to proceed with certainty.
>
> There is at the present time an urgent need for the inauguration of a far sighted, comprehensive program of investigation of materials and methods of construction now employed in highway improvement *(3)*.

Agg then urged the BPR to take the lead "to secure, by whatever means it can devise, the scientific investigation of the various problems requiring solution before engineers can proceed with certainty in the construction of public highways"*(3)*.

This proposal was seconded by A. R. Hirst of Wisconsin, President of AASHO, who not only endorsed the idea of the BPR's taking the lead in the needed investigations but also pledged AASHO's support to the Secretary of Agriculture and the BPR for "this very great and necessary work":

> I agree thoroughly with Mr. Agg in his statements that the present facilities for highway engineering investigations are not adequate to meet the situation, or to develop the theories upon which the future science of highway engineering should be based.
>
> It is to my mind certain that unless the United States Bureau of Public Roads builds up a good and extensive organization to prosecute these inquiries, that nothing of value can or will be done by any other existing organization *(3)*.

It was no accident that Agg and Hirst had chosen *Public Roads* magazine as a forum for their appeal. Page had launched *Public Roads* in May 1918 as a vehicle for exchange among the States of information on methods for financing, building, and maintaining roads. By 1919 *Public Roads* was an important voice for the highway industry nationally and, until AASHO began its own publication, *American Highways*, in 1922, *Public Roads* published many papers by State highway officials.[3]

National Research Council Initiates Highway Research Program

Action on Agg's appeal was not long in materializing, and in fact was already under way when his appeal was published. Early in 1919, the Engineering Division of the National Research Council (NRC) of the National Academy of Sciences had formed a committee of distinguished engineers to meet with MacDonald of the BPR to plan for a national program of highway research. This conference was held in Chicago on October 8, 1919. The outcome of the meeting was a recommendation by the NRC committee members that the Council proceed at once to establish six highway research

[3] *Public Roads* devoted two entire monthly issues to publishing the proceedings of the Annual Convention of AASHO held at Louisville, Ky., in December 1919.

committees to coordinate a national program of research in all aspects of highway engineering *(4)*.

The Engineering Division accepted these recommendations and on October 31, 1919, created a Highway Research Committee "to coordinate and assist the highway research work now being conducted by the United States Bureau of Public Roads, by the state highway departments, by manufacturers, research departments, and commercial laboratories" (*4*). The members of this committee were the same four engineers who had represented the NRC at the Chicago meeting: Anson Marston, Dean, Division of Engineering, Iowa State College (chairman of the committee); A. N. Talbot of the University of Illinois; H. H. Porter, President of the American Water Works and Electric Company; and George S. Webster, Director of Philadelphia's Department of Wharves, Docks, and Ferries. The Division also activated three of the six recommended technical committees:

- Committee on Economic Theory of Highway Improvement—T. R. Agg, Chairman.
- Committee on Structural Design of Roads—A. T. Goldbeck, Chairman.
- Committee on Tests and Properties of Road Materials—H. S. Mattimore, Chairman.

To mobilize support for the Committee's work Anson Marston addressed the AASHO at its annual meeting, December 1919:

> The country is about to spend untold billions of dollars in the construction of paved roads. Yet there is a very serious lack of the fundamental scientific data which are absolutely essential to the correct design and construction of paved roads. In this respect we are still in the situation of the bridge engineers prior to 1850, who were building bridges without knowing how to compute the stresses in the different members . . .*(5)*.

He was careful to point out to the AASHO delegates that the proposed national committee on research would not be a reviewing or investigating body, but rather a correlating body: "The National Research Council merely fulfills the function for which it was organized by the United States Government, that of taking the initiative and of coordinating the work of all investigators, so that they will not cross each other's field, and so that the whole field will be covered adequately. The results are to be taken right off the griddle, as it were, as the meal proceeds" *(5)*.

Having launched the national research program with its own Highway Research Committee, the Engineering Division of NRC next sought to broaden participation by proposing a conference of governmental agencies, technical societies, and educational institutions for the purpose of organizing a national advisory board on highway research. In response to this invitation 36 delegates representing a score of organizations met in New York City on November 11, 1920. Out of this meeting came a general agreement on the form and purpose of the proposed advisory board and pledges of support and cooperation. Anson Marston was elected Chairman of the National Advisory Board on Highway Research (later changed to Highway Research Board) to serve for 1 year. Later, an Executive Committee was appointed of which Thomas H. MacDonald, Chief of the Bureau of Public Roads, was a member. The organization of the Board was completed July 1, 1921, with the appointment of W. K. Hatt of Purdue University as Executive Director.

In 1920 the Bureau of Public Roads was, by a wide margin, the foremost highway research organization in the United States, with 13 major studies underway in the field of physical research. The Bureau was spending about $150,000 per year on scientific investigations as distinguished from road construction, or about one-third of the total national expenditure on highway research at that time *(4)*. MacDonald was prepared to take the lead in the national program by expanding the Bureau's in-house activities, and also by entering into cooperative research agreements with highway departments and universities.[4] The first of these agreements was with the Maryland State Highway Department and the University of Maryland for a study of highway traffic. Many others were to follow.

The BPR led the attack on all fronts: The investigation and measurement of traffic and the design of highway systems, the study of driver behavior, physical research into the properties of soil and pavement materials, geometric design, the structural design of pavements, the study of maintenance and construction methods, highway finance, engineering economy, and transportation economics. As rapidly as findings were made and verified, they were published in *Public Roads*—which had been transformed into a research journal—or in the Proceedings of the Highway Research Board and the bulletins of a number of universities and colleges. These publications became the chronicles of the emerging discipline of highway engineering.

Highway Planning and Research

Highway research received a strong stimulus from the

[4]The BPR was already skilled in cooperative research through participation in the wartime concrete ship program, and through its investigation of core pressures in hydraulic fill dams in cooperation with the Miami Conservancy District *(6)*.

Hayden-Cartwright Act of 1934 and subsequent Federal-aid Acts which authorized the States to spend up to 1½ percent of their Federal-aid funds first for planning and for engineering investigations and, later, for highway research. With the assistance of the BPR, all of the States developed strong planning organizations to carry on the statewide highway planning surveys of the 1930's. Ultimately, all States coordinated or merged the planning functions with their ongoing and expanding research programs to make them integral parts of a coordinated, cooperative national program of highway planning and research. These early surveys investigated all aspects of highway transportation and included intensive studies of highway usage, traffic distribution, driver behavior, highway capacity, and highway safety. These, and related studies by universities and the BPR, laid the foundations of the science of traffic analysis.

Wide-ranging investigations of soils, road materials, pavement design, and geometric design paralleled and intertwined with the traffic studies. The coordinative role of the Highway Research Board became more and more important as research projects proliferated.

As the program gathered momentum, the State highway departments and universities increased their efforts, so that the Bureau of Public Roads' own program became a smaller and smaller part of the whole. Nevertheless, the BPR engineers and scientists, through sheer ability and experience, continued as leaders in most fields of inquiry. Most importantly, the national research program received the full and continuous support of Thomas H. MacDonald, who, as Chief of the Bureau of Public Roads and through his membership on the Executive Committees of both AASHO and HRB, was in a strategic position to direct the total effort and keep it moving in productive channels. Before his retirement from the Bureau in March 1953, MacDonald had the satisfaction of seeing the seed he helped to plant in 1919 germinate and grow to full fruition. Today's highway designers owe a debt of gratitude to this modest engineer and research scientist who, probably more than anyone else, deserves to be called the *father of modern highway engineering*.

The account which follows traces the principal threads of the national research program in the fields of traffic and geometric design up into the 1950's. Research is still in progress in all of these fields, but the fundamental principles were largely established by 1950.

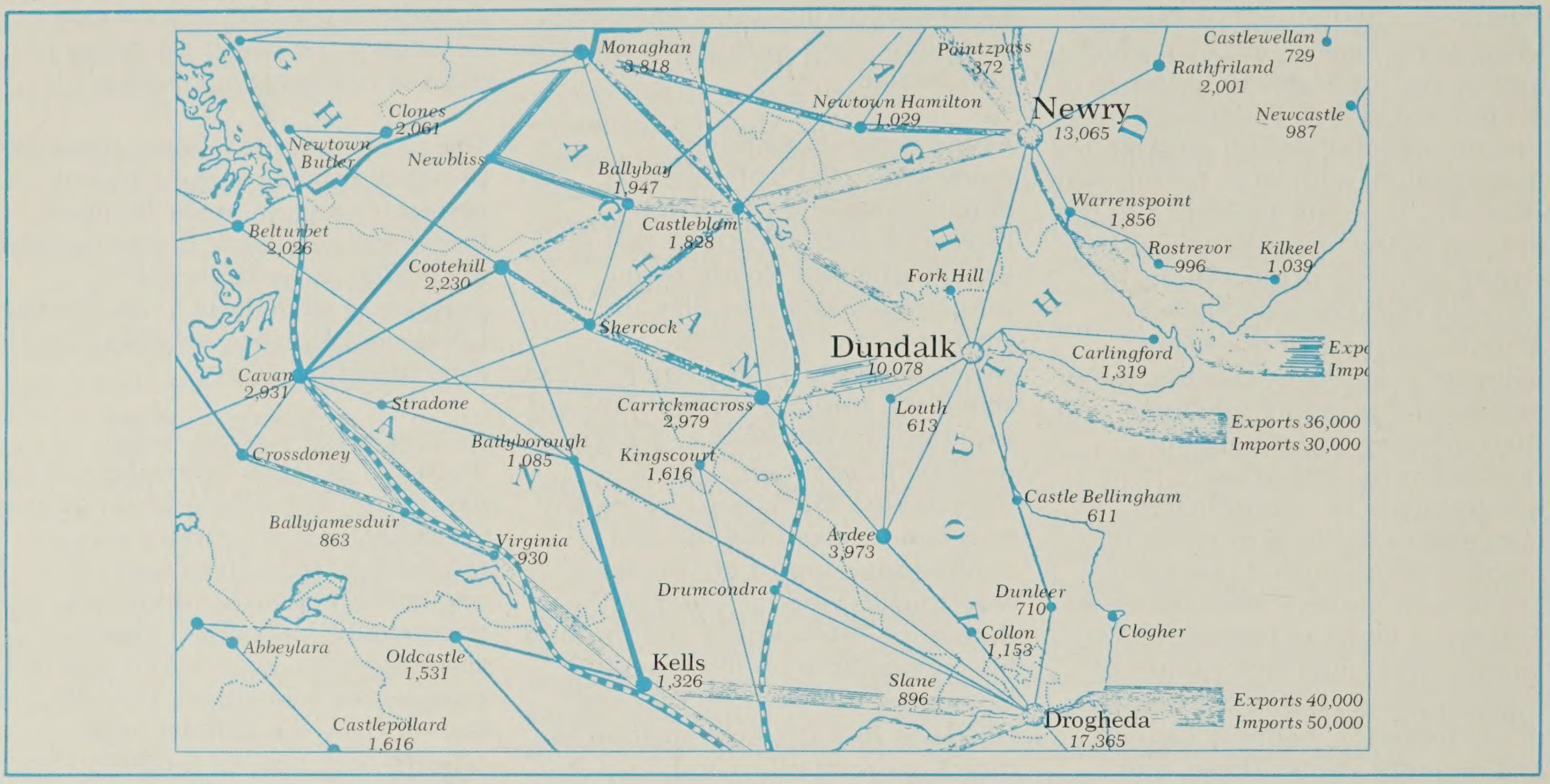
Investigations leading to the discovery of these principles can be described here only in bare outline, yet collectively they make a fascinating story. Hundreds of engineers, chemists, physicists, statisticians, instrument makers, scientific aids—even automobile test drivers—were involved, yet only a few—usually the authors of the reports—can now be identified by name. These hundreds of workers who, over three decades, patiently and persistently ferreted out the principles of highway engineering are the real heroes of this story.

Part I: The Beginnings of Traffic Measurement

The Traffic Census

The origin of the traffic census is obscure and may date from Roman times or earlier. The first modern census was conducted by the Irish Railway Commission in 1837 to gather traffic information for planning a system of railways for Ireland. The Commissioners stationed enumerators on all of the major roads and canals with instructions to count all persons, carts, coaches, and cargo.

Figure 1.–Traffic on Irish roads in 1837.



Lieutenant Harness, the Commission's engineer, summarized this information on flow charts—probably the earliest employment of this useful device (fig. 1) *(7)*.

In the 1870's the French Corps of Bridges and Roads began taking traffic censuses as a means of estimating surface wear on macadam roads, so that contracts could be let for replacement aggregate. Maintenance patrolmen, specially selected for intelligence and reliability, did the counting under the supervision of the district maintenance engineers (*8*).

Early in their census program the French engineers discovered that most traffic traveling past any place on any road originates within a few kilometers of that place. They also found that traffic varies widely:

■ Between different roads.

■ From place to place on the same road.

■ From season to season on all roads.

■ From hour to hour during the day.

■ From year to year on the same road.

To average these variations, the French carefully chose the locations for the counting stations so that each station would represent a section of road "of which it is supposed that the circulation is almost constant thruout the year" (*8*). These stations were then retained for succeeding censuses unless there was a radical change in land use between censuses which altered the traffic pattern. This method of station selection resulted in a large number of stations and a high degree of accuracy.

To iron out seasonal and daily variations, the counts were scheduled at 13-day intervals throughout the census year. These intervals yielded a count on a different day of the week in each of the four quarters, or 28 counts per station per year. The counts covered the period 6:00 a.m. to 9:00 p.m., except that once in every quarter they were carried through 24 hours.

At first the French counted every kind of animal or vehicle that came down the road, but they gradually simplified the tally into five classes of which two were for unharnessed beasts being driven to pasture or market. In 1904 they added four classes of motor vehicles.

To translate animals and vehicles into surface wear, a standard unit for measuring traffic was needed:

> The traffic over a highway is usually made up of various units, no two of which may be exactly alike in their effect. For instance, the effect on the roadway of a loaded two-wheeled cart drawn by a single animal is quite different from that of a pleasure vehicle drawn by a rapidly trotting horse, and the effect of a swiftly moving motor car is very different from that of either of these *(8)*.

French engineers met this need by designating the *collar* as the standard measure of use of the roads. One collar was defined as a single animal harnessed to a loaded vehicle or to a public vehicle for conveyance of passengers. Empty freight vehicles and private carriages counted as one-half collar, while unharnessed animals counted as one-fifth collar. A pair of cattle harnessed to a heavy load counted as 2 collars. Beginning with the census of 1904, motor vehicles were assigned the following equivalency factors: Motorcycles, 0.3 collar each; vehicles licensed to make over 30 kilometers per hour, 3.0 collars each; and vehicles licensed to make less than 30 kilometers per hour, 1.0 collar each (*8*).

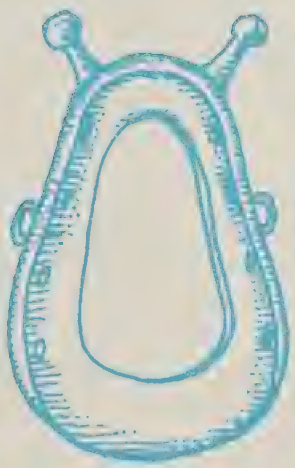
French methods for taking traffic censuses were copied widely—in Europe and in the United States. A number of European countries adopted the collar as the measure of use, although with different equivalency factors. In Great Britain the traffic unit was the English ton. Various classes of motor vehicles were assigned arbitrary weights, ranging from 0.13 ton for motorcycles to 10.0 tons for steel-tired lorries. Animals and animal-drawn vehicles were assigned weights ranging from 0.1 ton each for sheep and pigs up to 3.0 tons for omnibuses drawn by two or more horses. Traction engines, the most destructive vehicles in terms of road wear, were assigned a weight of 12 tons and trailers drawn by such engines, 8 tons. The duty of a road was taken to be the weight of traffic in tons per yard of width per year or tons per mile per year (*8*).

Early American Censuses

In the United States, Maryland—the first State to make a traffic census—counted 21 classes of vehicles. The results were reduced to tonnage by assigning average weights to the several classes, and the duty of the road was expressed in tons per month (*9*).

In 1915, James and Reeves of the U.S. Office of Public Roads, after studying traffic on the Rockville Pike experimental road near Washington, recommended that the ton-mile be used as the standard unit for traffic. Their weights for various traffic classes ranged from 0.28 ton for a rubber-tired, horse-drawn vehicle up to 2.43 tons for a loaded motor dray. A motor touring car was counted as 2 tons (*8*).

These various measures of road use were attempts to find a common denominator for congestion, surface wear, and structural adequacy—something that probably does not exist. Eventually, as will be seen later, the single vehicle—motor driven or horse drawn, regardless of size—became the standard unit for traffic in the United States and the world, as it still is today.



The Maryland State Roads Commission made the first statewide traffic census in the United States in 1904. Illinois made one in 1906, and Massachusetts and New York in 1909. Altogether, some 15 State highway departments made reasonably extensive traffic censuses from 1904 to 1920, but methods of vehicle classification, the number of counting stations, and hours of operation varied widely among these States.

Compared to the French censuses, these counts were little more than spot checks. Maryland spaced counting stations about 7 miles apart on main roads, but not closer than 1 mile to cities. At first, they counted once a month for 12 to 14 hours per day at 50 stations. With the expansion of the State system the number of stations was increased to 191 covering 1,600 miles of highway. Massachusetts counted at 238 stations (later reduced to 57 stations) from 7 a.m. to 7 p.m. on 7 consecutive days in August and again in October. Illinois counted 4 different days per month for a year at 37 stations (later increased to 81 stations) from 6 a.m. to 9 p.m. (*9*).

A few of the more populous counties also made use of the traffic census. Jefferson County, Ala., for example, observed traffic on practically all the roads in the county for 2 days each week for 3 consecutive months, counting 14 hours per day. The observers were first stationed 5 miles from the Birmingham city limits and each week thereafter they moved 5 miles farther out on the same road to record the progressively diminishing influence of the city on traffic. This 1919 census showed that 20 percent of the county's roads carried 80 percent of the traffic, 75 percent of the traffic was motor driven, and 75 percent of the traffic did not pass beyond a 15-mile radius from the center of Birmingham (*9*).

Beginning with its organization in 1914 the Los Angeles County Road Department made annual censuses at certain *fixed points of vantage* throughout the county, counting 8 hours per day for 7 consecutive days at each point. These counts were converted to show average tonnage per 24-hour day by applying average weights for the various classes of vehicles. Washington Boulevard—an important artery connecting Los Angeles City with the City of Venice—carried an average of 4,105 tons per 24-hour day in August 1915, which was good performance for a macadam road with a 16-foot traveled way. In 5 years, however, traffic more than doubled to 8,832 tons per day, and this road—still only 16 feet wide—was carrying the astonishing volume of 7,269 vehicles per day, of which 41 were horse drawn and 196 were trucks! (*10*).

The main purpose of the Los Angeles census was to watch and measure the increase in traffic on the county roads due to road improvement, increased use of motor vehicles, and the gradual development of the country served by the roads. The Los Angeles engineers also hoped to establish a correlation between traffic and cost of maintenance. Still another use of the census was to compute the economic value of the roads to the public. County Road Department studies showed that there was a direct saving of 15 cents per ton-mile in the cost of hauling freight by wagon or truck over paved roads as compared to dirt roads and a saving of 2 cents per vehicle-mile in the cost of operating an automobile. In 1918 these savings amounted to $855,119 for Harbor Boulevard in Los Angeles—more than twice the entire cost of constructing and maintaining this road since its opening to traffic in 1912.

> The fact that this [saving] is not readily recognized by the public at large is due to the condition that this operative income does not show up in revenue, but in saving of expenses to the public without their directly realizing it. Lower cost of transportation is reflected in lower prices, economy in time of transportation brings dairy and agricultural products to the markets in fresher condition, and the public become so gradually accustomed to these conditions that they forget about it (*10*).

The main contribution of the traffic census to the study of traffic was the recognition that traffic is not a steady stream, but is more like a tide which ebbs and flows hourly, daily, weekly, monthly, and seasonally. It can never be measured exactly, but only sampled in the hope of arriving at average values which can be used for the needs of the moment. A number of counting or sampling schedules were devised over the years, such as the French schedule mentioned earlier. The accuracy of some of these schedules is discussed in part 2.

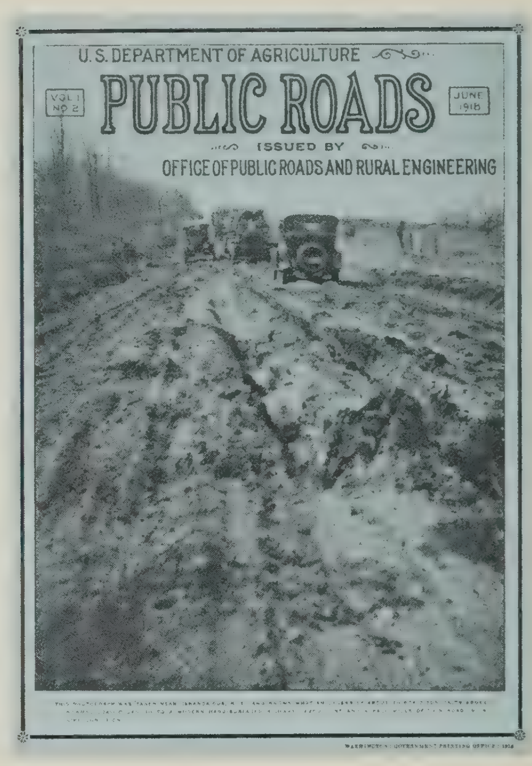
Table 1.—Average daily traffic on main roads in Massachusetts (*11*)

Class of traffic	Census year 1909	1912	1915	1918
Light horse	91	68	40	24
Heavy horse	88	88	72	43
Total	179	156	112	67
Automobiles and light trucks	131	280	555	923
Heavy trucks	0	17	45	75
Total	131	297	600	998
Total traffic	310	453	712	1,065
Horse traffic, Percent of total traffic	58	35	16	6
Automobile and truck traffic, Percent of total traffic	42	65	84	94

Decline of Animal-Drawn Traffic

From the historical viewpoint, perhaps the most interesting accomplishment of the State and county traffic censuses was to chronicle the decline of animal-drawn vehicles as a component of highway traffic. In 1906–07 when the first Illinois census was made, there were so few motor vehicles on the roads that some stations recorded none during the entire 2 years of the census. Five years later, motor vehicles accounted for 20 percent of all traffic counted at 80 stations on the 64 main roads of the State (*8*).

On the road between Baltimore, Md., and suburban Druid Hill Park there was an average of only 2 cycles and 1 motor vehicle per hour in 1904



as compared to 44 ridden horses or horsedrawn vehicles. By 1913, while the total traffic had doubled, horsedrawn vehicles had dropped to only 7 per hour (*8*).

In Massachusetts horsedrawn traffic on the main roads dropped 63 percent from 1909 to 1918 while motor vehicles increased 661 percent. Horsedrawn traffic, which was 58 percent of the total in 1909, dropped to only 6 percent in 1918. The rapidity of the change is shown in table 1.

California Investigation of 1920

In 1920, in response to charges of poor judgment in the location of the highways and the selection of surface types, the California Highway Commission requested that the U.S. Bureau of Public Roads make a complete investigation of the California highway system. The Bureau complied, placing two of its ablest senior field engineers, L. I. Hewes and T. W. Allen, in charge of the work (*12*). This study was the first cooperative research effort between

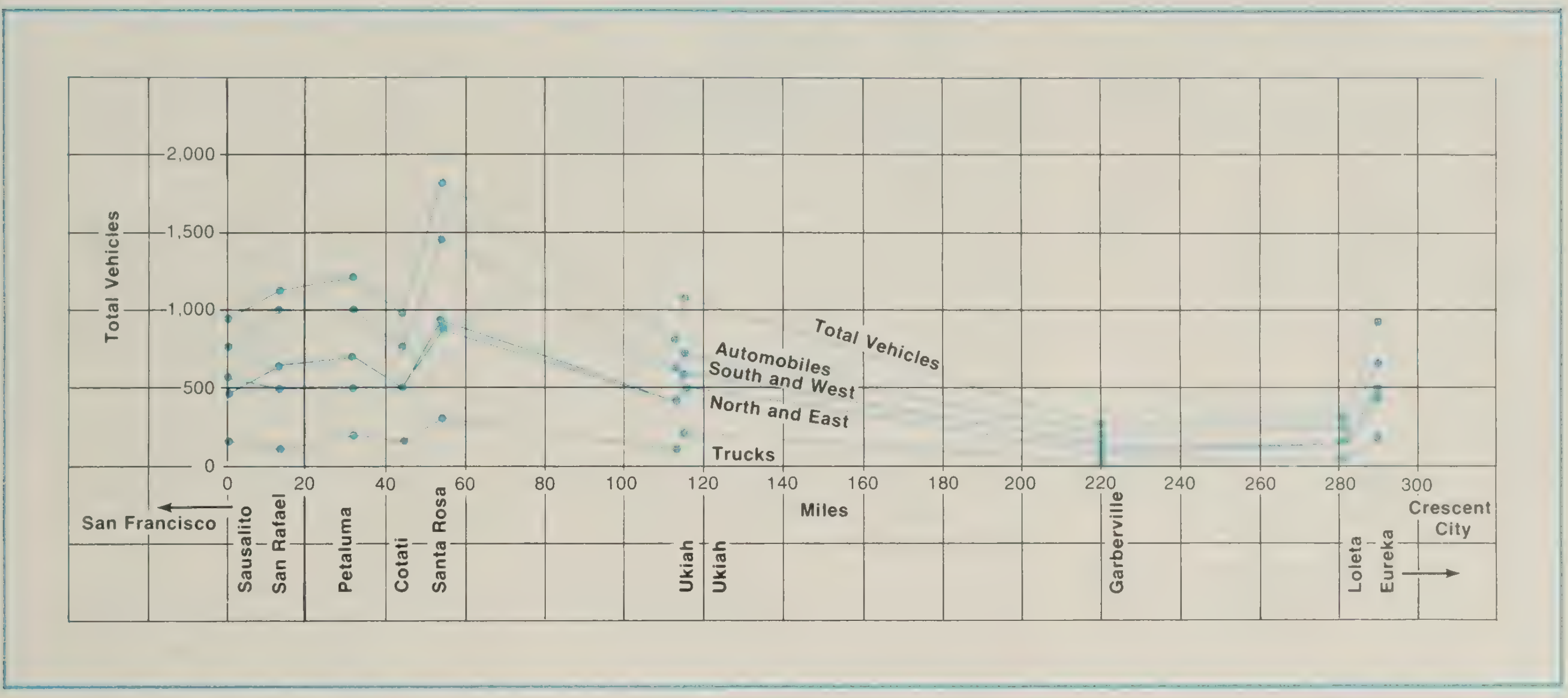


Figure 2.–Traffic diagram–Route 1, San Francisco to Crescent City (12).

a State highway department and the Federal Government, and as such was the precedent for a long series of cooperative studies which, during the next two decades, laid the foundations of traffic engineering and highway design.

Traffic studies were only an incidental and minor part of the California investigation, which dealt mostly with the physical performance of subgrades and pavements, and the routing and design of highways. However, the researchers did break new ground in several directions. One of these was the use of mail questionnaires to obtain information from highway users.[5] They sent requests to 21,000 truck owners for information on average daily operating distance, average net and gross weight, average speed, and gasoline consumption. The return of only 1,930 replies was disappointing, but the effort had some value as a check on the data gathered at the census stations. Another innovation was an attempt to measure average running speeds by stop-watch timing on measured sections of highway. These showed that the fastest vehicles were commercial passenger buses which averaged 33 miles per hour on the open road—a rather brisk pace when one considers that most of the California State highways of this period were only 15 feet wide.

Although not original with this investigation, the researchers made good use of the *traffic profile* to compute the average annual use of the highway in vehicle-miles. They constructed a profile for each route by plotting road miles as abscissae and average daily traffic as ordinates (fig. 2). The resulting curve was a series of peaks at high-count stations near cities with valleys between for the low-traffic rural sections. By measuring the area under the curve the researchers could get the total vehicle-miles of travel per day, which, when multiplied by 365, gave the annual use of that highway. The annual movement in 1920 on the State roads covered by the study (about 2,150 miles) was 375 million vehicle-miles.

These conclusions were based on a very abbreviated traffic census made at 103 stations, and covering only one 16-hour day in the summer. However, the information gathered was considered of such value in the management of the highway system, particularly in apportioning maintenance funds, that the investigators recommended that the Commission make a more complete census not later than June 1921 and at regular intervals thereafter.

The California study was followed by cooperative *transportation surveys* conducted by the BPR and the highway departments of Tennessee (1921–22) and Connecticut (1921). These were essentially censuses to determine traffic density preparatory

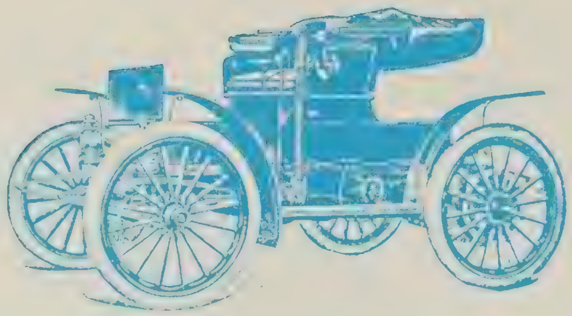
[5]The earliest documented use of the road-user questionnaire was by the Wisconsin Highway Commission in 1916 (*13*).

to establishing State road systems. However, the Connecticut survey of 1921 led directly to another and much more comprehensive study in 1922 and 1923.

Connecticut Highway Transportation Survey of 1922–23

This second Connecticut Highway Transportation Survey was unique in several respects. It was the first to be primarily research oriented, the first to make extensive use of the origin-destination interview, and the first to employ machine tabulation to analyze the data. Its main emphasis was on analyzing the position of the motor truck in the overall transportation picture. The BPR engaged University of Wisconsin transportation economist J. Gordon McKay to manage the work (*14*).

In the course of the study McKay and his researchers looked into every aspect of highway transportation. They counted traffic at 64 stations covering the principal primary and secondary roads, and determined the vehicle density and percent of trucks. They noted the ownership of vehicles (whether in-State or "foreign"), the origin and destination of cargoes, the type of shipment (whether pick-up-and-delivery or terminal-to-terminal), the



commodity, trip length, the size and weight of trucks, and the types of tires they ran on. For passenger cars they recorded the number of passengers per vehicle, the trip purpose (whether business or nonbusiness), and the trip origin and destination. Some of the more interesting findings were:

- Motor trucks were 15 percent of all traffic on the State highway at New Haven and 10 percent at Hartford but much less at other places.
- The average trip mileage for trucks of all capacities was less than 70 miles.
- Of the tonnage transported, 40 percent was hauled 9 miles or less, and only 32 percent for 30 miles or more. This was taken to indicate that trucks did not offer serious competition to railroads except for short-haul, less-than-car-load freight, the haulage of which was unprofitable to the railroads anyway.
- Passenger traffic averaged 2.5 persons per vehicle with an average trip length of 45 miles. Thirty-five percent of the passenger movement was for business.
- Peak traffic movement occurred in October, fading away to a low in February that was only 60 percent of October for trucks and 30 percent for autos.
- Truck overloading was widespread, but 65 percent of the overloads were only 1 ton or less.

While the Connecticut survey was in progress the California Highway Commission and the BPR were conducting a second statewide survey, this one directed principally to the study of traffic. In all, this survey covered 3,200 miles of State highways and 2,100 miles of county roads. The investigators counted traffic at the 103 stations occupied in the 1920 census, and at 138 other stations on the State system plus 190 stations operated by cooperating counties. The studies covered not only the volume and distribution of traffic, but also average speeds, the growth of vehicle registration, the average life of vehicles, and the weights and operations of trucks (*15*).

The California studies of truck operation generally confirmed the Connecticut findings, including the prevalence of overloading. Of all 1922 traffic, 98.8 percent was motor driven and of the total vehicles about 10 percent—summer or winter—were trucks. Only 8 percent of the travel was during the night, and 42 percent of the weekly total was on Saturday and Sunday.

The statistical studies of vehicle registration and population showed that California had the fastest rate of increase in vehicle ownership in the United States—about 36 percent per year from 1907 to 1923—and the lowest ratio of population to vehicles—3.5 persons per vehicle.

These early cooperative studies, and a number of others, notably those by A. N. Johnson, of the University of Maryland, led to the formation in January 1922, of a new committee of the Highway Research Board to "establish an adequate method of studying highway traffic and to show how traffic records should be interpreted" (*16*). This Committee for Highway Traffic Analysis, under the chairmanship of G. E. Hamlin of Connecticut, was charged with guiding and coordinating research in such matters as:

- The relation of community development to the origin and destination of traffic.
- Means for estimating future traffic.
- Methods for studying and recording volume of traffic and for interpreting traffic records.
- Devising units of measure to apply to traffic and defining these units.
- The relation of highway betterment to traffic increase.

A continuous series of cooperative traffic and transportation studies followed the pioneering efforts in California and Connecticut. From 1922 to 1936 there was always a study underway somewhere in the United States. Each study built upon the experience gained from previous studies. With increasing sophistication and generally broader coverage, each added to the growing fund of knowledge about traffic.

The Unit of Traffic

At the very beginning of these studies the researchers were confronted with the need to adopt a standard unit for measuring traffic. The early traffic censuses had been reported in terms of *average daily traffic* or *average daily number of vehicles traveling,* and at first this meant the average number counted during the census day which might be 12, 14, or 16 hours. As early as 1914, however, some authorities—notably the City of Los Angeles—were figuring traffic for a 24-hour day. The *average daily movement* in a 24-hour day was the measure of *traffic density* for the Connecticut Highway Transportation Survey of 1922–23 and for the various subsequent statewide traffic studies of the 1920's and 1930's.

Definitions appeared for the first time in the report for the Maine Survey of 1924:

> *Vehicles* refers only to motor vehicles (passenger cars and trucks) exclusive of horse-drawn conveyances.
>
> *Traffic* is defined as the movement to and fro of vehicles over a highway.
>
> *Density of traffic* is defined as the number of motor vehicles passing any given point on a highway in a unit of time. Unless a different unit of time is specifically stated it refers to the number of vehicles passing any given point on a highway during a day of 24 hours (*17*).

In the United States, the *average daily traffic density throughout the year* or *average annual density* became the standard unit for expressing the traffic on a road after 1922. It was usually found by averaging the four seasonal averages. In later years this became known as the *average annual daily traffic* (ADT) and it was obtained by dividing the total yearly volume by the number of days in a year (*18*).[6]

[6]Until publication of the 1950 Capacity Manual, the terms *volume* and *density* were practically interchangeable. Before 1965 the abbreviation *ADT* was always used for *average annual daily traffic.* Now the recommended abbreviation in the United States is *AADT*.

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Highway Engineers Look at Rivers as a System

Infrared aerial photograph depicting a river system interacting with geologic structures and highways.

by Milo D. Cress
and Everett V. Richardson

One complicated problem faced by the highway engineer is the crossing of and beneficial use of rivers in highway planning. A manual and course curriculum prepared through a coordinated effort between the Federal Highway Administration and Colorado State University contain information useful in the location and design of river crossings and encroachments to protect the environment and the safety of the traveling public. The manual stresses that the designer of a river crossing or encroachment must look at the entire river as a system. Changes in the river, either natural or man-induced, can adversely affect the designed crossing even if the change occurs hundreds of miles away. The manual will be widely distributed and the course curriculum will be used by the National Highway Institute in future training programs.

Throughout history, rivers have held the potential for man's development as well as his destruction. Rivers have been used for navigation and irrigation; their fertile flood plains are ideal for agriculture; and industry has sprouted along their banks. However, effects of flood control measures, irrigation and power projects, and channel improvement measures carried out during the last century have proved the need for considering the delayed and far-reaching effects of any alteration man may make in the naturally developed alluvial river system. Experience has also proved the need to study these effects in order to gain a knowledge of river formation processes and to apply this knowledge in the design of river crossings and channel improvement measures.

A major aspect of highway design and construction is the crossing of streams and rivers. A concurrent problem is the encroachment of the highway onto the flood plain or even, at times, the stream or river channel. This encroachment may be at right angles to the stream or river—as with approaches to a bridge, or parallel to the stream or river—which is sometimes the only feasible or economical location for the highway. In either case, the design of the crossing or encroachment must insure the safety of the traveler, must protect the river environment, must not create hazards or problems to adjacent landowners and community, and must be economical. For these reasons the designer needs a basic understanding of hydraulics, hydrology, sedimentation, and fluvial geomorphology. These disciplines are encompassed by the term **river mechanics**. Although there is a considerable fund of knowledge of these subjects, **river mechanics** is still an art as well as a science. It is the conclusion of Dr. D. B. Simons, professor of civil engineering, Colorado State University, that, while there remains a definite need for further research, there is adequate knowledge of river processes to allow the development of solid design concepts and procedures. However, up to this time, the knowledge of the river formation processes and the interaction of primary variables have been retained by experienced engineers and scattered throughout the literature.

There has existed for some time the need for consolidation of research findings and knowledge gained by experts in the field of river engineering who are involved in both laboratory and field investigations, as well as practical applications of procedures previously developed, into a manual on river mechanics. Such a manual could be used both in the dissemination of the knowledge and in the design of river crossings or lateral encroachments. Through the use of the manual, structures would then be placed in or along the river in such a way that the river as a system would react favorably. Preparation of such a manual and training material was the objective of a recently completed project cosponsored by the Federal Highway Administration's Offices of Research and Development and the National Highway Institute in cooperation with the Office of Engineering. Through contractual

agreement, the expertise and experience of the engineering staff of Colorado State University were used in the preparation of the manual which is to be used as an aid to instructors and designers alike.

The manual was prepared by engineers from the viewpoint of the highway engineer and is entitled "Highways in the River Environment—Hydraulic and Environmental Design Considerations." It includes the following chapters:

- Open Channel Flow
- Fundamentals of Alluvial Channel Flow
- Fluvial Geomorphology
- River Mechanics
- River Stabilization, Bank Protection and Scour
- Needs and Sources for Data
- Hydraulic and Environmental Considerations of Highway River Crossings and Encroachments. (The last chapter is based on case histories.)

The manual presents techniques used in the design of control measures and river crossings which have been proved reliable through practice. To test the viability of the manual for its intended purpose, it was used as the text for a 2-week training course presented and recorded on video tape by Colorado State University.

The 2-week course stressed the necessity for consideration of the river as a **system.** It was consistently pointed out that the engineer must take into account the delayed and far-reaching effects of any alteration he makes in a naturally developed alluvial river system and the effects that development of the river by others will have on his design. He must approach the design of channel improvement measures and river crossings knowing that the river will react as a system to any changes that are made upstream or downstream by himself or others. He must, using all available knowledge, maintain a balance between the issues of economics, politics, environmental impact, and the conservation of natural resources. He must have a basic knowledge of—or employ the services of experts in—hydraulics, hydrology, economics, erosion and sedimentation, river mechanics, environmental impact, and related fields, in the development of plans for a proposed highway or the design of a river improvement measure. The design must be a team effort. It must fully consider effects of construction on the landscape, navigation, economics, recreation, ecosystems, water supplies, and society. Furthermore, the design must consider the effects of natural or manmade changes of the river system on the river crossing.

A preliminary evaluation of the manual and training course by 33 highway engineers who attended the pilot course indicated that it was a success. As a result of recommendations from those who attended the pilot course, the manual and curriculum were made even more responsive to the needs of the practicing engineer. A second 2-week course was conducted by Colorado State University in the early fall of 1974. As a result of this course, further changes were made in the manual and curriculum.

The Offices of Research and Development, the National Highway Institute, and the Office of Engineering value the opportunity to take part in the organization and support of this effort with Colorado State University, which ultimately will result in the advancement of technology, a saving of dollars, and a safer and more environmentally compatible highway design. The Federal Highway Administration will arrange for a wide distribution of the manual and plans to support future training in the field of river engineering.

It is expected that the manual will be in final print late in 1974. More information about the manual and course curriculum can be obtained by contacting the Director, National Highway Institute, Federal Highway Administration, Washington, D.C. 20590.

Second Annual FCP Review Held in Texas

by William D. Whitby

The second annual review of the Federal Highway Administration's "Federally Coordinated Program of Research and Development in Highway Transportation" (FCP) was held at the Inn of the Six Flags in Arlington, Tex., from September 9 through 13. More than 300 highway researchers and others participated in the meeting.

The review meetings provide a forum where all segments of the highway community can participate in the development of the FCP program and learn of the progress of ongoing research and studies planned for the near future. At this conference, in-depth reviews were conducted for approximately half of the projects in the program.

The 5-day session, continuing a series initiated in 1973, attracted representatives from the highway departments of nearly all the States, as well as a large contingent from FHWA's Washington headquarters and field organization. Also attending were more than 50 delegates from several universities and an equal number from industrial firms, more than a dozen from highway-related trade and other organizations, a scattering from municipalities, and three from Canada.

Discussion group during an overview session.

J. W. White welcomes participants.

J. W. White, Regional Federal Highway Administrator for Region 6, Fort Worth, host for the meeting and responsible for the success of the detailed arrangements, welcomed the participants at the opening of the Monday morning session. In his opening remarks, G. D. Love, FHWA's Associate Administrator for Research and Development, emphasized the importance of the FCP in focusing attention on the most pressing R&D problems and through a coordinated effort at the Federal, State, and local levels assuring maximum utilization of available resources for research and development in solving some of the critical problems in the Nation's highway program.

C. F. Scheffey, Director of the Office of Research, then reviewed the status of the FCP, mentioning that research on several projects has been successfully completed and implementation has begun, and announced that four new projects would be started in fiscal 1976, making a total of 31 active. In the absence of Rex Leathers, Director of the Office of Development, Mr. Love concluded the opening session with a review of the implementation program, which makes available to the highway community the

G. D. Love emphasizes the importance of the program.

products of the Federally-aided highway R&D program and the highway research outputs of States, cities, other government highway-related agencies, and independent research organizations.

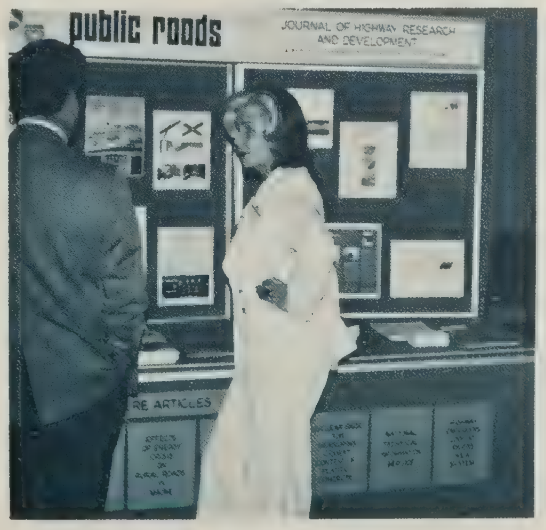
Following the Monday morning introductory session, the afternoon and all of Tuesday were devoted to a series of overviews of the past year's progress in the five principal categories of FCP. The remainder of the week's sessions consisted of in-depth detailed reviews of progress, current activities, and future plans for each of 12 projects within those categories. The chiefs of five of the technical divisions of the Offices of Research and Development, assisted by their group chiefs, conducted the presentations; each session included general questions and discussion by other participants.

In conjunction with the program reviews, the Transportation Research Board invited maintenance specialists from most of the Western

J. A. Wentworth starts off in-depth review session on Advanced Protective Barrier Systems.

States to participate in the session on Project 6F.[1] In addition, the steering committee for the pooled fund Concrete Median Barrier Study invited participants for a special session.

[1]For further information on FCP, write to the Associate Administrator for Research and Development (HRD–3), Federal Highway Administration, Washington, D.C. 20590.



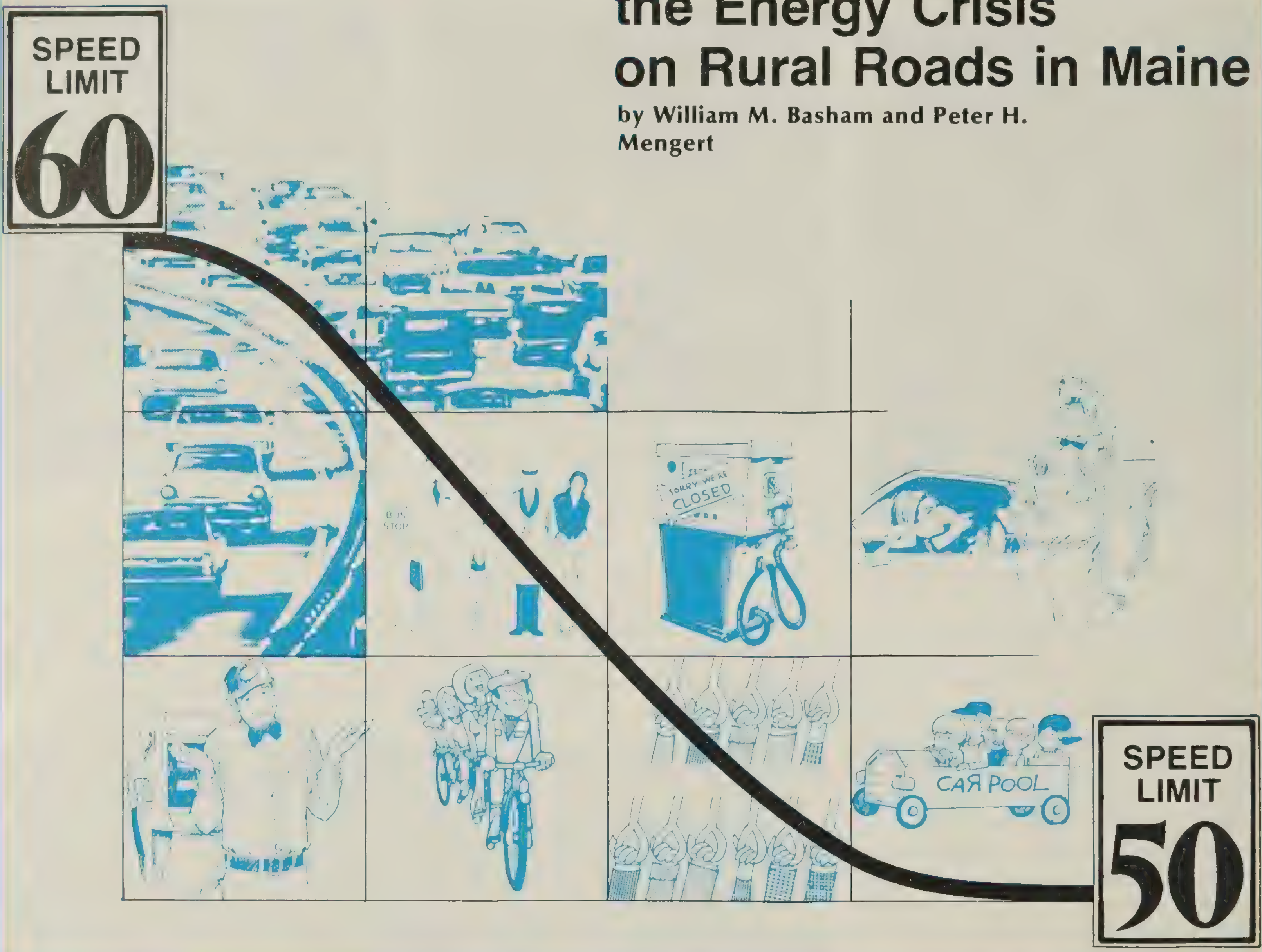
In addition to the formal sessions, participants in the meeting were invited to take a bus tour of the Dallas Corridor Study area and its control center. Another feature was an information center which operated during the in-depth reviews Wednesday through Friday. Each division had displays related to its R&D projects, with copies of reports and brochures for distribution, and a staff member in attendance to answer questions relating to the program. An exhibit for *Public Roads* included a display of the September issue, with the editor in attendance at the exhibit.

As a change from the days of meetings, Region 6 arranged a barbeque at the Inn on Wednesday evening, where representatives had a chance to mix informally.

The general feeling expressed by participants at the end of the meeting was that it had been informative and constructive. In a final statement, Mr. Scheffey expressed his belief that the objective of communication between researchers and users had been achieved.

The Effects of the Energy Crisis on Rural Roads in Maine

by William M. Basham and Peter H. Mengert



The reaction of the driving public to the 1973–1974 winter energy crisis was observed on two two-lane rural roads in Maine. Vehicle velocity data was collected on U.S. Route 2 at the Maine Facility site and traffic volume data was collected on U.S. Route 1 at the town of Waldoboro. Results of this study show that vehicle speed reductions occurred with the establishment of a mandatory lower speed limit. Specifically, when the Governor of Maine established the new maximum 50-mph (80 km/h) legal speed limit on non-Interstate highways: (1) The percentage of automobiles traveling at speeds at or below 55 mph (89 km/h) increased from 48 to 60 percent and from 46 to 70 percent for eastbound and westbound traffic, respectively; (2) mean speed reduction was only 0.5 mph (0.8 km/h) and 4.2 mph (6.8 km/h) for eastbound and westbound traffic, respectively; (3) speed variance decreased by one-third; and (4) vehicle speed profiles stabilized quickly and remained fairly constant throughout the remainder of the study. The negative aspect of the establishment of the 50-mph speed limit was that the percentage of automobile drivers not complying with the new speed limit doubled to approximately 70 percent.

Both weekday and Sunday traffic volume reductions, compared to volumes of the previous year, were observed during the winter of 1973–1974. The declining traffic volume on Route 1 generally tended to follow the monthly statewide gasoline sales, indicating a similar traffic volume trend statewide.

Introduction

Beginning in November 1973, a traffic experiment was conducted at the Maine Facility *(1)*[1] on a section of U.S. Route 2, approaching and through the village of Palmyra, Maine—29 miles (47 km) west of Bangor. The experimental objective was to determine the effect of traffic sign configurations on driver understanding of, acceptance of, and compliance with the posted speed limit as drivers travel on two-lane rural roads through towns. During the time that data was being collected for this experiment, the Nation was experiencing the 1973–1974 energy crisis. In Maine this was highlighted by the following events:

■ On the evening of November 7, 1973, the President of the United States, in a nationwide radio and television address, urged the individual States to reduce highway maximum speed limits to 50 mph and individuals to voluntarily do less driving in order to conserve gasoline *(2)*.

■ In a second nationwide television speech on November 25, the President requested that all gasoline stations be closed on Sunday and that the States allow buses and trucks to travel at 55 mph instead of the original 50 mph *(3)*.

■ The Governor of Maine, on November 27, in a statewide radio and television address, established a new 50-mph speed limit for all vehicles on non-Interstate highways *(4)*.

■ The new 50-mph speed-limit signs were to be installed statewide by the first of January. During the sign-posting period, State police handed out *courtesy warnings* to motorists exceeding the 50-mph speed limit *(4)*.[2]

■ A statewide shortage of gasoline, although not as severe as in many areas of the country, was experienced, especially from December through April. Table 1 presents Maine gasoline consumption (taxable only) data from September 1973 through April 1974.

The data collected during the village of Palmyra experiment was used to determine the effects of the energy crisis on a typical rural two-lane road—Route 2 in Maine. Specifically, data has been analyzed to determine driver reaction to the crisis in terms of possible traffic volume and speed reduction. In analyzing the data, two general hypotheses were advanced: (1) A decrease in the percentage of those vehicles traveling at velocities greater than 50, 55, and 60 mph (97 km/h) over the study period would give an indication of driver reaction to the energy crisis, and (2) a decrease in traffic volume over this period as compared to previous years would indicate the unavailability of gasoline and/or a voluntary compliance to drive less frequently.

Procedure

Vehicle velocity data was collected on Route 2 by means of permanently installed sensing loops (nodes) embedded in the road. As a vehicle passed over a node, data was transmitted to a central computer, processed, and stored on magnetic tape *(1)*. Vehicle velocity was determined by calculating the vehicle traversal time between two nodes and dividing this time into the known distance between the two nodes, 400 ft (120 m). This value, expressed in miles per hour (mph), is called a vehicle link speed.

For this study, four nodes—two east and two west of Palmyra—of the 22 employed in the Palmyra experiment were used to measure the velocity of vehicles approaching the village. One to three thousand vehicles per day, 8 to 12 percent of which were trucks, passed over these nodes during the study period. At these nodes, the asphaltic pavement is 24 ft (7.3 m) wide and the shoulders are 8.5 ft (2.6 m) or wider.

The only interference with the tendency of drivers to drive at the 60 (reduced to 50 on November 27) mph speed limit was the location of a 35-mph (56-km/h) speed zone at Palmyra, 1,000 ft (300 m) downstream from the center of each pair of nodes. For a major portion of the study, the 35-mph signs were considered no restriction since they

Table 1.—State of Maine gasoline consumption[1]

Month	1972–1973	1973–1974	Percent of change
	Thousands of gallons	*Thousands of gallons*	
September	45,760	46,042	+0.6
October	44,605	46,646	+4.6
November	42,717	43,303	+1.2
December	41,239	38,330	−7.0
January	40,240	35,779	−11.0
February	36,255	33,426	−7.8
March	40,314	38,143	−5.3
April	40,108	38,491	−4.0

[1]Data supplied by the State of Maine Fuel Allocation Office. Data includes aviation fuel (approximately 2 percent of total) but not Federal Government consumption (approximately 0.5 percent of total).

[1]Italic numbers in parentheses identify the references on page 106.

[2]The 50-mph speed-limit signs were installed on Route 2 at Palmyra on Dec. 12, 1973.

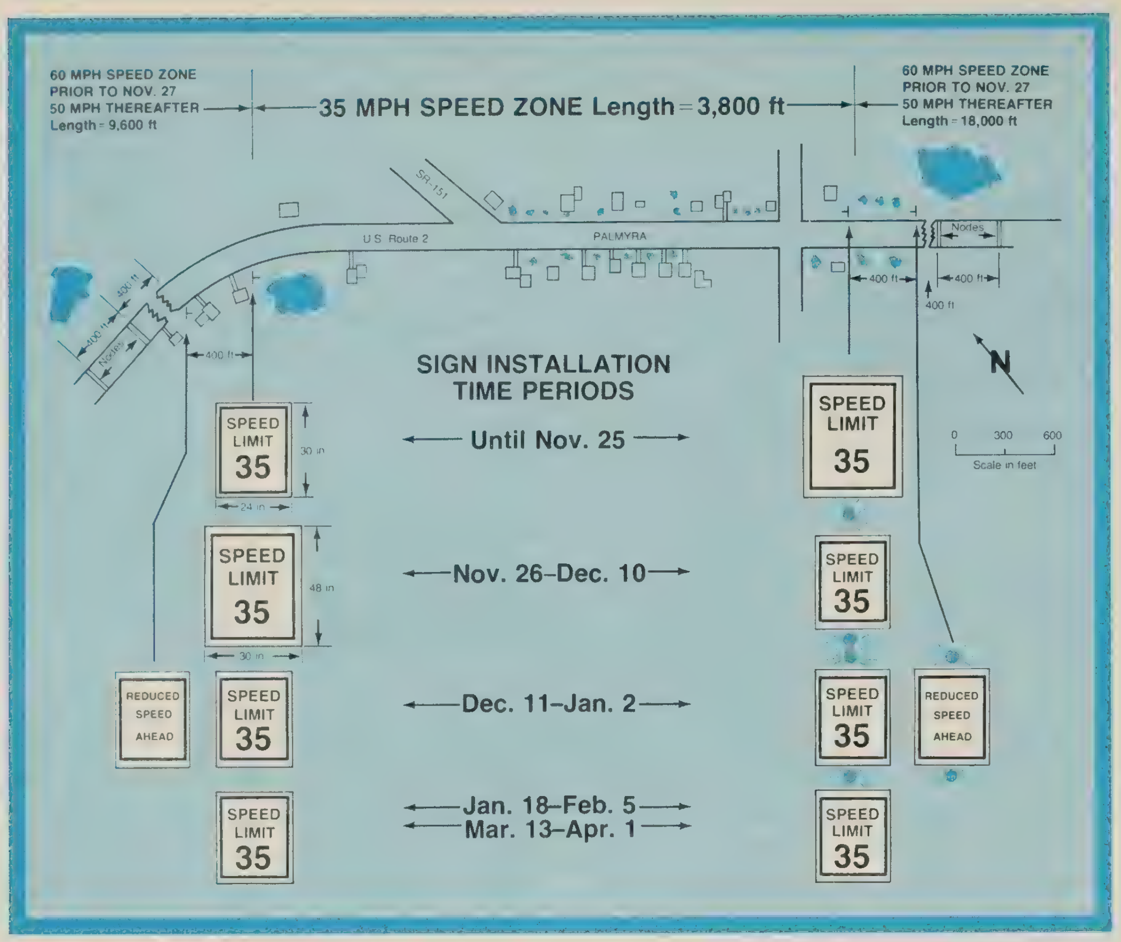


Figure 1.—Study test site: Node, sign, and speed zone locations.

Table 2.—Automobile population statistics

Direction of traffic	Statistic	Time period 1 Nov. 5–27	2 Nov. 28–Dec. 12	3 Dec. 13–19	4 Jan. 18–Feb. 1 Mar. 26–29
Eastbound	Sample size	1,269	467	320	716
	Mean value	54.96	53.55	54.13	53.71
	Standard deviation	8.09	6.03	6.45	6.30
Westbound	Sample size	1,374	533	356	682
	Mean value	55.65	51.44	52.16	52.38
	Standard deviation	7.86	6.31	6.12	6.10

were not noticeable from a distance of 1,000 ft. However, from November 26 until January 2, the 35-mph speed-limit sign, located downstream of the east nodes, was removed as part of the ongoing Palmyra experiment and a new 35-mph speed-limit sign with two flasher units was installed. Also, from December 11 to January 2, a *Reduced Speed Ahead* sign with flashers was installed 400 ft (120 m) upstream of the new flashing speed-limit sign. Node, sign, and speed-zone locations are presented in figure 1.

Vehicle velocity data was collected for 2 to 6 hours per day in such a manner that approximately equal amounts of data were collected for each daylight hour. Data was not collected on weekends, at night, during bad weather (precipitation and/or wet pavement), and during the Palmyra experiment sign configuration changes (November 20–26 and December 10 and 11). On the average, 14 hours of data per week were collected from November 5 to December 19, 1973. Additional data was collected during the last weeks in January and March to observe the effects of time on the velocity parameter.

The volume data collected on Route 2 was not considered adequate for this study because the data was collected in the manner described above. However, volume data was made available for this study by the Maine Department of Transportation at a site on Route 1 at Waldoboro, 80 miles (130 km) southwest of Bangor. The two rural roads are similar, except that the average daily traffic on Route 1 is twice that of Route 2. Volume data was collected 24 hours a day, 7 days a week, from September through April in 1972–1973 and 1973–1974, by a loop detector embedded in the pavement in conjunction with a recording unit. No data was collected during the weeks of November 11 and 18, 1973; December 16 and 23, 1973; and January 6 and 20, 1974, due to mechanical problems with the recording unit.

Results

The data was analyzed to answer the following questions about driver behavior during the 1973–1974 winter energy crisis:

- Did a speed reduction trend occur as a result of the energy crisis?
- If such a trend did occur, when did it occur, and did it remain stable during the rest of the study period?
- Did the new lower speed limit reduce the mean vehicle velocity and variance?
- Did the new lower speed limit reduce the percentage of drivers exceeding 60, 55, or 50 mph—the new posted limit?
- Did the new legal speed limit reduce the percentage of vehicles obeying the posted speed limit?
- What was the reaction of drivers

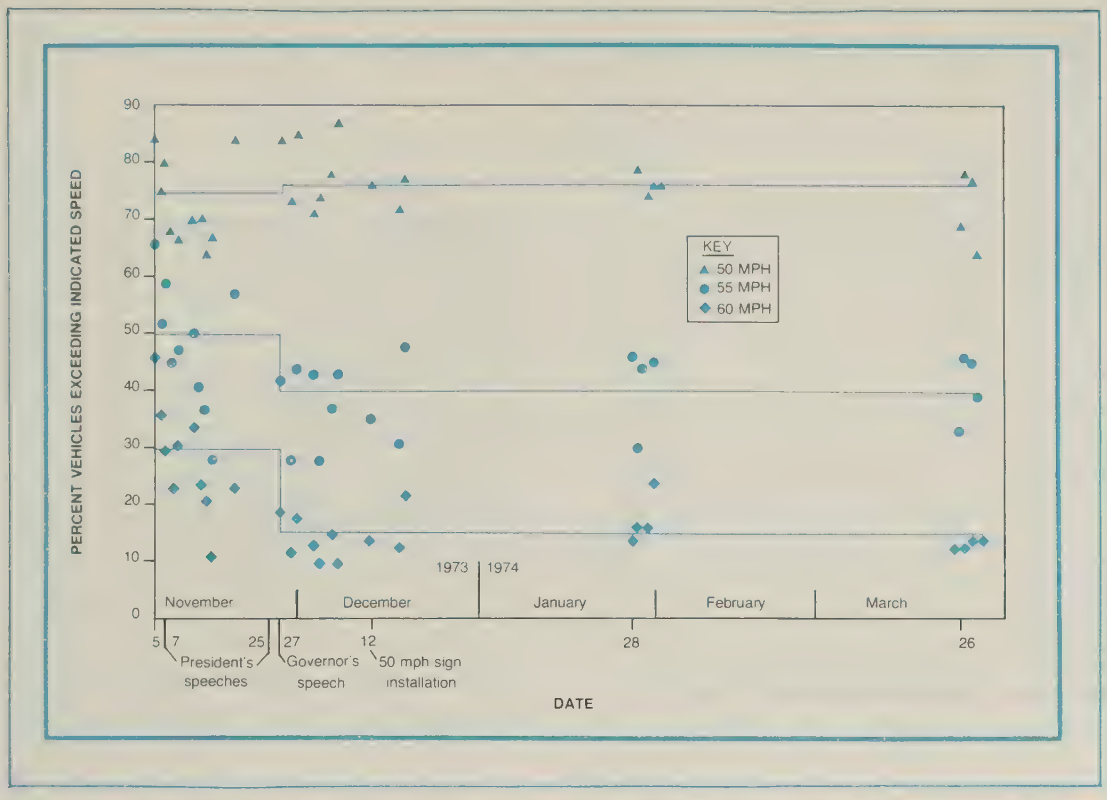


Figure 2.—Eastbound automobile velocity percentiles.

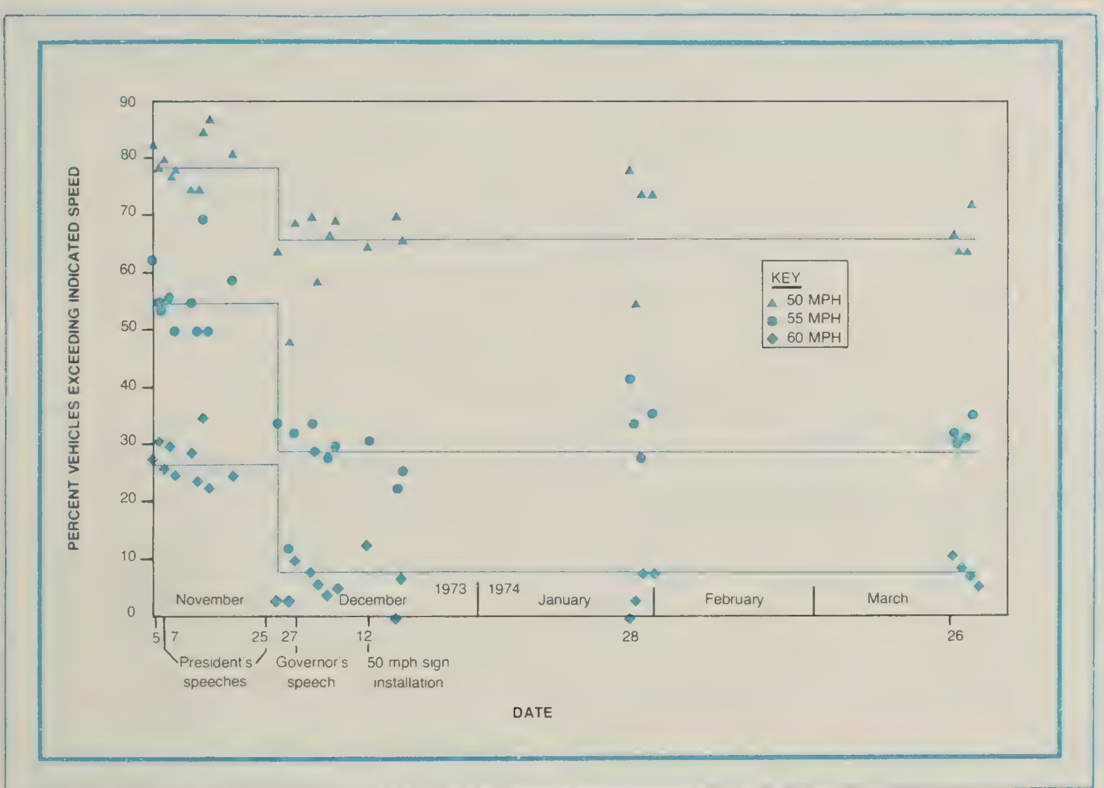


Figure 3.—Westbound automobile velocity percentiles.

of large vehicles to the new speed limit?

■ Did the volume of traffic during weekdays and Sundays decrease as a result of the crisis?

Velocity

Table 2 presents automobile population sample sizes, average velocities, and standard deviations for eastbound and westbound traffic for the following time periods:

1. November 5 through 27—prior to the Governor's November 27 speech, speed limit 60 mph.

2. November 28 through December 12—after the Governor's speech until the 50-mph speed-limit signs were installed on Route 2, speed limit 50 mph.

3. December 13 through 19—the week after the 50-mph speed-limit signs were installed on Route 2.

4. January 18 through February 1 and March 26 through 29—speed limit 50 mph.

The data in table 2 was used to test the hypothesis that the average velocity of two different samples (time periods) came from the same population with the same means. The hypothesis was tested at a 5-percent level of significance by means of student "t" tests. The following were found for both eastbound and westbound traffic:

■ A significant difference between the time period 1 and 2 populations was found.

■ No significant difference between the time period 2 and 3 populations was found nor between time periods 3 and 4.

A mean speed reduction occurred for both the eastbound and westbound automobile populations with the establishment of the 50-mph legal speed limit on November 27. The installation of the new speed-limit signs on December 11 had no apparent effect on the behavior of the driver population, i.e., no significant mean speed changes occurred. Finally, once the initial speed reduction occurred after November 27, the mean speed remained fairly constant throughout the remainder of the study.

Although a decrease in mean automobile velocity was observed from time period 1 to period 2, a more precise question concerning driver reaction needs to be asked: Was this decrease due to an increase in the percentage of drivers traveling less than 50 mph—those drivers already obeying the legal speed limit—or to a decrease in the percentage of drivers exceeding 60 mph—those drivers who attempted to comply with the new 50-mph speed limit—or to a combination of the above two effects? This question was answered by the use of velocity percentile plots. Figures 2 and 3 present plots of

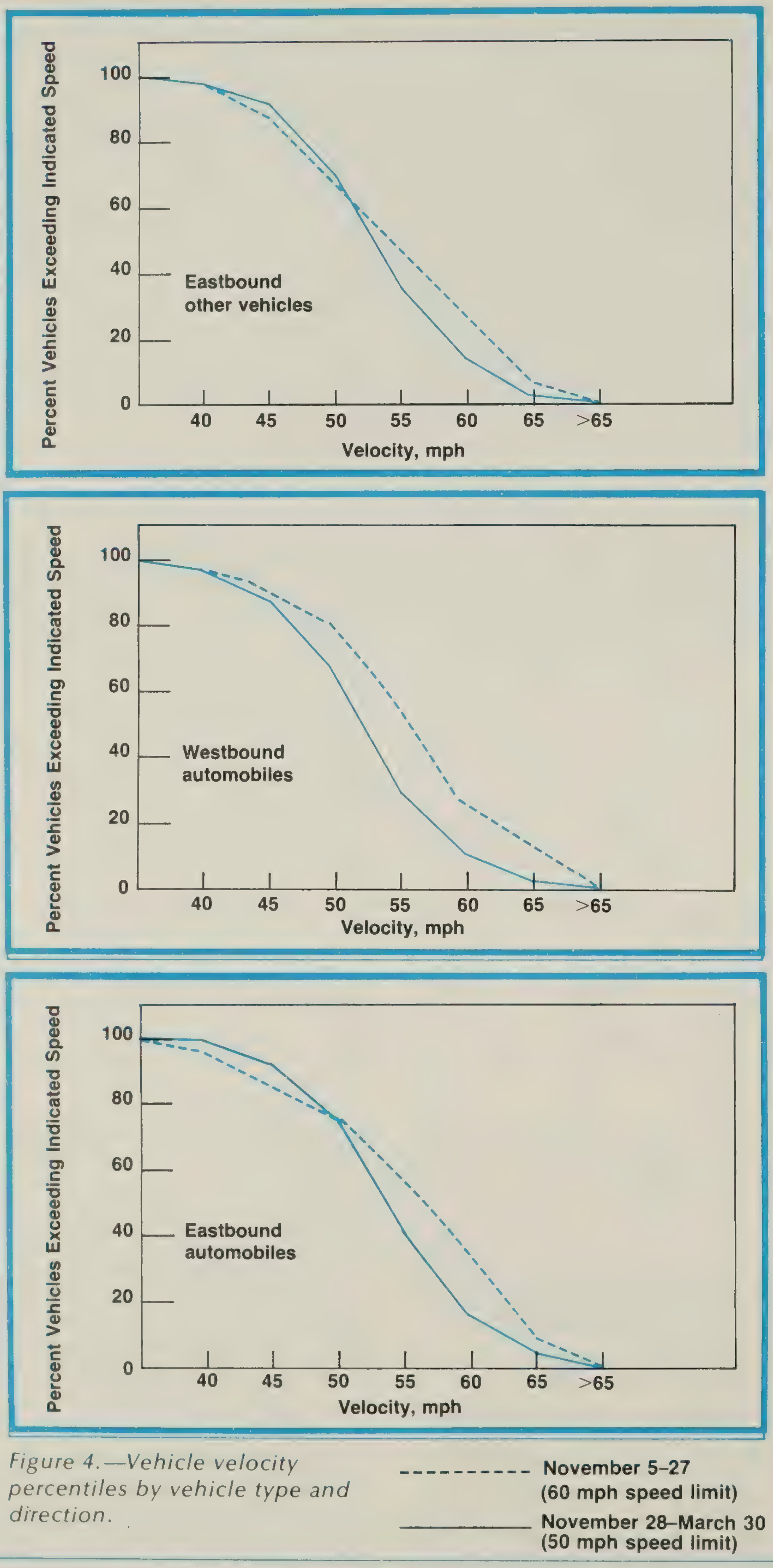


Figure 4.—Vehicle velocity percentiles by vehicle type and direction.

the percentage of the vehicle population traveling at or exceeding a given velocity—50, 55, and 60 mph—for eastbound and westbound automobiles, respectively. Each solid line is the percentage average for the period of time when the legal speed limit was 60 mph and 50 mph (after November 27, 1973). Part of the pronounced percentage decrease observed after November 27 in the figure 3 westbound plots was thought to be due to the installation of the flashing speed-limit sign on November 27. The presence of the flashing sign, 1,000 ft downstream of the east nodes, may have caused a certain percentage of drivers to decrease vehicle speed. However, since no percentage changes were observed after December 11, when a second flasher sign—an advance warning sign—was installed, or in January or March when the flasher signs were removed, the effects of these signs on driver behavior were probably secondary to the energy crisis effects.

Cumulative velocity distributions for eastbound and westbound automobiles are presented in figure 4 for the time periods when the legal speed limit was 60 and 50 mph. Information concerning the percentage of automobiles traveling at a given velocity or at greater than this velocity may be obtained from these plots. For example, the plot shows when the legal speed limit was 60 mph, 30 percent of the eastbound automobiles were traveling at speeds in excess of or equal to the legal speed limit. In comparing the 60- and 50-mph speed-limit plots, the following observations were made:

- The percentage of automobiles traveling at speeds greater than or equal to 50 mph did not decrease for eastbound traffic and decreased from 88 to 66 percent for westbound traffic.

■ The percentage of automobiles traveling at speeds greater than or equal to 60 mph decreased from 30 to 15 percent for eastbound and from 26 to 8 percent for westbound traffic.

■ The velocity of automobiles at the 15 percentile decreased from 64 (103 km/h) to 60 mph (97 km/h) for eastbound and from 63.5 (102 km/h) to 58.5 mph (94.1 km/h) for westbound traffic.

■ The median velocity decreased from 55.5 (89.3 km/h) to 53.5 mph (86.1 km/h) for eastbound and 55.5 to 52 mph (83.7 km/h) for westbound traffic.

■ The percentage of drivers *not* complying with the current legal speed limit increased drastically from 30 to 76 percent for eastbound and from 26 to 66 percent for westbound traffic.

The cumulative velocity distribution for eastbound nonautomobiles—vehicles whose length is greater than 20 ft (6 m)—is also presented in figure 4. A comparison of the two test periods indicates a general increase in the size of the driver population traveling at speeds below 60 mph but not nearly as pronounced as that associated with the automobile plots. The velocity distribution for westbound nonautomobiles showed no apparent change during the study period.

Changes in the percentages of vehicles traveling at speeds greater than 50, 55, and 60 mph are variable from day to day within the two legal speed-limit time periods, as observed in the figures 2 and 3 daily percentage data. This is due in part to daily variability and in part to sampling variability. It is, therefore, of interest to statistically compare the two test periods. Consequently, the following statistical hypothesis was tested: The percentage of vehicles—automobiles and nonautomobiles—that exceeded *x* miles per hour, where *x* was either 50, 55, or 60 mph, was less in the second time period (50-mph legal speed limit) than in the first time period (60-mph legal speed limit). When this hypothesis was tested by means of chi square tests on contingency tables at a 5-percent level of significance, the following results were observed:

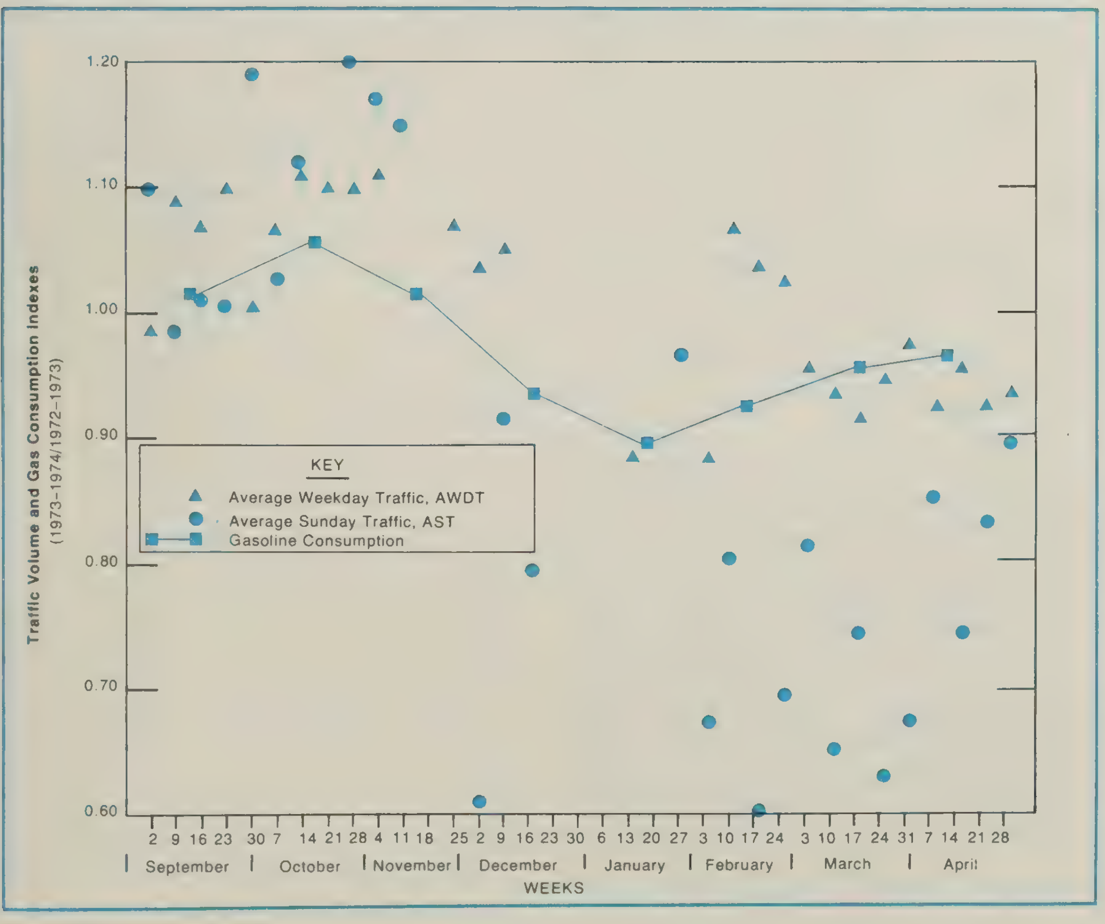
■ Significant decreases in the percentage of westbound automobiles exceeding 60, 55, and 50 mph were found.

■ No significant decrease for westbound nonautomobiles was found.

■ Significant decreases were found for eastbound automobiles and nonautomobiles at the 55- and 60-mph levels.

The results of the chi square test statistically confirmed previous observations from figure 4.

Figure 5.—Traffic volume and gasoline consumption over time.



Volume

The results of the traffic volume study are presented in figure 5 for average weekday (AWDT)—Monday through Friday—and Sunday (AST) traffic, respectively. The AWDT and AST indexes, the ratio of the 1973–1974 to the corresponding 1972–1973 traffic count, are plotted versus time. A ratio greater than 1.0 indicates an increase in traffic, while one less than 1.0 indicates a volume reduction. Also plotted in the figure is the monthly gasoline consumption index; the ratio of the 1973–1974 to the corresponding 1972–1973 monthly gasoline consumption. During the 1973–1974 study period, the maximum weekday and the Sunday traffic volume was 5,258 and 6,301, respectively (week of September 2, 1973) and the minimum was 2,423 (week of February 3, 1974) and 1,954 (February 17, 1974). Because beginning in 1965 traffic volume on Route 1 had experienced yearly increases, a slight traffic increase probably should have been observed in 1974. The volume data presented in the figure clearly indicates that the winter of 1973–1974 was not a normal winter. In a very general way, the AWDT and AST data tend to follow the gasoline consumption curve. From September 16 until the end of November all index values are equal to or greater than 1.0. From December through April both the gasoline consumption index and AST index are less than 1.0, as is the AWDT index, except for a few weeks in January and February. Toward the end of the study, the AST index showed an increasing trend, indicating in part the increasing availability of gasoline and the reopening of some gasoline stations on Sunday.

Conclusions

Although a tendency for drivers to travel at lower speeds (eastbound traffic only) was observed immediately following the President's November 7 speech, indicating a voluntary speed reduction for a small percentage of the driver population, the most pronounced speed reduction occurred immediately after the legal speed limit was officially lowered by 10 mph (16 km/h) on November 27. The new 50-mph legal speed was effective in reducing the size of the driver population which had traveled at speeds at or in excess of 55 mph—11- and 24-percent reductions for eastbound and westbound automobiles, respectively. A one-third reduction in the speed variance was also observed over this time period. Only a small mean automobile speed reduction—0.5 mph (0.8 km/h) eastbound and 4.2 mph (6.7 km/h) westbound—was observed. There was a negative aspect of the new legal speed limit: The percentage of automobiles which did *not* comply with the current legal speed limit more than doubled; from 30 to 76 percent for eastbound and from 26 to 66 percent for westbound traffic. Once the new legal speed limit was established, no further systematic change in vehicle velocity was observed, indicating either a continuing driver awareness of the energy crisis and/or the continuing effect of the statutory limit. Although a decrease in the percentage of nonautomobile drivers who traveled in excess of 55 mph was also observed, no definite conclusions can be made concerning this vehicle-type population.

At the Route 1 test site, a decrease in both the 1973–1974 average weekday and Sunday traffic volumes occurred. The decrease in Sunday traffic volume was expected, largely because of the closing of gasoline stations on Sunday. Since these two test roads are similar in geometry and traffic volume to many other rural two-lane roads across the Nation, it is likely that the effects of the energy crisis would be similar elsewhere.

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(4) *Morning Sentinel,* Nov. 28, 1973, vol. 71, Waterville, Maine: Morning Sentinel, Inc., City Edition, p. 1.

The National Technical Information Service

by[1] Stanley Metalitz

The National Technical Information Service (NTIS) has been receiving highway research and development reports for its enormous information bank for over 10 years, yet only recently has its importance as a primary source of scientific and technological information begun to register beyond the relatively narrow confines of the technical librarian and information specialist. This article discusses not only how NTIS works—how to get information from it as well as how to contribute inputs—and in what forms the information is available, but also why NTIS prints and microfiches cost what they do, and what services NTIS can perform.

Readers desiring further information should contact NTIS.

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Va. 22151
General information: 703-321-8000
Telex: 89–9405

Introduction

The National Technical Information Service (NTIS) is a governmental bookseller and publisher, but should not be confused with the U.S. Government Printing Office (GPO), reputedly the largest publisher in this hemisphere.

NTIS's catalog contains 800,000 titles. This number may not be overwhelming, but GPO's catalog includes only about 24,000. The U.S. book publishing industry as a whole has about 400,000 titles in print. NTIS annually issues about 60,000 new titles—twice as many as the entire U.S. book publishing industry and 12 times the annual output of GPO.

NTIS is unique in several other ways:

- It is NTIS policy that no title ever goes out of print.
- The top best seller for fiscal year 1973 sold slightly under 3,000 copies.
- The average title stocked by NTIS sold 12 copies in that year. Understandably, a title which sells 100 copies is considered to do well.
- Thousands of the items available have never sold a single copy, and quite likely never will.

Mission of NTIS

Under the law (*1*)[2] NTIS functions as a central source for the collection, retrieval, and public sale of the published results of Government-sponsored research. It also receives inputs from foreign sources and private industry. The agency is required to collect information from "whatever sources, foreign and domestic," to make such information available to industry, business, government (including State and local levels as well as Federal), and the general

[1]Permission was obtained from Bo W. Thott of NTIS to use portions of his article "The National Technical Information Service," published in the *Drexel Library Quarterly*, vol. 10, Nos. 1 and 2, Policies and Practices in the Bibliographic Control of United States Government Publications, January–April 1974, pp. 39–52.

[2]Italic numbers in parentheses identify the references on page 114.

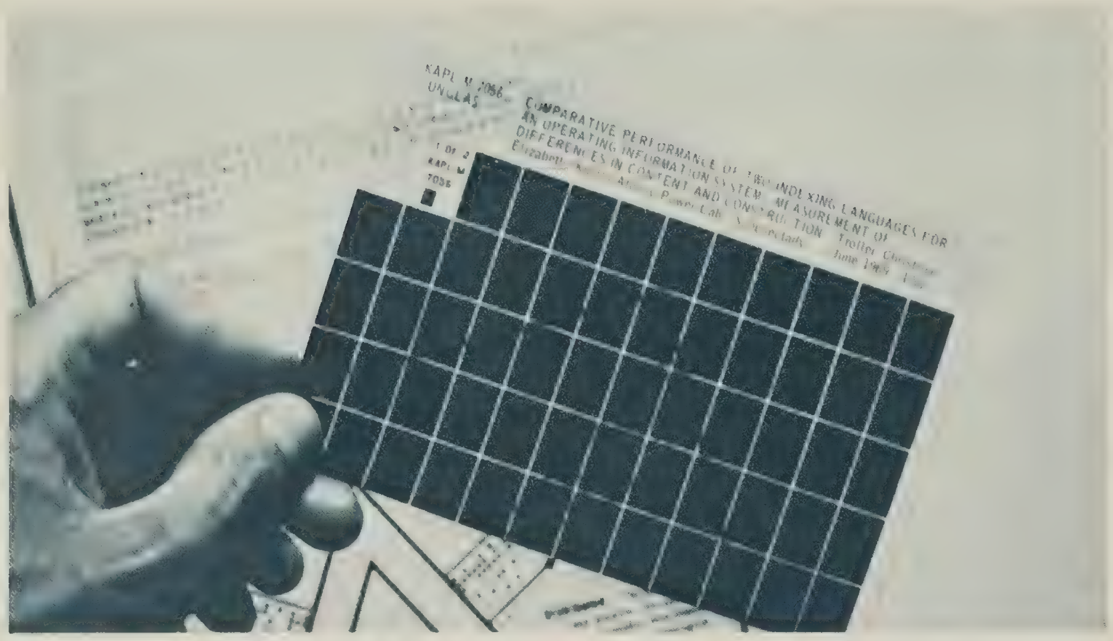

Figure 1.—An example of microfiche. The black rectangles are negative images of the report's original pages.

public, and ultimately to support itself in these activities. President Nixon, reiterating this mission in his 1972 message on science and technology, designated NTIS as the focal point for making the results of Government research and development activities available to the private sector.

The law dictates the agency's mission and requirement for self-support, but compels no one to supply the information which NTIS is responsible for storing, retrieving, reproducing, and dispensing. Developing this tremendous data bank input has been a sales and persuasion effort of years' standing, from 1946 when the agency started in the Department of Commerce (where it remains today) as the Office of Technical Services (OTS). It became the Clearinghouse for Federal Scientific and Technical Information (CFSTI) in 1964, and, with its mission broadened to include business and commercial information, took its present identity in 1970.

To function effectively, NTIS (and its predecessor agencies) has had to persuade Federal agency chiefs and information managers that NTIS can serve them and their users. This effort has succeeded so well that its recently instituted policy of charging not only for output but also for input has caused very little comment among its contributors. In this way the agency hopes to support itself while simultaneously expanding its services.

Services and Prices[3]

What does NTIS do for its customers?

The agency is set up to supply copies of published technical and scientific reports of Government-supported and other research and development from over 300 Federal offices and agencies, and from some State, local, private, and foreign sponsors. These reports are available in two principal forms—paper prints or microform. Occasionally, if the contributor supplies copies, NTIS can distribute copies of the original edition of the report. Far more often, the customer gets an offset-printed black-and-white facsimile (hard copy). The price depends on the item's number of pages, and on whether it is currently stocked or whether it must be reprinted on order from film or paper originals. Since the price includes postage, a customer in a foreign country pays more. The lowest price, for a report of under 26 pages currently stocked, sent to a domestic address, is $3. A foreign addressee would pay $5.50. The domestic price scale goes up to $11 for a 600-page report, with $2 increments for each additional 100 pages.

[3]Price information is correct as of September 1974. For current price lists, readers should contact NTIS.

For reports reproduced on order, the price range is higher (based on 5 cents per page plus a handling charge): $4 (domestic price) for a 20-page report, $5.50 for 50 pages, etc. For foreign shipment add $2.50.

What NTIS can supply on paper, it can also usually supply in *microform* (microphotographs in any of several formats). The microform format most widely used today is *microfiche*. Microfiche consists of film sheets about 4 by 6 inches containing microphotographs (negatives) of report pages reduced to $^1/_{24}$th of original size, with 98 pages per sheet (fig. 1). At $2.25 per document (up to 1,000 pages) to domestic customers, microfiche is much less expensive than paper reprints, but does require a special projection or reader unit to magnify the negative transparencies to readable size.

Other microform formats available include *microfilm* on reels, either 35 mm or 16 mm, with the latter—the more common—accommodating 22 pages to a foot, or 2,200 pages per 100-ft reel; and *aperture cards*, which are standard tabulating (punch) cards into which microfilm images have been inserted. The cards are key-punched for mechanical retrieval.

NTIS can also supply certain computer programs and data files on tape and cards.

NTIS Customer Information Program

Unlike commercial publishers, and because it is a Federal agency, NTIS cannot engage in conventional advertising. It has, therefore, devised a customer information program through which it aims to tell each customer what is new and of interest to him; at the same time, the program pays for itself. The program's main component is a variety of information services available by subscription.

Government Reports Announcements (GRA)

GRA is the comprehensive NTIS listing, with basic bibliographic information and abstracts of current and recent reports accessioned—adopted and identified as part of the NTIS collection and made available to customers. Appearing every 2 weeks, its annual domestic subscription price is $70. Citations are arranged by 22 fields and 175 groups according to the subject category list by the Federal Council for Science and Technology's Committee on Scientific and Technical Information.

Government Reports Index (GRI)

The GRI, published concurrently with GRA, includes indexes arranged by subject, personal and corporate author, contract numbers, report numbers, and accession numbers. Domestic subscription price is $70 or, combined with GRA, $125. NTIS also publishes a *Government Reports Annual Index* of almost 7,000 pages available at $300.

Weekly Government Abstracts (WGA)

The WGA, compiled from GRA, provide frequent and up-to-date announcements of citations in 23 broad, high-interest subject areas selected to make the WGA into awareness tools for the engineer, scientist, and businessman, each of whom can select and subscribe to the WGA series on the areas of interest to him. Subscription prices run from $30 to $45; over 20,000 copies of WGA are mailed each week to subscribers.

The customer information program also includes direct mail, using lists which have been refined to achieve responses as high as 30 percent—considered very successful for this method.

Information Retrieval

Going beyond the announcement techniques, NTIS offers subscribers another service—reports in microfiche form, with the subscriber receiving at a much reduced rate per item *all* the reports in the categories in which he has an interest. Called SRIM (for Selected Research in Microfiche), the categories may either be subjects or sources. When a user subscribes under more than one subject, NTIS screens out duplicate reports falling in more than one category. NTIS also offers a customized SRIM service based on an individual user interest profile. Figure 2 shows the SRIM sorting method.

Functioning more as an information retrieval facility than as a publisher, NTIS also offers *NTISearch*—a

Figure 2.—Lighted cubbyholes in SRIM sorter indicate which reports are desired by the subscriber. Clerk selects the reports from the indicated cubbyholes.

computerized, on-line retrieval service that uses the 360,000 bibliographic citations accumulated by NTIS since July 1964 (fig. 3). This is the only comprehensive publicly available file of Federal research reports. Customer searches are priced at $50 for up to 100 abstracts, with added charge for additional abstracts. Searches of Federal research projects in progress can also be executed through NTIS at the Smithsonian Information Exchange (SSIE).

NTIS Inputs

NTIS depends for its successful operation as much on its input, to provide the raw material for its product, as on selling the product. Federal agencies provide 99 percent of the input to NTIS. (A few major agency sources frequently can be recognized by the letter prefixes to the catalog or *accession* numbers—AD for Department of Defense, N plus the year for NASA, and COM for Department of Commerce. Most others—as are those from the Federal Highway Administration—are prefixed PB.) In addition, a number of State governments and related agencies, and a few trade associations and private firms send inputs to NTIS.

NTIS sees the effort to enlist new sources as a necessity, not only to keep up with the expanding quantities of research and development reports and related publications, but also to keep up with expanding numbers of suppliers of such information. This effort is complicated by a fiscal problem: Although the NTIS reproduction and distribution operation pays for itself, input processing operations do not. They are subsidized by appropriated funds, which account for 16 percent of NTIS's total budget. To make NTIS operations self-supporting, contributor fees must replace appropriated funds. Consequently, new contributors are now paying an input charge of $35 per title. Old contributors will be required to make similar payments as soon as new agreements are concluded.

Maintaining standards for inputs

The documentation and physical condition of inputs to NTIS are of primary importance to the effectiveness of the agency's function. Aside from the cost of processing, the main problems associated with NTIS inputs are quality—in terms of reproducibility—and standardization of both format and bibliographical information.

To deal effectively with these problems on a nationwide scale, NTIS encourages its contributors to comply with the Z39 series documentation standards issued by the American National Standards Institute and by the National

Figure 3.—On-line terminal for NTISearch system. The terminal provides both a readout display on a cathode-ray tube and a printout of the item displayed.

Microfilm Association. NTIS requires, for example, that reports sent for accessioning contain the prescribed Report Documentation Page (RDP) or Bibliographic Data Sheet (BDS), and that they conform to reasonable rules on page size, pagination, legibility and reproducibility, and foldouts.

In the U.S. Department of Transportation, the substance of these standards is embodied in DOT Order 1700.18A, which provides for further implementation by the constituent operating administrations of the Department. In the Federal Highway Administration (FHWA), the provisions of the Order are implemented for the Offices of Research and Development in *Repro Copy Requirements* (RCR), a pamphlet available free either from the Contracts and Procurement Division of FHWA or from the author, Federal Highway Administration (HDV–14), Washington, D.C. 20590. RCR provides the details of format for technical reports, the standards that reproducibles must meet to be acceptable for publication, and instructions on making out the RDP for maximum bibliographic and information-retrieval utility.

NTIS's format review of reports submitted results in about 12 percent being returned to contributors for improvements, mostly in legibility. NTIS also takes action to improve the acceptability of submittals. For example, the legibility of computer printouts has improved markedly over the past few years, possibly as a result of an NTIS letter campaign which suggested a change to new ribbons for the computer printer whenever the output is intended for reproduction rather than normal analysis.

An active program to promote the use of unique report numbers, meaningful titles, single-spacing of texts, and pagination has been generally successful but is not always accepted initially by contributors. A contributor once insisted that his 38-page report needed no pagination. Another could not understand why it is not acceptable to achieve literary variation by having four different titles on one report. It is true that NTIS can usually—though with some delay—locate and supply a report by title only, without a number. But even NTIS must return unfilled requests in which the requestor quotes a cover title that does not match the one NTIS takes from the title page.

NTIS sometimes accepts, reluctantly, reports that are marginally reproducible when they might otherwise be lost to the public, though it can do not much more about it than to add a caveat to the citation. NTIS cannot edit or retype reports received for publication.

Pricing policy

That information has value is not a new idea. That it has a price is by no means so generally agreed. NTIS Director William Knox holds that information costs money to collect and disseminate and people ought to be willing to pay for it, just like anything else (2). The prices put on the information NTIS issues must reflect market values. The prices are based on factors (page count, format, content, expected demand) realistically related to cost; hence the sale of documents essentially supports itself. On the input side, subsidized until now, the $35 charge per unit input is expected to go far toward making that operation self-supporting.

One additional point regarding price policy is worth noting and is one of the characteristics in which NTIS departs radically from most other publishers. The demand for reports from NTIS, although huge overall, is modest in the particular because of the specialized nature of the subject matter. NTIS has no choice but to calculate and then to recover its actual costs. Some users, accustomed to paying 25 cents per page for fulfilling their special requirements, can appreciate this and consider NTIS's charges quite reasonable. Those more accustomed to GPO's partly subsidized prices find such charges harder to accept. GPO does not attempt to recover in its price all printing and distribution costs, but also does not keep the publication available indefinitely, as NTIS does.

Though some Government publications are simultaneously available from both NTIS and GPO, the price policies of the two do not conflict. While a title is in the GPO catalog, NTIS supplies only microfiche of it. Only after GPO drops the item does NTIS furnish hard copies.

NTIS and R&D Documentation in the Federal Highway Administration

Cooperation in documentation between NTIS and the Offices of Research and Development, Federal Highway Administration (and its organizational predecessor, the Bureau of Public Roads), dates back to before the U.S. Department of Transportation was created in 1967. As reflected in DOT and FHWA directives, and in those of the Offices of R&D, documentation through NTIS (or its predecessor, CFSTI) has for 10 years been part of FHWA R&D technical report publication procedure, and is extended when feasible to other publications for which such documentation would be relevant. Form DOT F 1700.7, Technical Report

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-00-00		

4. Title and Subtitle	5. Report Date
XXXX XXX XXXXX XXXXX XXXX. *(Vol. No. is part of subtitle.)* Vol. 4. Xxxx Xxx Xxxxxx Xxxx	Month 197X
	6. Performing Organization Code
7. Author(s) X. A. Xxxx, X. B. Xxxx, and X. C. Xxxxxx	8. Performing Organization Report No.
9. Performing Organization Name and Address Xxxxx, Xxxxxx, & Xxxx Associates 000 Xxxxxx Street Xxxx, Pennsylfornia 00000	10. Work Unit No. (TRAIS) 000-0000 FCP 00X0-000
	11. Contract or Grant No. DOT-FH-11-0000
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590 *If sponsor also is performer (staff studies), omit 1st line.*	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code
15. Supplementary Notes FHWA contract manager: X. X. Xxxx (HXX-00) *If appropriate, identify cosponsors and give other credits in this space.*	*For staff studies, name project manager, if he is not the first author.*

16. Abstract

Xxxx xx xxxx xxx xxx xxxx xxx. *Abstract entire study (series or multivolume report).*
X xx xxxx xxxxx xxxxxxxx xxxxxx xxxxxxx xxxxxxxx.
X xxxxxxxxxxxxxxxxxx xxxxxx xxxxxxxxx xxxxxx xxxxxxxxxxxx xxx xxxxxx xxxxx xxxxxx.
Xxxxx xxxx xxxxxxxx xx xxxxx xxxx xxxxxxxx Xxxxx Xxx Xxxxxxxx. X xxxxxx xx xxxxxx.

Xxxxxxxxxxx xx xx xx xx xxxxxxx. *Abstract this volume only (series or multivolume report).*
X xxxx xxxxx xxxxx xx xxxxxxx xxxxxxxxxxxxx xxxx xxxxx xxxx.
Xxx xxx xxxxxxx. Xxx xx xxxxxxxxxx xxxxx xxxxxxxxxxxx.

This report* is the fourth in a series. The others in the series are:

Vol. No.	FHWA No.	Short title	NTIS (PB) No. (if available)
1	00-00	Xxxxxxx Xxxxxxxxx Xxxxx	000000
2	00-00	Xxxx xx Xxxxxx Xxxxxx	000000
3	00-00	Xxxxxxxxxxxxxxx	000000
5	00-00	Xxx Xxxxxxxxx xx Xxxxxxx	000000
6	00-00	Xxxxxxxxxxx Xxxxxxxx Xxxx	(not yet available)

**For multivolume reports, substitute "volume" for "report."*

17. Key Words	18. Distribution Statement
Xxxxxxxxxxx, Xxx xx xxxxxxxx, Xxxxxxxxx, Xxxxx, Xxxxxxxxxxx, Xxxxxxxx xx xxxxxxx xxxxxxxxxx	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	000	

Figure 4.—Form DOT F 1700.7.

Documentation Page—formerly Technical Report Standard Title Page—is an adaptation of the NTIS Bibliographic Data Sheet. As required by NTIS for processing any submittal, it appears right after the front cover in every report for which the Offices of R&D are responsible. Figure 4 shows a sample of this form.

In addition, FHWA R&D reports newly available through NTIS are listed with their accession numbers in *Public Roads.* These listings are not cumulative, so it is necessary to scan back issues to find the numbers of earlier reports.

In the Offices of Research and Development, the processing of reports for submittal begins in the Offices' respective technical divisions. In each division a clerk follows an R&D Order (3) which prescribes setting up a file, assigning an *abstract number,* recording the document in a log, preparing notification post cards and copies of the Technical Report Documentation Page, and sending them with at least one copy of the document to the Receiving Section of NTIS. After 2 to 4 weeks the post cards arrive at their addresses, one of which is the originating technical division. NTIS has added the accession number and the price. At this point the clerk records the accession number assigned in the file, so that inquiries for copies after the original edition is out of print can be referred to NTIS. (In a few cases, FHWA does not actually publish the report; the original goes to NTIS, and NTIS distribution constitutes the actual publication.) Other notification cards are addressed to the DOT Library, to the editor of *Public Roads* magazine for its quarterly listing, and to others.

The Future of FHWA R&D Report Documentation and NTIS

One of the major gaps remaining in the Offices of Research and Development's report documentation is publication of a complete list or catalog, organized by subject or title as well as by author, number, or source. Such a complete catalog does not exist. The quarterly lists in *Public Roads* would constitute a continuing supplement to such a catalog. Before 1970, lists of R&D reports classified by subject were published (but not cumulated) in the annual *Highway Research and Development Studies,* predecessor of the present annual *Highway Transportation Research and Development Studies* (HTRDS). HTRDS as now published contains compilations of ongoing studies, but *not* of the reports which represent the ultimate product of the studies.

As of this writing, the Associate Administrator for Research and Development is considering this problem and has assigned members of his staff to develop a solution. One possibility is to enlist the services of NTIS, which since 1964 has been receiving FHWA R&D reports and adding them to its data bank. With its computerized resources and its experience in solving related bibliographical problems for others (e.g., a 3,800-item bibliography which it developed recently for the Environmental Protection Agency), NTIS may be able to help bring to present accessibility FHWA's R&D information of the recent past.

Another possible source for this kind of compilation is the Highway Research Information Service (HRIS), a component of the Transportation Research Board (*4*). Printouts of abstracts produced as a result of literature search requests to HRIS include the NTIS accession number when this has been entered as part of the information input. The accession number notification post card routinely goes to HRIS directly from NTIS for every report processed by FHWA Research and Development technical divisions.

The availability of at least preliminary (prototype) versions of a complete catalog in published form will depend on several factors, most importantly the success of the computerized compilation. One of the features considered most significant to the usefulness of such a compilation is the facility with which a researcher can locate and identify a particular report or group of reports. The format and kinds (for example, by author, contractor, title, etc.) of listings that best contribute to this ease of recovery ought to be ascertained before the compilation is published and made available for general use. Several limited-circulation prototypes may have to be issued to determine the best format. The objective is to issue the compilation in optimum form during 1975. The decision has not yet been made as to whether to attempt cumulative published revisions on an annual or more frequent basis, to use annual revisions with *Public Roads'* quarterly listings serving as update information, or to provide some other arrangement.

Dealing with NTIS

As might be expected, dealing with NTIS is quite different from dealing with more traditional Government agencies. A customer can place an order by mail, telephone, or Telex; the agency claims a turnaround time of 1 day in filling orders for items in stock and not requiring special searches (such as would be necessary if only the title and no identifying numbers such as the accession number are known—those take a little longer). Besides the conventional individual order prepayment method, orders can be prepaid with a deposit account—a check for $25 opens it. It is also possible to place the order and be billed, but this *ship and bill* arrangement costs an extra $5 per order. No special order form is needed, though such forms are published in NTIS catalogs.

For a particular publication, the accession number and title will suffice. If the number is not known, all other bibliographic information available (report number; authors, both individual and corporate; date; sponsoring agency, etc.) should be supplied.

A contributor will find that the requirements for reports or other publications to be submitted to NTIS make sense and are automatic for any conventionally acceptable technical report. The main additional requirement is the special title page form (BDS or RDP). Contributors working under FHWA contract or under other FHWA-sponsored arrangements, such as the Highway Planning and Research (HP&R) program, should follow *Repro Copy Requirements* and use form DOT F 1700.7 in place of the BDS or RDP. Problems may be encountered with reports of unusual format or with oversize pages that have to be folded to fit within the report covers. For further details, the reader is referred to NTIS's own published requirements (5, 6).

Identifying Reports in Highway R&D

One problem in bibliographical search peculiar to researchers in the highway R&D literature is how to identify reports arising out of specific research studies. The suggestions below may be of some help.

If budget permits, both HRIS and NTIS can perform bibliographical searches for a fee. Inquiries about these services should be addressed to the agencies directly.[4]

If this is not possible, a good first step is with positive identification of on-going FHWA-supported studies in the subject of interest. The most recent listings of such studies are *Highway Transportation Research and Development Studies 1973* (HTRDS) (*7*), and the similarly entitled 1972 edition (*8*). The information on each study—over 1,100 in fiscal 1973—includes not only the objective, title, funding, duration, etc., but also the name of the FHWA project monitor and his or her organizational location; a directory in the front of the book provides the monitor's telephone number. If a study in the subject of interest is listed in this source, an inquiry to the project monitor will yield information on the availability of published reports on the study. The project monitor may be able to supply a copy of the report; if not, he may have the report's accession number. If an accession number has not yet been issued, obtain the FHWA report number and exact title, and whatever other bibliographic information is available. If the first two items are accurate and NTIS has received the report, there should be no difficulty in obtaining a copy.

If reference to HTRDS indicates that no study has been underway during the period covered, the lists in current and back issues of *Public Roads* may be consulted to see if a report may have appeared some time ago. The "Federally Coordinated Program of Research and Development in Highway Transportation" (FCP) (*9*), which blueprints the R&D plans of FHWA for the predictable future, may also be consulted. The FCP will not help with identifying already published reports, but will indicate whether the subject is likely to be covered by a study (and subsequent report) later on.

Summary

The National Technical Information Service is the Nation's largest collector and publisher of technical information. To it more than 300 Government agencies, as well as local and State governments and some private sources, contribute over 60,000 technical documents a year. This collection of technical information is a national resource of inestimable potential value, value which becomes actual as manufacturers, service industries, and others avail themselves of it. The mission of NTIS is to make this resource available, and to support itself as it does so. The usefulness of this resource applies also in highway transportation research and development; FHWA has been supplying technical inputs to NTIS for over 10 years. Highway managers and engineers as well as highway researchers would do well to make the fullest use of this resource, the availability of which improves as new indexes and bibliographic services extend the accessibility of technical literature.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Bo W. Thott, Special Assistant, Administration, NTIS, and to the other members of the NTIS staff who generously provided him with information and source material for this article.

[4]For HRIS information, write the Transportation Research Board, 2101 Constitution Avenue, N.W., Washington D.C. 20418.

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(*4*) Paul E. Irick and Arthur B. Mobley, "HRIS Introduces On-Line Retrieval," *Public Roads*, vol. 37, No. 7, December 1973, pp. 257–261.

(*5*) "NTIS Contributor's Guide," available free from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

(*6*) "Guidelines to Format Standards for Scientific and Technical Reports Prepared by or for the Federal Government," the more complete guide, is available by stock number PB 180600 from the National Technical Information Service.

(*7*) "Highway Transportation Research and Development Studies 1973," *Federal Highway Administration*, Washington, D.C. 20590, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 for $4.50.

(*8*) "Highway Transportation Research and Development Studies 1972," *Federal Highway Administration*, Washington, D.C. 20590, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 for $4.20.

(*9*) "Federally Coordinated Program of Research and Development in Highway Transportation." Introduction and summary volume are available from the Associate Administrator, Offices of Research and Development (HRD–3), Federal Highway Administration, Washington, D.C. 20590.

Our Directors

Rex C. Leathers became Director of the Office of Development in July 1974. As Director, Mr. Leathers is responsible for utilization and implementation of the results of the FHWA research program and for the development of the practical applications of this research to highway transportation. This involves a system of field testing, a program for experimental projects under Federal-aid highway construction, operation of a clearinghouse for information on new products or systems development, mechanical and electronic shop and inspection facilities for service to other offices, operation of R&D computational facilities, conducting workshops, publication of technical research reports, and other implementation activities.

Mr. Leathers began his career with the Bureau of Public Roads in 1946 as a junior engineer in Washington, D.C. In 1952 he became a highway research engineer and from 1952 to 1956 was a research engineer for the WASHO Road Test. From 1956 to 1961 he worked on the AASHO Road Test in Ottawa, Ill., as an engineer of special assignments. He then went to Region 6, Fort Worth, Tex., as a roadway structural design engineer.

In 1964 Mr. Leathers became the Assistant Division Engineer-Engineer Coordinator in the Ohio Division. From Ohio he went to the Arkansas Division as Division Engineer in 1967, and in 1970 returned to Columbus as Ohio Division Engineer.

A native of South Dakota, Mr. Leathers holds a B.S. degree in civil engineering from the South Dakota School of Mines and Technology. From 1943 to 1946 he served on active duty with the U.S. Navy Air Corps. He is a registered professional engineer in Texas.

He received the FHWA's Sustained Superior Performance Award in 1959 and 1966 and the DOT Secretary's Award for Meritorious Achievement in 1973.

Mr. Leathers and his wife, Delores, have four children: Jeff, Lucy, Mike, and Dan. They live in Falls Church, Va.

Charles F. Scheffey, Director of the Office of Research, came to the Bureau of Public Roads in 1964 from a career of some 20 years in design, teaching, research, and consulting, most recently with the Department of Civil Engineering at the University of California, Berkeley.

He is a native of Pennsylvania and holds a B.S. degree in civil engineering from Drexel Institute of Technology, an M.S. degree from the University of California, and spent a year in Germany as a Science Faculty Fellow of the National Science Foundation engaged in advanced graduate studies, lecturing, and research on the optimum design of steel structures. Following his B.S. degree in 1943, he served 5 years in the U.S. Corps of Engineers, 2 of which were on active duty.

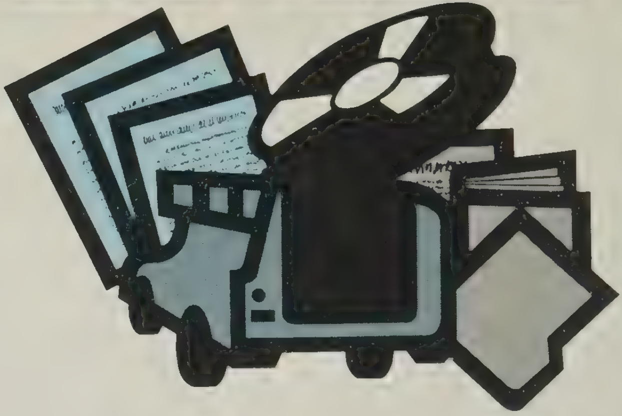
From 1948 until 1964, Mr. Scheffey was engaged as a faculty member and research engineer at the University of California. He also joined others in the formation of a consulting firm, which conducted a variety of studies on structural behavior, water quality, pressure vessel design, and computer simulation of network flows.

Beginning in 1964, he served for 6 years as Chief, Structures and Applied Mechanics Division, where he was responsible for planning and coordination of a research program of national scope on bridges, pavements, soil-structure interaction, hydraulics, and highway safety hardware. He assumed his present post on August 10, 1970, and is now responsible for a broad program of research in materials, structures, traffic systems, and environmental protection.

Mr. Scheffey is a registered civil engineer in California and is a member of the ASCE and other national organizations, and serves on committees of the ASCE, TRB, and other research coordinating bodies. In 1955 he was awarded the Arthur M. Wellington Prize of the ASCE and in 1970 he received the Federal Highway Administrator's Award for Superior Service for his leadership in the investigations of the collapse of the Point Pleasant Bridge.

Mr. Scheffey and his wife, Ella, have two boys, Carl and John.

Implementation/User Items
"how-to-do-it"



The following items are brief descriptions of selected reports which have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). These reports will be available from the Implementation Division unless otherwise indicated. Those placed in the National Technical Information Service (NTIS) will be announced in this department after an NTIS accession number is assigned.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division, HDV-20
Washington, D.C. 20590

Project Management System (PMS) Through the Use of the Critical Path Method (CPM)
by FHWA Implementation Division

In the transportation field, the job of planning, designing, constructing, and maintaining highways has evolved from a relatively simple task to a major undertaking requiring the highly coordinated efforts of all resources for proper accomplishment. Today's multimillion-dollar highway program has created situations that were previously unknown and has made the solution of previously uncomplicated problems more difficult.

Within the past several years a number of techniques have been developed to aid management. One of the most successful of these is the Critical Path Method (CPM). This method has gained wide acceptance and represents an excellent management planning and control tool for defining, integrating, and monitoring what must be done to accomplish program objectives on time.

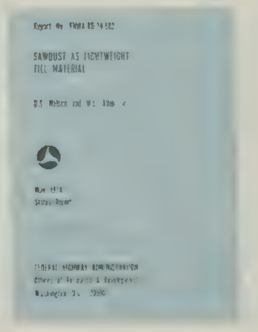
R&D report FHWA-RD-74-7 provides scheduling, cost and resource control, and information handling convenience for individual and multiproject scheduling, giving highway engineers a new management tool to help with decisionmaking. Decisions based on CPM will help the contractor overcome project management weaknesses as well as afford him such side benefits as collection, storage, and maintenance of historical data files, and the utilization of collected data for estimating and scheduling future projects.

"Project Management System (PMS) Through the Use of the Critical Path Method (CPM)," Final Report—Electronic Computer Program, March 1974, supersedes Report FHWA-RD-73-6, "Project Management System (PMS) Through the Use of the Critical Path Method (CPM)," February 1973, listed by NTIS as PB 222009.

A source FORTRAN program with sample input problem and a 35-mm slide and cassette tape presentation are available on 10-day loan from FHWA's Office of Highway Operations, Construction and Maintenance Division.

Sawdust as Lightweight Fill Material
by FHWA Implementation Division and Washington Division Office

Unstable embankments and potential slide areas have always been an expensive maintenance problem. The Washington State Highway Department recently developed a unique solution to this problem by using a lightweight waste product—sawdust. By replacing existing high density fill material with sawdust, they successfully repaired an unstable roadway section, reducing the driving weight of this potential slide by 71 percent. The slopes are sealed with an emulsified asphalt to inhibit deterioration and give the sawdust a life expectancy of at least 15 years as a stable fill. This application of a waste product appears particularly suited to secondary and county roads with unstable soil conditions where economics often prohibit major slide repair solutions.



Report FHWA-RD-74-502 is available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151 (Stock No. PB 233754; paper copy—$3.25; microfiche—$1.45).

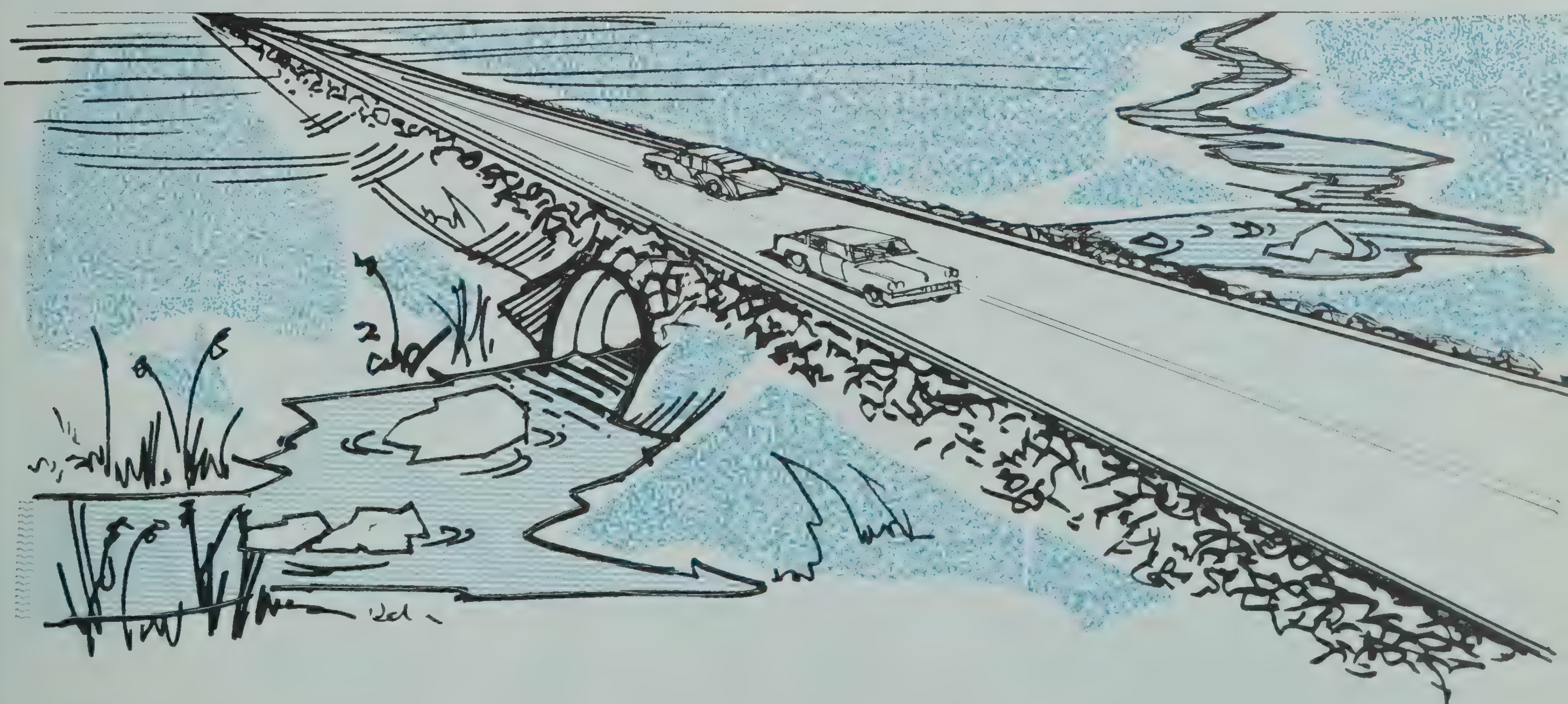
Flood Peak Estimates from Small Rural Watersheds

by Dah-Cheng Woo

The design of highway drainage structures depends on accurate estimates of flood hydrographs of streams that cross highways. This article describes the special characteristics of small rural watersheds and the Federal Highway Administration's extensive involvement in a program of small-stream gaging, data analysis, and methods development for such estimates.

Available data on rainfall and streamflow from small rural watersheds are insufficient, and the geographical distribution of streamflow data is extremely poor. These conditions greatly hamper progress toward development of accurate general methods for estimation of flood peaks from small rural watersheds for nationwide use. However, better methods for estimation of flood peaks can be developed for local use on the basis of marginal local data by researchers who know the area well.

Accurate and sound methods of estimating flood peaks from small rural watersheds must be developed. This will require action on several fronts. The current program of national rainfall and streamflow data collection for small rural watersheds should be greatly expanded. Methods of generating more adequate local rainfall data should be studied. The best stratification schemes for regional analysis should be identified and accurate regional and local models should be developed.



Introduction

Rapid growth of highway transportation in recent years has greatly increased the necessity for safer and more economical highway drainage structures. A major obstacle in the design of these structures is the lack of accurate estimates of flood hydrographs[1] of the numerous small streams crossing highways. Insufficient research has been done on this problem primarily because of the pressing need to collect data from large rivers whose floods cause severe and costly damage. Because of its close association with the problem, the Federal Highway Administration (FHWA) has been one of the major sponsors of research in streamflow estimates and of development of accurate methods for estimation of flood hydrographs of small watersheds for national and local use.

A small rural watershed, unless otherwise noted, is defined here as a watershed of less than 25 sq mi (65 sq km) in area, free of lakes and swamps, and with less than 10 percent of the area consisting of manmade deterrents to drainage, e.g., urbanization, strip mining, or reservoirs. Small rural watersheds have characteristics that are quite different from those of medium and large watersheds. Surface runoff—the portion of rainfall that is not absorbed into the land surface of a watershed—is important in small watersheds. In larger watersheds, there is a greater chance that surface runoff from heavy local rainfall will be moderated by the river channel. In small watersheds, runoff from the land surface is likely to be responsible for floods in small streams. As a result, the factors that influence land surface runoff greatly affect the magnitude of streamflow from small watersheds.

Surface runoff is basically a function of climatic and watershed parameters. Therefore, the occurrence and timing of intense summer storms, heavy spring rainfall, snowmelt, and hurricanes are some of the climatic factors that must be considered. Vegetative cover, soil properties such as thickness and moisture content, and the nature of the underlying geological formations are some important watershed characteristics. These watershed characteristics must be well defined before an accurate estimate of flood hydrographs can be established. Unfortunately, small watersheds are quite complex and varied. This fact, plus seasonal changes and temporary fluctuation of some of the parameters, renders the task of runoff prediction very difficult.

Adequate rainfall and streamflow data from small rural watersheds are necessary to develop accurate methods of estimating flood hydrographs. For economic reasons, it is impossible for the National Weather Service to cover the entire country with a dense network of rainfall gaging stations. Detailed weather data, therefore, can be obtained from only a relatively small number of key locations, sometimes called *first-order stations.* From these data, general rainfall information for an area can be derived; however, for a particular small watershed, use of local data and employment of special techniques are required to supplement this general information.

Small Rural Watershed Stream Gaging Program

Large-river data collection priorities prevent the U.S. Geological Survey (USGS) from mounting a large-scale small-stream gaging program. To fill the gap, FHWA, in cooperation with State highway departments and USGS, initiated a small rural watershed stream gaging program. Started in the early 1960's, the program was designed to develop an accurate, sound method for predicting flow frequency for any gaged or ungaged small rural watershed.

Approximately 30 States presently participate in this program under the Highway Planning and Research (HP&R) program. After USGS District offices and State highway departments select the sampling sites, USGS installs the gaging stations, collects and reduces the data, makes a detailed survey of basin characteristics, and develops a method for making flood estimates.

The maximum size of a watershed gaged ranges from 10 to 50 sq mi (26 to 130 sq km), and about 2,000 watersheds are less than 25 sq mi (65 sq km). Half of these are gaged by continuous recording gaging stations, the remainder by dual gages for recording both rainfall and streamflow data and by crest-stage gages for peak flow data only. For most of the watersheds, 5 to 7 years of data have been collected. A minimum of 10 years of data, however, is needed for meaningful analysis by USGS. For this reason, many ongoing studies should be continued. A review of the studies will be undertaken shortly to determine whether data collection at certain stations can be terminated after 10 years of data is obtained.

[1] The flood hydrograph is defined here as a graph showing, for a given point on a stream, the flood discharge with respect to time. The flood peak is the maximum flood discharge of a flood hydrograph.

Flood conditions on TH 25 north of CSAH 2. —courtesy, Minnesota Department of Highways.

Recent Research in Developing Simple Accurate Methods for Estimation of Flood Peaks

Although significant advances have been made in knowledge of basic hydrology during the past 25 years, and numerous mathematical models, both deterministic and statistical, have been proposed to deal with major hydrologic problems, practicing engineers still largely depend upon the so-called rational method[2] to estimate flood peaks from small rural watersheds. More sophisticated methods are used only if heavy economic losses might result from flooding of a small stream. These methods involve very complicated mathematical models and require the use of electronic computers, making them too costly to use for general design of small highway drainage structures. Furthermore, since most of the models were based on data from only one or two watersheds, their application to watersheds of different climatic and geographic regions often produces inaccurate results.

Therefore, there is an urgent need to develop a sound and simple method or methods for estimating floods up to a 50-year recurrence interval for any given gaged or ungaged small rural watershed in the United States. This method should use only parameters that can be easily obtained or derived from the available maps and climatic data. The final formulation should be in a readily usable, noncomputerized format. If this cannot be done immediately, possible directions for future studies should be defined.

Although the ultimate goal is to develop design methods for accurately estimating flood hydrographs, presently available data and knowledge are inadequate for such a task. Therefore, the first step is to deal with flood peaks.

Between 1967 and 1972, the FHWA sponsored totally or in part several studies in the development of better methods of estimating flood peaks for small rural watersheds. The results of the five major complete studies are reported here.

First, a national study was made to develop general methods of estimation for nationwide use. It was not successful. From this experience, two feasibility studies were carried out to investigate the possibility of developing national methods of estimation. At the same time, two local studies were successfully carried out in developing better local methods of estimation.

The national study

In the fall of 1967, the Travelers Research Corporation (TRC), now the Center for Environment and Man, Inc., conducted a national study entitled

[2] The rational method equation $Q=CiA$ states that the flood peak from a watershed of any recurrence interval can be computed by the product of the size of this watershed, A, a runoff coefficient, C, and the rainfall, i, which has the same recurrence interval as the flood peak and a duration determined by the time of concentration.

"Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds" *(1)*.[3] It had two major objectives: To assess the availability of all reliable streamflow data from small rural watersheds in the United States and to develop accurate practical methods of estimating flood peaks from small rural watersheds for national use.

A total of 493 watersheds was selected for this study from about 5,000 watersheds gaged by USGS. Criteria for the selection were drainage area of 25 sq mi (65 sq km) or less; maximum annual peak discharge values available for 12 years or more as of 1969; complete topographic map coverage of scale 1:62,500 or larger; minimal manmade controls such as diversion, regulation, and less than 20 percent urbanization; and noncontributing drainage area, such as swamps and ponds. This information, called the National Small Stream Data Inventory (NSSDI), is stored on magnetic tape that is kept at the Office of Water Data Coordination, Geological Survey, U.S. Department of the Interior. The NSSDI data contains 116 items for each of the 493 watersheds. The items cover annual peak discharge and topographic, hydrologic, climatic, and physiographic groups. Runoff hydrographs are not included in the data. Another 179 stations with peak discharge data recorded for 5 to 12 years were not used in this study but were included in the NSSDI data bank. The NSSDI data bank has since been updated and supplemented by USGS.

[3] Italic numbers in parentheses identify the references on page 122.

The TRC researchers chose the statistical approach and the stepwise screening regression technique for analysis. This technique permits the evaluation of the prediction capabilities of each predictor or variable in a stepwise fashion until the addition of another predictor does not meet a selected significance level.

Data from 395 watersheds were analyzed for development of national and stratified prediction equations, and the remaining 98 watersheds were used for verification purposes. Nine stratification studies were made and based on the criteria of mean annual precipitation, mean annual flood, 10-year 60-minute precipitation, mean annual temperature, area of watershed, mean basin elevation, soil erosion classification, geological zone classification, and geographic location of the watersheds.

The results showed that three sets of national and stratified predictions were superior to the others developed. But in preliminary tests in estimating flood peaks from independent watersheds, they were no better than 31 current highway department design procedures.

Feasibility studies

Although the TRC study did not produce accurate design methods for estimation of flood peaks for national use, it did assess and screen streamflow data from small rural watersheds, thus making the data more available for research. The study demonstrated that the data covered too short a period of time, for too few streams, in too poor a geographical distribution for meaningful statistical analysis. With the availability of the data base established by TRC, two feasibility studies were carried out independently by Hydrocomp International and Pennsylvania State University. The purpose of the feasibility studies was to test the applicability of recent technology for developing accurate general design methods for national usage.

Hydrocomp International study (2–4)—The Hydrocomp Simulation Program (HSP), a practical version of the Stanford Watershed Model *(5, 6)*, was chosen as the most potentially promising approach for developing general design methods for national usage. It was applied to 11 sample small watersheds to derive flood peak frequency curves. They ranged in area from 1.2 to 25.3 sq mi (3.1 to 65.6 sq km), and their records covered periods of 14 to 19 years from 1946 to 1969. Results were compared with those derived from regional flood frequency analysis (USGS method) *(7, 8)*, Potter's statistical procedure (Bureau of Public Roads method) *(9)*, and an arbitrarily standardized version of the rational method developed by Hydrocomp International. These three methods had been selected for comparison with the HSP method because of their popularity and superior analysis procedures.

Digital computer simulation by the HSP method appears to be better for reproducing flood peak frequency curves than the other three methods. The HSP method had the advantage of a calibration using 3 years of actual records of the watersheds, while the other three methods were applied to the watersheds as ungaged watersheds. There is no clear evidence of the superiority of the HSP method. Nevertheless, the results of this study do show that it may be possible to develop this method into a simple general method for estimating flood peak frequency of ungaged watersheds. Methods for the extension of rainfall data to overcome the effect of inadequate records should be developed. Further research should be devoted to the exploration of the HSP method and to the search for ways to apply this method by studies of larger areas, such as a State or a substantial portion of a State.

Pennsylvania State University study (10)—A practical approach emphasizing close examination of selected watersheds by field visits was employed in this study. Detailed hydrographs were studied from 134 watersheds in and around Pennsylvania and Ohio. The watersheds were smaller than 200 sq mi (518 sq km), and each had a stream record of at least 6 years. Included were some 50 watersheds less than 25 sq mi (65 sq km). Eleven small watersheds on Beaver Creek in Arizona ranging in area from 0.1 to 3.8 sq mi (0.3 to 9.8 sq km) were included in the study. These watersheds are in the volcanic high country of Arizona, which represents a climate and physiography in sharp contrast to the humid eastern region. They were selected to test the validity of methods or approaches developed from the Pennsylvania watersheds.

Unit hydrograph methods were applied to data from the eastern watersheds, but it was not possible to develop a simple single-event model for estimating flood peak frequency. Regional flood frequency analysis was then investigated, and the rational method and five other current methods *(9, 11–14)* were studied. Results show that watershed and climatic variables can be related to flood parameters by statistical techniques in producing simple, readily usable forms. The key to success of this analysis was stratification of data into hydrologically homogeneous subsamples before prediction equations were developed. It was also shown that the mean annual flood peak for an equivalent watershed with an area of 10 sq mi (26 sq km) can be used as a numerical tool for stratifying hydrologically homogeneous regions. Further research is needed to explore this approach.

Local studies

The results of the national and feasibility studies showed that development of accurate general predictive methods for national use is probably not possible because of the lack of adequate rainfall and streamflow data. Further research is needed to continue efforts made through these feasibility studies and to foster sound means of extension of rainfall data from historical records. Despite inadequate data, improvement of present local design methods is possible with marginal data if well-qualified researchers are available. They have intimate knowledge of local areas, so that the best research approach can be used to suit the nature of the available data, such as in the Pennsylvania and Michigan studies described here.

Pennsylvania State University-Pennsylvania (PSU-Pa) study (14)—A method for estimating flood peaks for local use was developed by PSU based on results of previous research studies on floods from gaged streams *(15)* and rainfall phenomena in Pennsylvania. The study was based on regional analysis and stratification of four major flood zones according to physiographic provinces. Used in the study were 117 watersheds in Pennsylvania and the adjacent States of Maryland, New Jersey, Delaware, and Ohio. They range from 2 to 200 sq mi (5 to 518 sq km) in area and include 10 to 60 years of stream records.

By the use of the stepwise multiple regression technique, mean annual flood peaks Q_a are related to physical features and geomorphic influences in each flood zone. From the analysis of series of annual flood peaks of all these watersheds, it was found that flood peaks of different frequencies could be estimated by simple multiples of Q_a for all physiographical provinces in Pennsylvania, and these multiples were almost identical for all four flood zones. Equations for computing Q_a for ungaged small rural watersheds in each flood zone and the design multiples for all four flood zones were derived.

Although the PSU-Pa method was developed from watersheds half of which range in size from 25 to 200 sq mi (65 to 518 sq km), a test on 26 watersheds in Pennsylvania less than 25 sq mi (65 sq km) in area demonstrated its superiority in flood prediction over other available methods.

University of Michigan study (16)—The University of Michigan study differs from the others described in this article by not only incorporating flood peak frequency for rural watersheds but also considering the very difficult problem of the effect of various degrees of urbanization on flood peak frequency. Because of the scarcity of adequate data, this effect has not previously been included in a practical study of flood peak frequency for a large region. The study covers southeastern Michigan, which has been experiencing intensive urbanization since the end of World War II.

The infiltration capacity unit hydrograph procedure was used as the basic approach because of its high degree of accuracy and simplicity of application after a thorough investigation of all known methods of analysis and from previous studies of Michigan watersheds. A total of 58 watersheds were studied in Michigan, Ohio, Illinois, Kentucky, Maryland, and Texas. They range from 0.02 to 734 sq mi (0.05 to 1,900 sq km) in area, including 42 that were less than 20 sq mi (52 sq km), with population density varying from 100 to 13,000 persons/sq mi (39 to 5,000 persons/sq km). A wide range of degree of urbanization was represented in the watersheds. The effect of urbanization on unit hydrograph shape was evaluated through analysis of about 1,400 storm events on all the watersheds. Infiltration values were derived from 16 southeastern Michigan watersheds.

A complete analysis of combined treatment of rainfall runoff and snowmelt flow, which had never been attempted before, was made in the derivation of final frequency curves. Use of the unit hydrograph technique and population index as a practical means of assessing the effect of urbanization was the result of previous research efforts by University of Michigan researchers during the past 10 years *(17)*. Other key innovations of this study have already been reported in major technical publications *(18)*.

A very simple method for estimating flood peaks for ungaged watersheds was produced for southeastern Michigan. Besides the population density index, the size of the watershed was the only other important parameter involved in the method. This indicates that the entire area of southeastern Michigan can be treated as a hydrologically homogeneous region. This finding is similar to the results of the PSU-Pa study.

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Our Authors

Frederick W. Cron began working for the Bureau of Public Roads (now the Federal Highway Administration) on the Mount Vernon Highway in 1928. He then worked for 28 years on the design and construction of national park roads and parkways in the East. Mr. Cron served 3 years with the Corps of Engineers in World War II, and after the war was Design and Construction Engineer for the Bureau's Philippine Division. In 1961 he became Regional Design Engineer of Region 9, from which position he retired in 1969.

Milo D. Cress is a hydraulic engineer in the Implementation Division, Office of Development, Federal Highway Administration. He is an implementation manager responsible for the identification, packaging, and promotion of items related to transportation facility location and design in the subject areas of hydrology, hydraulics, and water quality.

Everett V. Richardson is a professor of civil engineering and an administrative engineer, Engineering Research Center, Colorado State University. His major fields of interest are experimental fluid mechanics, open channel flow, fluvial hydraulics, and stream morphology. He is presently active in the study of the characteristics of turbulence in open channel flow.

William D. Whitby is a civil engineering technician in the Traffic Systems Division, Office of Research, Federal Highway Administration. He has been actively engaged in research in traffic operation and control since joining the Bureau of Public Roads in 1951. In addition to contract management duties, he is currently responsible for the control of the Traffic Systems Division input to the R&D Management Information System and the National Technical Information Service.

William M. Basham is a transportation systems engineer in the Traffic Control Programs Division, Transportation Systems Development Directorate, Transportation Systems Center. He is a systems engineer on the Federal Highway Administration sponsored Maine Facility Program. Before joining TSC in 1971, Mr. Basham was a research engineer for the United Aircraft Research Laboratory.

Peter H. Mengert is a mathematician in the Information Sciences Division, Technology Directorate, Transportation Systems Center. He works in the areas of computer analysis and statistics and has published several research papers in this field. Prior to 1969, Dr. Mengert was with the NASA Electronics Research Center and before that with Honeywell, Inc., in the fields of computer and statistical analysis and pattern recognition.

Stanley Metalitz is a technical publications writer-editor in the Engineering Services Division, Office of Development, Federal Highway Administration. He is primarily concerned with the management of the technical reports publication program in the Offices of Research and Development and is also involved with other aspects of dissemination of technical information.

Dah-Cheng Woo is a senior hydraulic engineer in the Environmental Design and Control Division, Office of Research, Federal Highway Administration. Dr. Woo was born in China and came to this country after World War II. He has been active in research in small rural watershed hydrology and urban storm drainage design and is the author of many technical papers.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R Research)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

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FCP Project 1C: Analysis and Remedies of Freeway Traffic Disturbances

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Title: Adaptation of a Freeway Simulation Model for Studying Incident Detection and Control. (FCP No. 31C1042)
Objective: Develop a microscopic freeway model to evaluate incident detection algorithms on freeways.
Performing Organization: KLD Associates, Inc., Huntington, N.Y. 11743
Expected Completion Date: December 1975
Estimated Cost: $205,000 (FHWA Administrative Contract)

FCP Project 1E: Safety of Pedestrians and Abutting Property Occupants

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Title: Urban Intersection Improvements for Pedestrian Safety. (FCP No. 31E2072)
Objective: Investigate the operational and safety problems associated with the interaction of pedestrians and motor vehicles at urban intersections. Data collection will include operational counts as well as behavioral observations. Provide the basis for the development and evaluation of remedial measures to improve the pedestrian/vehicle mix at intersections.
Performing Organization: Biotechnology, Inc., Falls Church, Va. 22042
Expected Completion Date: June 1976
Estimated Cost: $263,000 (FHWA Administrative Contract)

Title: Provisions for Elderly and Handicapped Pedestrians. (FCP No. 31E2242)
Objective: Study existing literature pertaining to elderly and handicapped pedestrians, provide an operational description of the problems they face, develop and evaluate solutions to these problems.
Performing Organization: Georgia Institute of Technology, Atlanta, Ga. 30332
Expected Completion Date: August 1976
Estimated Cost: $243,000 (FHWA Administrative Contract)

FCP Project 1F: Energy Absorbing and Frangible Structures

Title: Test and Evaluation of Barrier Concepts. (FCP No. 31F1172)
Objective: Conduct 43 full-scale crash tests and evaluations of crash cushions, traffic rails, and sign and luminaire supports. Provide T/E support for two research contracts.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: January 1977
Estimated Cost: $291,000 (FHWA Administrative Contract)

FCP Project 1H: Skid Accident Reduction

Title: Innovative Materials and Techniques for Construction and Maintenance to Insure Skid Resistant Surfaces. (FCP No. 31H1164)
Objective: Locate, classify, and field-test evaluate the various innovative skid resistant treatments currently in use in the State of California and adjacent States for their potential to provide and reasonably retain adequate levels of friction and texture. Field-test evaluate selected recommended innovative materials systems

developed under NCHRP Project 1-12(3).
Performing Organization: California Department of Transportation, Sacramento, Calif. 95819
Expected Completion Date: March 1977
Estimated Cost: $200,000 (FHWA Administrative Contract)

Title: Traffic Railing Impact; Hydroplaning Potential. (FCP No. 31H3142)
Objective: Evaluate non-contact measurement methods. Develop specifications for traffic railing impact measurement system and prototype of hydroplaning potential measurement system.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78228
Expected Completion Date: December 1976
Estimated Cost: $200,000 (FHWA Administrative Contract)

FCP Project 1K: Accident Research and Factors for Economic Analysis

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Title: Methodology for Reducing the Hazardous Effects of Highway Features and Roadside Objects. (FCP No. 31K6022)
Objective: Improve the safety and operations on highway systems by improving horizontal curve design and provisions for decision sight distance. Develop alternative strategies to reduce the frequency and severity of run-off-the-road accidents on non-freeway facilities.
Performing Organization: Calspan Corporation, Buffalo, N.Y. 14221
Expected Completion Date: December 1976
Estimated Cost: $690,000 (FHWA Administrative Contract)

FCP Project 1T: Advanced Vehicle Protection Systems

Title: Modeling the Interaction of Heavy Vehicles with Protective Barriers. (FCP No. 31T1011)
Objective: Develop and validate mathematical models for simulating both articulated and non-articulated vehicle collisions with rigid and yielding barriers or roadside objects.
Performing Organization: IIT Research Institute, Chicago, Ill. 60616
Expected Completion Date: December 1976
Estimated Cost: $416,000 (FHWA Administrative Contract)

FCP Category 2—Reduction of Traffic Congestion, and Improved Operational Efficiency

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FCP Project 2C: Requirements for Alternate Routing to Distribute Traffic Between and Around Cities—Single Diversion Point

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Title: Human Factors Requirements for Real-Time Motorist Information Displays. (FCP No. 32C1762)
Objective: Develop, evaluate, and make design recommendations for real-time driver information displays to be used on freeways and parallel alternative routes.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: January 1977
Estimated Cost: $916,000 (FHWA Administrative Contract)

Title: Motorist Aid Transceiver. (FCP No. 32C5252)
Objective: Design, fabricate, test, evaluate, and deliver a low cost engineering model of a two-way motorist aid transceiver and the associated roadside terminal unit required to provide emergency communications for stranded motorists.
Performing Organization: Honeywell, Inc., Minneapolis, Minn. 55413
Expected Completion Date: September 1975
Estimated Cost: $229,000 (FHWA Administrative Contract)

FCP Project 2D: Traffic Control for Coordination of Car Pools and Buses on Urban Freeway Priority Lanes

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Title: Traffic Control of Car Pools and Buses on Priority Lanes. (FCP No. 32D1503)
Objective: Establish guidelines for the design, control, and operation of car pool and bus priority lanes. Make field evaluations of candidate pavement marking schemes, signing arrangements, operational practices, and enforcement plans.
Performing Organization: Florida Department of Transportation, Tallahassee, Fla. 32304
Expected Completion Date March 1977
Estimated Cost: $200,000 (FHWA Administrative Contract)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operation

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FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

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Title: Cost Effective Rest Area Components. (FCP No. 33E1032)
Objective: Provide design and maintenance engineers with a handbook of component alternatives for rest areas to assist in the design, renovation, and basic maintenance of rest areas.
Performing Organization: Ultrasystems, Inc., Newport Beach, Calif. 92660
Expected Completion Date: June 1976
Estimated Cost: $189,000 (FHWA Administrative Contract)

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Transportation Systems and Regional Air Quality. (FCP No. 43F3112)
Objective: Analyze line source (highway corridor) and regional air quality models, sensitivities, and correlations involved and make pertinent measurements using five pilot locations in California.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: June 1979
Estimated Cost: $512,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4C: Use of Waste as Material for Highways

Title: Technology for Use of Incinerator Residue as Highway Material. (FCP No. 34C1062)
Objective: Develop the technology required for using municipal incinerator residue in the construction of roadway bases and surface courses.
Performing Organization: Valley Forge Laboratories, Devon, Pa. 19333
Expected Completion Date: June 1976
Estimated Cost: $203,000 (FHWA Administrative Contract)

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Methodology for Prediction and Minimization of Detrimental Volume Changes of Expansive Clays in Highway Subgrades. (FCP No. 34D1132)
Objective: For design, construction, and maintenance of highways on expansive clays and shales: Develop state of the art; delineate physiographic areas having similar soil conditions; develop methodology for prediction of performance of subgrades; develop recommendations for design, construction, and maintenance in delineated physiographic areas.
Performing Organization: Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. 39180
Expected Completion Date: July 1978
Estimated Cost: $750,000 (FHWA Administrative Contract)

Title: Development of Methodology for Design and Construction of Compacted Shale Embankments. (FCP No. 34D5012)
Objective: Identify factors responsible for rapid deterioration of shales and develop (1) techniques to evaluate the stability of existing embankments, (2) remedial treatments for existing distressed embankments, and (3) design criteria and construction control techniques for compacted shale embankments.
Performing Organization: Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. 39180
Expected Completion Date: June 1978
Estimated Cost: $800,000 (FHWA Administrative Contract)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5B: Tunneling Technology for Future Highways

Title: Drilling and Preparation of Reusable Long-Range Horizontal Bore Holes in Rock. (FCP No. 35B2072)
Objective: Assess available horizontal rock penetration techniques; propose modifications of conventional equipment for increasing the range. Present new conceptual design alternatives for developing new equipment.
Performing Organization: Foster-Miller Associates, Waltham, Mass. 02154
Expected Completion Date: December 1975
Estimated Cost: $192,000 (FHWA Administrative Contract)

Title: Management of Air Quality In and Near Highway Tunnels. (FCP No. 35B4012)
Objective: Analyze all factors involved in creating and maintaining satisfactory air quality in and near highway tunnels. Develop improved feasible air quality management.
Performing Organization: Science Applications Inc., McLean, Va. 22101
Expected Completion Date: December 1976
Estimated Cost: $309,000 (FHWA Administrative Contract)

FCP Project 5C: New Methodology for Flexible Pavement Design

Title: Development of Pavement Structural Subsystems. (FCP No. 55C2112)
Objective: Develop flexible type pavement structural subsystems utilizing implementable mechanistic techniques to analyze specific distress modes in pavement structures for various environmental, traffic, and construction conditions.
Performing Organization: Materials Research and Development, Oakland, Calif. 95814
Expected Completion Date: January 1977
Estimated Cost: $250,000 (NCHRP)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Pavement Rehabilitation Design Procedures. (FCP No. 35D2202)
Objective: Develop pavement overlay thickness design procedures for the rehabilitation of all common pavement types. Develop design procedures for eliminating or reducing the reflection cracking of pavement overlays.
Performing Organization: Austin Research Engineer, Austin, Tex. 78723
Expected Completion Date: June 1977
Estimated Cost: $264,000 (FHWA Administrative Contract)

Highway Research and Development Reports Available from the National Technical Information Service

The following highway research and development reports are for sale by the National Technical Information Service, Sills Building, 5285 Port Royal Road, Springfield, Va. 22151.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.	
PB 220826	Flexible Pavement System Computer Program Documentation.
PB 230930	Construction and Testing of an Experimental Prestressed Concrete Bridge.
PB 231998	Creep and Shrinkage Study of Concrete Made from Hawaiian Aggregates—Phase II.
PB 232541	The Use of Spectral Estimates for Pavement Characterization.
PB 232546	Highway Focus Toward an Understanding of Earthquake.
PB 232557	Transverse Joint Construction and Sealing Practices 1968–1972.
PB 232603	A Comparison of Transverse Weakened Plane Joints Formed by Sawing and by Plastic Insert.
PB 232605	Full Depth Asphalt Concrete Test Section Instrumentation.
PB 232606	Elastic Moduli Determination for Simple Two-Layer Pavement Structures Based on Surface Deflections.
PB 232607	Prediction of Long-Term Stress Ranges—Study Report.
PB 232608	Pavement Design and Performance Study—Phase B: Deflection Study, Subgrade Moisture and Temperature Variations Under Road Pavements in Virginia.
PB 232967	Dynamic Testing of Luminaire Supports.
PB 233000	California Skid Resistance Studies.
PB 233140	Performance of an Embankment Constructed on Varved Clay.
PB 233211	A Study to Determine the Feasibility of Using Remote Sensing Techniques to Prevent Ship Collisions with Selected Draw/Lift Bridges—Final Report.
PB 233253	Pendulum Tests on Transformer Bases for Luminaire Supports.
PB 233490	Prediction of Long-Term Stress Ranges. User's Manual: Bridge Load Generator.
PB 233491	User's Manual: Bridge Dynamic Stress Analysis.
PB 233506	Vehicle Redirection Effectiveness of Median Berms and Curbs.
PB 233537	Road Roughness Technology, State of the Art.
PB 233589	Structural Behavior of a Flexible Metal Culvert Under a Deep Earth Embankment Using Method A Backfill.
PB 234223	Prediction of Long-Term Stress Ranges—Study Report.
PB 234257	Test and Evaluation of Earth Berm Median Barrier.
AD 783627	Laser Measurement of Pavement Surface Textures.

MATERIALS

Stock No.	
PB 231255	Evaluation of Lignite Fly Ash as a Mineral Filler in Asphaltic Concrete.
PB 231272	Develop Improved Asphaltic Concrete Mixture Using Materials Available to Nebraska.
PB 232198	Frost Susceptibility of Massachusetts Soils—Evaluation of Rapid Frost Susceptibility Tests.
PB 232202	Determination of Cement Content in Soil-Cement Mixtures and Concrete.
PB 232604	Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair.
PB 232888	Asphalt Core Sampling and Recovery Techniques—Interim Report.
PB 232890	Further Evaluation of Deicing Chemicals.
PB 233156	Shale Suitability—Phase II.
PB 233269	A Study of Concrete Slab Jacking Slurries.
PB 233270	Evaluation of Several Types of Curing and Protective Materials for Concrete—Interim Report.
PB 233534	Soil-Cement Study.
PB 233726	Sealing Cracks in Bituminous Pavement.
PB 233757	Criteria for Seal Coating Bituminous Surfaces.
PB 233941	Methods and Parameters for the Use of Emulsified Asphalts for Prime Coat and Binders for Open-Graded Asphaltic Concrete Finishing Courses.

PB 234194 Synthetic Aggregate from Incinerator Residue by a Continuous Fusion Process—Final Report.
PB 234258 Thick Film Sensors for Moisture Measurement in Highway Materials: Report No. 1—Final Report.
PB 234328 Studded Tire Pavement Wear Reduction and Repair, Phase III—Final Report.
PB 234531 Seibert Experimental Project.
PB 234548 Effects of Retarding Admixtures on Plastic Shrinkage of Portland Cement Paste—Interim Report.
PB 234569 Field Electrical Measurements for Bridge Deck Membrane Permeability and Reinforcing Steel Corrosion.
PB 234609 Durability of Paving Asphalts: Laboratory Tests and Field Comparison—Final Report.
PB 234815 The Waco Ponding Project.
PB 234911 Laboratory Evaluation of the Response of Reinforced Concrete to Internal Vibration.
PB 234954 Skid Resistance Studies—Aggregate-Skid Resistance as Applied to Pennsylvania Aggregates.

TRAFFIC

Stock No.
PB 232091 The Evaluation of the Pass/No-Pass Highway Marking System.
PB 232134 Major Interchange Design, Operation, and Traffic Control (Complete set).
PB 232135 Vol. 1—Text of Report.
PB 232136 Vol. 3—Appendixes H–M.
PB 232137 Vol. 2—Appendixes A–G.

ENVIRONMENT

Stock No.
PB 232851 Vegetative Cover for Highway Rights-of-Way—Interim Report.
PB 233375 The Suitability of Salt Tolerant Species for Revegetation of Saline Areas Along Selected Ohio Highways.
PB 233545 Effectiveness of Bridge Pier Riprap Practice in Washington State.
PB 233751 Hydraulic Performance of Bridges— Excavations at Bridges.
PB 233938 Development of Procedures to Simulate Motor Vehicle Pollution Levels.
PB 234710 Highway Litter in Georgia.

IMPLEMENTATION

Stock No.
PB 232407 International Enquiry on Transportation Research Information Transfer—Final Report.
PB 232556 Predicting the Bearing Capacity of a Pile from Dynamic Measurements—Final Report.
PB 232609 Causes of Bridge Pier Staining—Final Report.
PB 232795 Culvert Outlet Protection Design: Computer Program Documentation.
PB 233071 1973 World Survey of Current Research and Development on Roads and Road Transport.
PB 233463 Development of a Laboratory Data System—Report 2.
PB 233551 Application of Computer Data Processing Through Automated Data Collection.
PB 233754 Sawdust as Lightweight Fill Material—Status Report.

PB 234200 Experimental Moisture Determination for Defining Saturated Surface Dry State of Highway Aggregates—Report No. 6.

PLANNING

Stock No.
PB 220515 Urban Corridor Demonstration Program, Early Implementation Phase.
PB 232452 The Economic Impact of Interstate Highway 35 on Towns in North-Central Oklahoma—1973.
PB 232528 Social and Economic Effects of Highways.
PB 233157 Community Effects of Highways Reflected in Property.
PB 233998 Urban Corridor Demonstration Program, Transit Improvement Program Evaluation.
PB 234002 Urban Corridor Demonstration Program, Environmental Impact/Section 4(f) Statement for the Reconstruction of New Cut Road.
PB 234010 A Guide to Parking Systems Analysis.

☆U.S. Government Printing Office: 1974—620-831/1

Publications of the Federal Highway Administration

The following publications are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and a new Graphical Evaluation Chart (1962), 25 cents.

Analysis and Modeling of Relationship between Accidents and the Geometrics and Traffic Characteristics of the Interstate System (1969), $1.

Bridge Inspector's Training Manual (1970), $2.50; (1971), $2.50.

Capacity Analysis Techniques for Design of Signalized Intersections (1967), 45 cents.

Corrugated Metal Pipe (1970), 35 cents.

Economics and Social Effects of Highways (1972), $1.25.

Evaluation of Potential Effects of U.S. Freight Transportation Advances on Highway Requirements (Research Phases 1 and 2), $2.75.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems (1971), 45 cents.

Federal-Aid Highway Map (42×65 inches) (1970), $1.50.

Federal Assistance Available (1971), 10 cents.

Federal Laws, Regulations, and Other Material Relating to Highways (1970), $2.50; (1972), $2.50.

A Guide to Parking Systems Analysis, $2.60.

Handbook of Highway Safety Design and Operating Practices (1968), 40 cents; (1973), $2.
Supplement No. 1 (Nov. 1968), 35 cents.
Supplement No. 2 (Nov. 1969), 40 cents.

Highway and Urban Mass Transportation (Fall 1972), 65 cents; (Winter 1972), 65 cents; (Spring/Summer 1973), 90 cents.

Highway Joint Development and Multiple Use (1970), $1.50.

Highway Research & Development Studies Using Federal-Aid Research and Planning Funds (1970), $2.50.

Highway Statistics (published annually since 1945): (1968), $1.75; (1970), $1.75; (1971), $2.85; (1972), $3.20. (Other years out of print.)

Highway Statistics, Summary to 1965 (1967), $1.25.

Highway Transportation (Nov. 1970), 65 cents; (Spring 1971), 60 cents; (Fall 1971), 45 cents; (Spring 1972), 55 cents.

Highway Transportation Research and Development Studies (1973), $4.50.

Hydraulic Design Series:
No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970), $1.25.
No. 3—Design Charts for Open-Channel Flow (1961), $1.50; (1973), $1.50.
No. 4—Design of Roadside Drainage Channels (1965), 65 cents.

Hydraulic Engineering Circulars:
No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965), 55 cents.
No. 9—Debris Control Structures (1971), 50 cents.
No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965), $1.
No. 11—Use of Riprap for Bank Protection (1967), 50 cents.
No. 12—Drainage of Highway Pavements (1969), $1.

Hydraulic Flow Resistance Factors for Corrugated Metal Conduits (1970), 55 cents.

Interstate System Accident Research Study (1970), $1.

Interstate System Route and Log Finder List (1971), 25 cents.

Joint Development Opportunities Outside the Highway Right-of-Way (1971), 20 cents.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970), $3.75.

Manual of Instructions for Construction of Roads and Bridges on Federal Highway Projects (1970), $3.25 (for use with specifications—FP–69).

Manual on Uniform Traffic Control Devices for Streets and Highways (1971), $3.50.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1970), $1.25.

Motor Carrier Safety Regulations (1971), 65 cents; (1972), 95 cents; (1973), $1.20.

National Highway Needs Report, H. Comm. Print 91st Cong., 70 cents.

The National System of Interstate and Defense Highways (1971), 15 cents.

The New Look in Traffic Signs and Markings (1972), 35 cents.

Park & Recreational Facilities (1971), 45 cents; (1972), 70 cents.

Program Documentation Urban Transportation Planning (March 1972), $6.25.

Quality Assurance in Highway Construction. (Reprinted from PUBLIC ROADS, A Journal of Highway Research, vol. 35, Nos. 6–11, 1969), 50 cents.

R&D Highway and Safety Transportation System Studies (1970), $2.50; (1971), $2.75.

Reinforced Concrete Bridge Members—Ultimate Design (1969), 45 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963), 30 cents.

Road User and Personal Property Taxes on Selected Motor Vehicles (1973), 90 cents.

The Role of Third Structure Taxes in the Highway User Tax Family (1968), $2.25.

Safety Rest Area Development (1970), $1.

Selecting Digital Computer Signal Systems, $1.05.

Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968), $2.

Standard Land Use Coding Manual (1965), 50 cents.

Standard Plans for Highway Bridges:
Vol. I—Concrete Superstructures (1968), $1.25.
Vol. II—Structural Steel Superstructures (1968), $1.
Vol. III—Timber Bridges (1969), 75 cents.
Vol. IV—Typical Continuous Bridges (1969), $1.50.
Vol. IVA—Typical Continuous Bridges Load Factor Design (1973), $1.40.
Vol. V—Typical Pedestrian Bridges (1962), $1.75.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (1969), $3.50.

Traffic Assignment—Methods, Applications, Products (1973), $2.45.

Transportation Planning Data for Urbanized Areas based on 1960 census (1970), $9.25; (1973), 40 cents.

Typical Plans for Retaining Walls (1969), 75 cents.

Urban Mass Transportation Travel Surveys (1972), $1.50.

Urban Origin-Destination Surveys, $3.20.

Urban Planning General Information (March 1972), $2.75.

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