130

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **130**

TRAFFIC DATA COLLECTION AND ANALYSIS: METHODS AND PROCEDURES

TRANSPORTATION RESEARCH BOARD
National Research Council

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TRAFFIC DATA COLLECTION AND ANALYSIS: METHODS AND PROCEDURES

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NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1986

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to traffic engineers, highway planners, and others concerned with the collection of traffic data for traffic engineering studies, for long-range planning, and for evaluation of traffic law enforcement. Information is presented on current practice in traffic data collection and analysis.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Although the types of highway traffic data collected over the past 50 years have not changed significantly, the quantities, analysis procedures, and presentations of these data have changed as a result of changing policies, operational concerns, and capabilities resulting from new technologies. This report of the Transportation Research Board describes the technology (both hardware and software) that is being used for traffic data collection, and discusses technological advances that have not yet been applied to the acquisition and presentation of traffic data.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

TRAFFIC DATA COLLECTION AND ANALYSIS: METHODS AND PROCEDURES

SUMMARY

The state of the art of highway traffic data collection and analysis is solidly based on experience and statistical analyses conducted over the past 50 years, with advances in electronic and other technology employed as they became economically feasible. The types of data collected have not changed greatly since the 1930s, although the quantities, analysis procedures, and presentations have changed as a result of changing policies, operational concerns, and capabilities resulting from new technology.

- Telemetry, inductance loops, and solid-state recording devices are generally reliable and are gaining acceptance for obtaining, recording, and transmitting traffic volume, vehicle classification, vehicle speed, and weight data.
- For coverage counts, air tubes with nonrecording mechanical accumulators remain the favored device by a wide margin because of their low cost compared to other available equipment.
- Requirements for monitoring compliance with the national 55-mph speed limit have resulted in development of equipment capable of continuous automatic vehicle classification (AVC) of vehicles where classification is based on axle arrangement.
- Weigh-in-motion (WIM) capabilities are continually improving and now provide reliable continuous vehicle weight and classification data. Recent improvements in results from instrumentation on existing bridges hold promise for extensive unobserved road section sampling at reasonable cost. AVI (Automated Vehicle Identification), using pavement sensors, transponders on the vehicle, and roadside units that read the transponder, may provide sufficient advantage to both truck operators and government to make feasible the automated monitoring of vehicle speeds, origin-destination (O&D), travel time, distance traveled, and, in combination with WIM, the automated billing of fees including weight-distance tax.
- Manual classification counting continues to be essential for planning and design data, such as vehicle and driver attributes, turning movements, occupancy, seat belt use, etc., that are not obtained by existing automated data-collection systems. Manual procedures have advantages for infrequently counted locations where installation of automated equipment is uneconomical.
- Continued development of automated procedures, using infrared, video, and pattern recognition technology has the potential for automated identification and classification beyond the capability of the human eye.
- The HPMS (Highway Performance Monitoring System) continues to improve its value in meeting federal data needs. It has improved statistical efficiency of providing data for federal policy analysis.
- Continuing efforts to develop an integrated, efficient transportation data system are needed to keep pace with the rapid advances in data acquisition technology.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The subject of traffic data collection and analysis has been a concern from the earliest days of highways. As a result, there is more literature available now than a dedicated enthusiast could read in a lifetime, and much of the recent material repeats earlier writings with or without attribution. In view of the amount that has been written, it is not surprising that many analysts facing a problem start a new study.

To help today's data users and analysts, rather than providing an extensive literature review, this synthesis emphasizes three areas. First, a fairly detailed background has been developed to show how basic procedures have evolved. Second, an effort has been made to identify early references to current procedures, such as the Petroff and Blensley (*1*) reports on ADT estimating procedures, as well as current readily available publications. Finally, current practices as reported by practitioners have been documented.

In contrast, the technology of acquiring the data has evolved by leaps and bounds during the last two decades. The general availability of computers and the development of the microchip have made possible entirely new approaches.

The use of statistical sampling procedures is documented. It was found that recent research efforts have aimed at stratification to facilitate analysis and use, rather than achieve new economies in traffic counting. For example, stratification by functional system facilitates use and credibility of the data, but reductions in counting requirements are not evident (*2*). Recent efforts to develop various stratified schemes for estimating statewide vehicle miles of travel (VMT) have demonstrated that for low-volume collector roads and local roads, accounting for more than 70 percent of total mileage, variability of counts is high and, therefore, a substantial sample is required to achieve reliability comparable to VMT estimates for high-volume roads (*3*).

Where recent research is available, particularly NCHRP efforts, the references have been used and results indicated, but an effort has been made to avoid rehashing the subjects.

HISTORY

Since the earliest days of commerce and transportation, humankind has been concerned with the numbers of people and things transported and the time and distance involved in moving them. As Deputy Associate Postmaster General, Benjamin Franklin was credited with reducing the time required to send a letter between New York and Philadelphia from weeks to overnight by 1764 (*4*). For the development and operation of the early Colonial and post-Revolutionary turnpikes, and later for canals and railroads, forecasts of traffic and monitoring of actual use (size and kinds of loads and speeds) were of concern to investors, managers, and users.

With the advent and proliferation of the automobile at the turn of the century, the first emphasis was on providing all-weather surfaces between major termini. By the depression of the 1930s the emphasis shifted to providing maximum benefit from the limited funds available for highway construction and maintenance. This, in turn, led to the Hayden-Cartwright Act of 1934, broadened in 1936, that permitted the use of 1 ½ percent of federal-aid highway funds for plans, surveys, and engineering investigations. This stimulated the "Planning Surveys" conducted by each of the states (*5*). Thus commenced the basic efforts to obtain traffic volume counts, manual classification counts, truck weight studies, speed studies, traffic operations studies, and origin-destination studies on a comprehensive basis. The Hayden-Cartwright Act gave a significant boost to the study of traffic operations and increased efforts to identify and standardize safe and effective traffic signs, signals, and markings.

Also in the mid 1930s, the War Department and the Bureau of Public Roads (BPR) identified about 27,000 miles of highways of strategic importance, later to form the nucleus of the 44,000-mile Interstate System. At the beginning of World War II emphasis was shifted to Defense Access Roads providing improved access to military installations, new factories, strategic materials, and so on. Comprehensive planning activities were deferred.

With the limited urban funds in the post World War II years, the ingenuity of city traffic engineers provided the means for obtaining optimum traffic service from existing streets. The data required for these efforts included speeds, queuing, turning movements, and highway capacity data that could be analyzed to establish generalized values applicable to a variety of situations without detailed studies of each one (*6*). Planning and research activity was intense, again concerned with optimizing the return from limited highway funds, with increasing emphasis on urban areas. The Maryland, WASHO, and AASHO road tests demonstrated the relationship between 18-kip equivalent single axle loads (ESAL) and pavement costs (*7–9*).

Efforts were also under way to improve the planning process. The largest share of planning resources were devoted to traffic volume counting. The search for increased resources for urban planning resulted in intensive study of the application of statistical sampling and other procedures to reduce traffic counting costs. Petroff and Blensley (*1*) showed that for the preponderance of road sections there was a stable relationship between the weekday traffic count on a road section and the average annual daily traffic (ADT) for the section, that these ratios tended to be similar on similar routes, and that the statistical reliability of estimated ADT values could be determined.

At the same time other studies had demonstrated the magnitude of highway deficiencies and the social and economic benefits to be derived through improvement of the Interstate System (*10–13*). The highway acts of 1956, which launched the Interstate program by providing priority funding, also required a highway cost allocation study, as well as other planning and research studies (*14*).

Cost allocation studies draw on nearly all facets of highway and traffic data. They require that costs be associated with various vehicle and highway attributes so that equitable tax rates can be developed and the costs attributable to each vehicle type can be recouped. Benefits, in terms of improved travel time, reduced operating costs, and safety improvements, must likewise be determined for analysis in accordance with a number of economic and pricing theories. The collection of the necessary data was a major effort. State planning resources were stretched to their limits.

As a result of the 1956–1962 Highway Cost Allocation and related studies, the highway user fee structure for the Highway Trust Fund was established, while design standards were established for the Interstate program. During these six years, emphasis shifted from comprehensive traffic data collection and analysis to forecasting design traffic for the Interstate sections and coping with complex social and economic problems of fitting freeways into urban areas. The concern was with establishing generalized relationships that could be used to identify and provide appropriate designs for Interstate sections that required more lanes or thicker pavement than warranted by minimum standards.

The energy crisis of 1972–1973 followed by funding shortages and associated economic problems from 1973–1980 again shifted the emphasis on data requirements and research. Resistance to IRS reporting requirements became a political issue in the 1976 presidential campaign and expanded to all government requests for data. The resulting extensive justification procedures discouraged efforts to acquire even minimum essential data, particularly where contacting individuals was necessary. Efforts were intensified to determine the vehicle and operational characteristics that maximized fuel efficiency. The wealth of previously accumulated data made it possible to develop credible estimates of the effectiveness of various proposed conservation strategies and measures.

One result was the Congressionally mandated nationwide 55-mph speed limit. This legislation required speed monitoring by all the states and has resulted in the development and funding of improved speed-measuring technology. A spin-off of this technology is automated classification data (*15*).

The fuel situation gave added emphasis to the search for more efficient low capital measures for providing mobility, while legislation permitting substitution of transit projects for urban Interstate sections led to increased effort to identify the most fuel and economically efficient options, now known as alternatives analysis. This led to the need for corridor-specific data that were comparable among modes. Dedicated lanes for high-occupancy vehicles (HOV), car pool matching efforts, and transit modifications required roadside and on-board occupancy data, travel time studies, and cost data suitable for meaningful alternatives analysis.

For the Highway Cost Allocation and Truck Size and Weight studies of 1978–1982, very detailed vehicle data were required. Fortunately there was improved understanding and application of statistical principles, data were available based on more detailed vehicle and highway categories, and there was better comparability with census data collected since 1957. Computers, software, and automated roadway and vehicle data acquisition systems had advanced substantially. These factors combined to make possible the data analysis needed for the Highway Cost Allocation and the Truck Size and Weight studies of 1978–1982 without the special data collection effort required for the 1956–1962 study.

As additional Interstate sections were opened to traffic during the late 1960s, concern with other parts of the highway network increased. The 1968 and 1970 Highway Needs Reports to Congress resulted in three shifts of significance to data requirements. First was the broadening of emphasis from concentration on the Interstate system to increased concern for all highway categories. Second was establishment of the concept of "Functional Classification" of highways, and third was a Congressional requirement for a biennial "Needs Reports" to Congress (*16, 17*). At the same time, concern with increasing accidents and fatalities attributable to highway characteristics had identified the need for very detailed highway data. The most significant result of these shifts in needs from a data point of view was the development of the Highway Performance Monitoring System (HPMS) (*18–20*).

The HPMS was based on the statistical concept that with a limited number of data items for all road and street mileage, and very detailed data for a sample of sections in each Functional Class, it would be possible to estimate a great many characteristics with considerable reliability and within reasonable costs.

As repair and maintenance of pavements became an increasing concern requiring more and more funds as materials costs rose with petroleum prices, efforts were directed at managing the problem. Efforts to improve pavement management have focused renewed efforts on determining the condition of pavements and identifying measures to maintain effectiveness at minimum cost.

Photologging, which became economically feasible in the late 1950s, is another technology that continues to develop. Video recordings and pattern recognition procedures may lead to further advances. Weigh-in-motion (WIM), developed in the 1950s, has been improved over the years. The federal funding of resurfacing, restoring, and rehabilitating pavements (3-R Program) and increased pavement monitoring efforts have provided additional impetus to WIM development (*21*). Photologging and WIM are important hardware technologies that have yet to develop their full potential, while in the procedural area the potential of HPMS has yet to be fully realized.

It is evident that traffic data were recognized as essential for effective management of highways from the beginning. Social, economic, and political forces have shaped data requirements, and there is every indication that they will continue to do so. Data needs have provided incentive for development of truly amazing and ingenious advances in acquisition and analysis technology.

SCOPE

This synthesis provides a description of the current practice in highway data collection and analysis. It also identifies state-of-the-art technology (both hardware and software) that is being used, and discusses technological advances that have not yet been applied to the acquisition and presentation of highway data. Because most WIM technology also provides automated classification and speed data, the status and capabilities of this technology receives considerable attention. In view of the recent National Cooperative Highway Research Program (NCHRP) synthesis on WIM (*21*) detail is not included in this synthesis. Planning data aid in developing, directing, and monitoring highway programs. Thus, delivery and availability of usable data is another area that was investigated.

The procedure used in this synthesis was intended to determine present practices, recent changes, and possible advances related to new technology, both highway and nonhighway. Analysis or research to develop or evaluate procedures in depth was not feasible. Therefore, the principal effort was directed toward a literature search; a survey of states, cities, provinces, and other agencies; a survey of vendors and manufacturers; monitoring of meetings and committee sessions at the TRB Annual Meeting and other meetings in the Washington area; and personal and telephone interviews. The panel members and consultants are themselves experienced practitioners in various aspects of data collection and analysis, and were effective in identifying and providing useful information and insight. Additional information was obtained from the FHWA's computerized inventory of permanent counting, speed monitoring, and WIM equipment (*22*).

DEFINITION OF TERMS

It is convenient and saves time to use specialized jargon and abbreviations. Definitions are therefore provided.

ADL Average daily load. The loading on a pavement section resulting from all vehicles in the traffic stream, computed by weighting the EAL of each vehicle by its proportion in the traffic mix; usually on an average annual daily basis. For design it may be computed by first estimating the total cumulative EAL value for the design life of the pavement and then computing the ADL that would produce the cumulative EAL.

ADT Average annual daily traffic. Customarily this is the arithmetic average of monthly daily traffic volumes (MADT) for each of the 12 calendar months, or an estimate of that value.

ALICE Automated Length Indication and Classification Equipment developed by the Transport and Road Research Laboratory, Crowthorne, U.K.

ATR Automatic traffic recorder. As used in this synthesis, ATR refers to continuous permanent count stations where equipment is provided to count and record traffic volumes 24 hours a day, 365 days a year, year after year.

AVC Automatic vehicle classifier. Equipment capable of automatically identifying vehicles of different types and recording the data. The equipment is either portable or installed at permanent locations for continuous operation.

AVI Automated vehicle identification. Equipment capable of identifying specific vehicles based on a license or identification number or symbol unique to each vehicle. Existing devices use inductive, reflective, or radio frequency technology and require the attachment of some type of identifying device on the vehicles to be identified.

CB Citizens band radio. Used by over-the-road truck operators and other drivers to communicate between vehicles.

c.v. Coefficient of variation. The standard deviation expressed as a percentage of the mean.

control section A section of road used in road inventory records such that sections break when values for control variables change. Such control variables may be width, pavement type, ADT, etc.

coverage count A traffic volume count of short duration on a road section, usually 24 or 48 hours, but sometimes as long as 7 days.

CPI Consumer price index. A value designed to indicate the relative price of a mix of consumer expenditure at a particular time compared to a base period.

DHV Design-hour volume. The hourly volume used for design purposes, usually a forecast of the 30th highest hourly volume of the design year, with trucks converted to passenger car equivalents and, for multi-lane facilities, the volume in the peak direction.

DMV Department of Motor Vehicles, or similarly named unit in each state responsible for registering and titling vehicles.

double bottom A truck or semi-trailer combination with two separate load-carrying units, such as a truck plus full trailer or a tractor unit with semi-trailer plus full trailer.

DWI Driving while under the influence of alcohol, narcotic, or other controlled substance.

EAL, ESAL, 18-kip equivalent, equivalent axle load, equivalent single axle load The relative load on a pavement (produced by a specific axle weight, group of axles, or mix of vehicles) compared to a single axle of 18,000 pounds. A kip is one thousand pounds.

18-kip equivalent *See* **EAL.**

fifth wheel The horizontal coupling plate on a truck tractor that carries the weight of the front end of a semi-trailer and provides for pivoting of the semi-trailer with respect to the tractor.

functional classification A stratification of roads and streets based on a rural, small urban, and large urban hierarchy of transportation functions ranging from "local" providing land service at the bottom, through "collector," "minor arterial," "major arterial," and "Interstate" at the top.

HPMS Highway Performance Monitoring System. The system is based on intensive and detailed data collection for a sample of road sections on each functional class, which can be expanded on the basis of mileage in each class, to provide estimates for policy planning and monitoring purposes.

HOV High occupancy vehicle. A vehicle occupied by a specified number of persons, usually three or more. Dedicated lanes for HOVs provide expedited service to car pools and buses.

kip One thousand pounds.

MADT Average monthly daily traffic. Customarily this is computed by averaging 24-hour volumes for all Saturdays, all Sundays, and all weekdays of the month, then multiplying the weekday average by 5, adding the average Saturday and average Sunday, and dividing this sum by 7.

mean The statistic of a normal distribution that is the arithmetic average of all observations.

modem Modulator-demodulator. A device for transmitting and receiving digital computer data over commercial telephone lines.

O&D survey Origin and destination survey. A data collection effort that obtains the origins and destinations of the trips in a specified area or on a specified highway link.

pattern recognition An analytical technique for associating patterns or sets of independent data with a specific dependent variable such that different data configurations or "signatures" may be identified for different dependent variables or ranges of the same variable.

PC Personal computer, microcomputer, any small stand-alone computer.

photologging The systematic photographing at uniform intervals of a road or highway and its environment and, at the same time, recording specific data about the highway. When a television camera and videotape recorder are used, it is called videologging.

reliability (or statistical reliability) The probability that a sample value will be within a specified range of the mean of a normally distributed population.

seasonal count One of a set of short traffic volume counts, usually four, one each in spring, summer, fall, and winter, at a single location to aid in grouping road sections of similar seasonal pattern for expansion of short counts to ADT.

semi-trailer combination A tractor unit with a trailer having the front end of the trailer carried by the tractor. A three-axle tractor unit pulling a two-axle semi-trailer is designated a 3-S2, with the numbers indicating the number of axles of each unit.

signature Any combination of digitized data from one or more images or transducers that can be identified as representing a specific condition or phenomenon. A particular vehicle type may produce a unique set of responses (its signature) from several different inductance loops, a coaxial cable, and a road tube that can be identified by computer and used to consistently differentiate that vehicle type from all others.

standard deviation The probability statistic of a normal distribution that includes approximately two-thirds of the cases around the mean value; abbreviated s.d.

standard error of ADT estimate The root mean square error of estimating ADT on a number of road sections used for analyzing expansion procedures.

standard error of estimate The root mean square error of a series of estimates of a value or values, customarily referring to values computed from a regression equation, compared to true values.

tape switch A device constructed from conductors and materials having variable inductance and insulating values such that when placed across a traffic lane and compressed by a vehicle tire, current flow is changed in such a way that it is possible to determine electronically the location of the tire with respect to the length of the tape.

telemetry The capability of transmission of digital data by electronic means from the source to a computer or electronic storage medium using radio or ground line.

TIP Traffic Improvement Project, a low capital modification of a roadway, employing traffic engineering modifications and improvements such as traffic signs, signals, and markings to achieve improvements in traffic operation and safety.

transponder An electronic device that has the capability of returning an identifying signal to a transmitter/receiver.

truck combination A truck and trailer; a two-axle truck pulling a two-axle trailer is designated a 2-2, with the numbers designating the number of axles on each unit.

VMT Vehicle miles of travel. One vehicle traveling one mile results in one VMT. VMT is customarily expressed as an annual total and is so used in this synthesis unless stated otherwise. VMT for a road section is the product of ADT times section length times 365. The VMT for a functional system or other category is the sum of VMT for all road sections in the system or category. Various methods are used for estimating VMT for systems, state totals, and other categories where ADTs for all road sections are not available.

WIM Weigh-in-motion; systems that use various devices and procedures for determining the weights of vehicles as they travel over the road.

CHAPTER TWO

DATA COLLECTION METHODS AND EQUIPMENT

MANUAL DATA ACQUISITION

During the early part of this century, most traffic data were obtained by manual means. Some states designated a single day of the year when large numbers of state highway department employees would "count" traffic for 8 or 12 hours, and these counts were employed for determination of trends, for planning purposes, and for highway design and operations. Speed information was obtained with the aid of stop watches, a measured course of a few hundred feet, and reflecting mirrors (Enoscope). Although most traffic data are now obtained and processed by automatic devices and computers and transmitted directly to central offices, a need remains for some manual data acquisition.

Manual acquisition of data is useful for (a) small scale O&D (origin and destination) surveys; (b) vehicle classification by body type or state of registration; (c) vehicle occupancy; (d) vehicle travel time, speed, and delay; (e) turning movements; and (f) other measurements where automated equipment is unavailable or the amount of data required is insufficient to justify equipment installation or set up.

Small-Scale Origin and Destination Survey

Area-wide O&D surveys are commonly accomplished by home interviews on a sampling basis and computerized analysis of the resulting information. Frequently, however, there is a need for small-scale O&D surveys: for example, of entering and exiting movements to a complex rotary intersection or to a series of closely spaced on and off ramps; in the vicinity of overloaded weaving sections; or around airports, stadiums, or large halls.

Such small-scale O&D surveys have been accomplished in a variety of ways: (a) by stopping traffic and passing out returnable postcard questionnaires, (b) by placing different colored tissue paper on windshields, and (c) by using license numbers.

Portable tape recorders have been used for recording license numbers, and computer programs are available for matching the license numbers. Often such surveys have recorded an insufficient number of license plate digits with resulting ambiguities in the data. For example, it may *seem* that use of three digits would be adequate to avoid nearly all ambiguities in matching license numbers. In fact, if 1000 three-digit license plate records are obtained at each of two locations, and if 200 are likely to pass both locations, there will also be about 340 spurious matches. In other words, a total of 540 matches would result, of which 340 would be wrong (*23*). (See Figure 1, but note that the abscissa is the number of vehicles *not* passing both locations; e.g., 1000 license plate records minus 200 *expected* matches equals 800 vehicles *not* passing both locations.) Use of four-digit records reduces spurious matches to 50, and use of one letter and three digits reduces them to 27.

As the proportion of vehicles passing two locations increases, spurious matches become less important. Also, use of short time intervals in matching vehicles reduces spurious matches. Hauer provides a method for correction of spurious matches (*23*).

The advantages of the license plate O&D survey include (a) no interference with traffic, (b) inexpensive for small surveys, and (c) computer matching is now possible. The principal disadvantages are that (a) as the number of locations increase, a large field crew and coding staff may be needed; and (b) computer matching of data is essential to minimize costs.

The tissue paper O&D survey's principal advantage is that the data may be obtained directly and quickly. The principal disadvantages are that (a) only a limited number of locations of origin are possible at one time, depending on the color of the "tissues"; and (b) traffic must be stopped. For the latter reason, staff requirements are slightly greater than for the license plate method.

The postcard questionnaire method's advantages are that (a) a large number of locations may be included on the postcard, depending on the planning of the study; and (b) only a limited number of locations need be manned. Its principal disadvantages are (a) traffic must be stopped, and (b) usually a low response rate and considerable manual data processing is required in addition to computerized analysis.

Another method is the recording of license numbers, which are then matched with addresses obtained from the Department

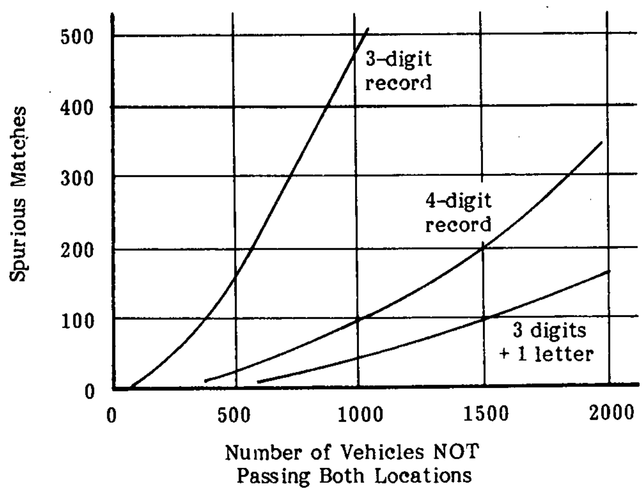


FIGURE 1 Expected number of spurious license plate matches for vehicles passing two locations (data from *23*).

of Motor Vehicles. When questionnaires are sent to the addresses, this method avoids the need to stop traffic and reduces field personnel.

There are several other methods of O&D surveys described in the Manual of Traffic Engineering Studies (*24*). These include (a) lights-on study, (b) stopped-driver interviews, (c) card pickup, (d) parked-vehicle license plates, (e) employee or resident mailed questionnaire, (f) transit-passenger questionnaires, and (g) use of available traffic simulation models.

Classification Counts

The preponderance of classification counting is done manually (Appendix Table A-5). Part of the reason for this is that some types of classification data can only be obtained by an observer. Some examples include the percentage of recreational vehicles on a highway (useful to determine the need for design or operational changes, such as climbing lanes), passenger car size (for fuel conservation analyses), vehicle occupancy (to develop or monitor car pool and HOV programs), use of full trailers (to monitor trends in use of these vehicles), and use of special equipment on trucks (e.g., drag shields and anti-splash tire flaps).

To simplify the obtaining and processing of classification data, field sheets are reproduced (*24,25*) and the counting is done with the aid of clipboards with mechanical tally counters mounted on each board. Boards are available with up to 16 tally counters and some boards are laid out in the configuration of an intersection. More elaborate devices provide keys electrically tied to electronic recording devices that record the data in computer-readable form.

One or more observers, each provided with clipboards, are stationed at locations where they can obtain a good view of the passing traffic for a distance sufficient to identify all passing vehicles. Each tally counter is identified with a particular highway lane, direction of travel, or approach to an intersection. A watch, on the clipboard, is used to determine starting and stopping time. As each vehicle is identified by the observer, the counter key associated with that vehicle is manually depressed. If the number of vehicle categories exceeds the number of tally counters, the counters are used for the most frequently observed categories and pencil tally marks are used for the others. Standard or specially designed recording forms typically provide a column for each vehicle type and line for each time period. Typical time periods are one signal cycle, 5 minutes, 6 minutes (0.1 hr.), 10 min., 15 min., or 1 hr. Under adequate observing conditions a motivated observer can accurately classify a dozen or more categories at volumes exceeding 1,000 vph for periods of two to three hours without a break, and for 8 hours with adequate breaks (*25*). The extent of manual counting by type of data is summarized in Table 1.

A variety of classification schemes are used depending on the purpose. For traffic operations and capacity calculations, four categories may suffice:

1. two-axle, four-tire
2. two-axle, six-tire
3. three-axle, single units
4. truck combinations

Sometimes just two categories are used: two-axle, four-tire and smaller; or two-axle, six-tire and larger. For the FHWA biennial truck weight data, suitable for cost allocation and other economic analysis, 16 or more categories may be observed at a typical location, and more than 30 different categories may be identified throughout the country.

The states and FHWA are in the process of establishing and implementing a standardized 13-category classification of vehicles. These categories are:

1. motorcycles
2. passenger cars
3. other two-axle, four-tire single-unit vehicles
4. buses
5. two-axle, six-tire, single-unit trucks
6. three-axle, single-unit trucks
7. four or more axle, single-unit trucks
8. four or less axle, single-trailer combinations
9. five-axle, single-trailer combinations
10. six or more axle, single-trailer combinations
11. five or less axle, multi-trailer combinations
12. six-axle, multi-trailer combinations
13. seven or more axle, multi-trailer combinations

It is stated that this meets FHWA data needs. State requirements are diverse, and a finer breakdown of many of the categories may be necessary for some states and, on occasion, by FHWA for special studies (*26*).

Some of the categories (especially 2, 3, 4, and 5) pose a problem for automated classification. At present, manual classification is the only method that can discriminate between (a) in-state and out-of-state vehicles, (b) passenger cars and pickup trucks, (c) panel vans and passenger vans, (d) trucks and buses of the same axle configuration, (e) the number of persons in a vehicle, and various other conditions that may be of concern.

TABLE 1

MANUAL COUNTING EFFORT BY TYPE OF DATA

	37 States[a]		9 Other Agencies		Total	
Data Category	No.	Person-days	No.	Person-days	No.	Person-days
Volume	16	11,020	2	210	18	11,230
Vehicle type	26	19,014	2	65	28	19,079
Turning movement	29	14,460	6	657	36	15,117
Body type	7	1,768	3	409	10	2,177
Pedestrians	12	1,542	6	476	18	2,018
Occupancy	8	209	2	405	10	614
In/out state	7	1,656	1	5	8	1,661
Seat belt use	1	2	2	30	3	32
Delay/queuing	6	83	4	65	10	148
Total[b]		44,718		11,727		56,445
Number of sites		31,105		2,020		33,125
Person-days per site		1.4		5.8		1.7

[a]"States" includes the District of Columbia.

[b]Values for individual categories do not add to the total person-days because (a) many agencies obtain data for more than one category at a time and (b) some agencies were able to provide the total person-days but not data for individual categories (See Appendix Table A-5).

In addition, an alert observer may identify new situations that have bearing on the use of the data.

There are a number of limitations on manual counting, some of which could be overcome by a reliable automated classification system. Manual classification requires adequate visibility, thus making classification counts difficult during darkness and inclement weather, except at lighted locations. Binoculars have been used successfully to classify under near-dark conditions. The presence of the counting personnel at a location where they have a good view of traffic (and thus where drivers have a good view of them) may bias results because of undesirable modifications in driver behavior. This may range from inattention to traffic to sudden slowing, which can cause backups and rear-end collisions. Bias is crucial when it is necessary to associate speeds with vehicle types. Hiding increases difficulty of observation and limits locations to those with dense bushes, billboards, or other hiding places. Typical human errors associated with manual counting include: (a) missing the stop time for an interval, (b) confusion as to lane changes and turns, (c) recording in the wrong cell, and (d) neglecting to show a critical detail of location or time on a continuation sheet. The recruiting, training, motivating, and monitoring of the count personnel is often demanding.

Vehicle Occupancy

Vehicle occupancy data are needed for monitoring the effectiveness of car pool high-occupancy vehicle programs, comparing the use of modes, analyzing alternatives, and analyzing fuel efficiency.

Occupancy data are usually collected using manual classification count procedures and equipment. Categories on the field sheet usually include: PV1 (passenger vehicle with one occupant), PV2, PV3, etc., up to PV6 or more. Higher occupancy categories may be used for passenger vans. Pickups and other small trucks may be classified by number of occupants also, while all large trucks may be counted in a single category assumed to have a single occupant.

A troublesome problem with ground count occupancy data is the high-occupancy vehicles, such as station wagons and vans. Often an occupancy is assumed for "five and more" or "six and more" because it is difficult for an observer to make an accurate count of persons in moving traffic. Although half, and sometimes more, of the vehicles in the traffic stream may be occupied by the driver only, high-occupancy vehicles are important in computing average occupancy for use in evaluations and comparisons with other modes of transportation. This can be illustrated by an example.

For the example, assume that PV1 means "passenger vehicle with one occupant," etc., and that the count is PV1 = 8, PV2 = 4, PV3 = 1, PV4 = 2, and PV5+ = 1 for a total of 16 vehicles. If the occupancy of PV5+ is actually 5 persons, then the total number of persons is 32 and average occupancy is 32/16 = 2.00. If the actual occupancy of PV5+ is 7, the total number of persons would be 34 for an occupancy of 2.125, a 6 percent error. The effect of underestimating the occupancy of the relatively few high-occupancy vehicles can be substantial as the number of vans increases. A special effort is worthwhile to obtain reliable estimates for station wagons and vans. Transit bus occupancy often requires an on-board count (*25*).

Vehicle occupancy counts are more accurate if obtained at entrances to parking facilities, but there may be uncertainty as to whether some or all passengers left the vehicle a block or two from the parking lot. This may justify special checking, driver interview, etc.

Vehicle occupancy can also be derived from home interview O&D data. Total person trips are divided by total driver trips to obtain average occupancy. There is a tendency toward higher occupancy on longer trips, so that the resulting average occupancy is low compared to an accurate roadside count or an average occupancy value based on passenger-mile per vehicle-mile. This requires that O&D driver and person trip values be weighted by trip length for each sample trip to obtain total person-miles and the corresponding vehicle-miles. This difference can bias results of an alternatives analysis, particularly where fuel efficiency in passenger-miles per gallon is derived by multiplying average occupancy times vehicle-miles.

Vehicle Travel Time, Speed, and Delay

Vehicle travel-time studies are useful in comparing different types of traffic control for benefit-cost analyses and they are helpful in timing traffic signals. Methods include (a) car floating with traffic, (b) recording of license plates (see section on Small-Scale Origin and Destination Survey), and (c) the volume/density method (*24,25,27*). The first method is useful over longer distances or near intersections. The third method (*27*) is useful only over shorter distances, especially approaching intersections. It has the advantage that a single trained observer equipped with watch and clipboard may, by using simple sampling procedures, obtain travel time on all four approach legs to a multilane intersection at the same time. The accuracy of this method is shown in Figure 2 and the "total density" is simply the number of vehicles counted during each interval on each approach to the intersection.

Spot speed studies are useful for helping to time traffic signals, set speed limits, and for other purposes. One important use has been to help determine the relation between speed and accidents as shown in Figure 3 (*28*). That figure shows that the lowest accident involvement rate occurs at or slightly above the average speed and both very low and very high speeds result in increased potential for accident. Spot speed studies may employ radar, pairs of loop detectors set in the pavement, pairs of air tubes, or pairs of temporary tape switches. Stop watches and Enoscopes are now seldom used for this purpose.

Delay studies undertaken with floating cars are especially useful because the causes of delays are important in determining whether parking restrictions, revised signal timing, or other measures are needed (*29,30*). Formerly, floating vehicles employed a driver, observer, stopwatch, car odometer, and a clipboard to obtain speed and delay information. Now, such floating vehicles are equipped with automatic recording equipment to record time and distance, and to compute speed and acceleration. Also recorded are brake movements, torque, and engine speed (*31*). Noise measurements may also be included and manual recording of causes of delay included.

Travel time and delay at intersections may be measured by using loop detectors placed in advance of the intersection and a computer program (*32*). The program calculates traffic volume, speed, density, headway, delay, and queue length. Use of the delay calculations produces some interesting findings. For example, Figure 4 (*32*) shows that both delay and queue length

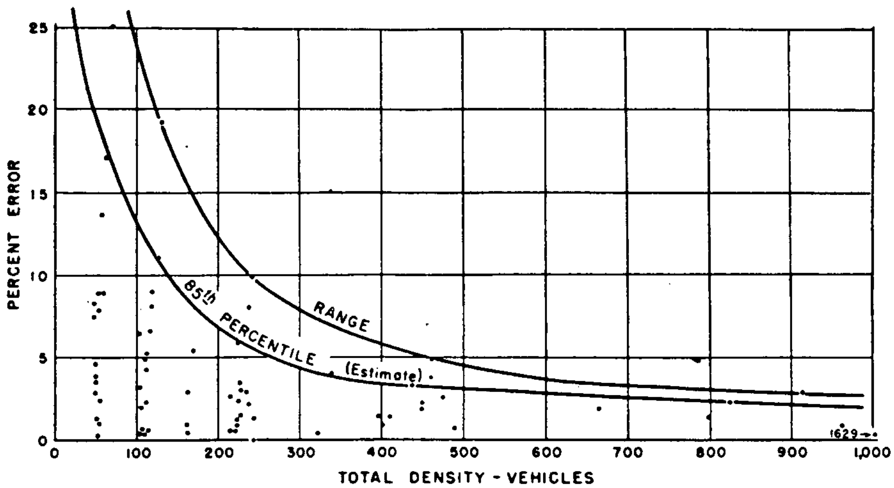


FIGURE 2 Variation of error in determining travel time with total density (*27*).

increase sharply as the capacity of an intersection is approached. Thus, operating an intersection at about 85 percent of its capacity will cut both delay and queue length in half.

Turning Movements

Information on turning movements at intersections is very important in estimating intersection capacity, determining the need for and length of speed-change lanes, designing signal timing, interpreting accident data, determining the need for and designing channelization schemes and interchanges, providing for pedestrians, rerouting trucks, and many other purposes. The importance of turning-movement data was pointed out by responses to the survey, which showed that 24 percent of all person-days devoted to visual counts by highway agencies are employed for this purpose, exceeding visual volume counts (18 percent) and second only to vehicle type on link (30 percent) (see Appendix, Table A-5).

Nearly all turning-movement data are obtained by manual methods. At times, time-lapse photography (usually one frame per second) is employed but even here manual analysis is needed. Where separate right-and left-turn lanes are available, roadway sensors and detectors may be employed to good advantage.

ROAD TUBE DETECTORS

Road tube detectors have been used since the 1920s to provide machine counts for 24-hour and longer periods. The detector consists of a rubber tube that is placed across one or more lanes of traffic. One end of the tube is sealed and the other is attached to a mechanism that is actuated by air pressure. As the tires of vehicles ride over the tube the air in the tube is compressed and the mechanism is actuated. In most counters two pulses are counted as one vehicle (*33*). Most counters are housed in sturdy weatherproof lockable metal cases with provision for chaining to trees, sign posts, or other sturdy objects.

In the simplest machine there is a register, similar to the odometer in a car, that accumulates the count. Total volume for the period is determined by noting the time and reading when the machine is set out and when it is picked up. These machines are relatively simple and inexpensive to operate and as a result they are used extensively where data by hour of the day are not required. The chief shortcomings are the complete loss of usable data if the tube is cut or another malfunction occurs before pickup and the need for setout and pickup at the same time of day when 24- or 48-hour volumes are desired. The survey indicated that more than 20 states use mechanical cumulative counters (Appendix Table A-4).

A more elaborate recording mechanism used to some extent by nearly all states includes a clock and a device for printing the time and the count every 15 minutes on adding machine tape. Usually the 15-minute counts are cumulative with the fourth one providing the hourly total and then returning to zero before starting the next hour. This device has been widely used since the 1930s. Advantages are: (a) volumes are provided for each hour, (b) usable data are often obtained even if a malfunction occurs after the machine has been set out for 12 hours or more, and (c) the count for a particular desired period can be determined even if the counter is not visited until much later. Disadvantages are: (a) the more complex electromechanical operation, (b) the requirement for a heavy battery (often an automobile battery), (c) the ink drying up, freezing, bleeding, running out, etc., and (d) the need for tedious manual analysis to determine volumes for particular periods, or the need to key and verify data for computer processing.

Several manufacturers have developed mechanisms to increase reliability, reduce weight and bulk, and automate data recording, transmission, and analysis. Punched paper tape, in place of adding machine tape, is fed through a reader that creates computer records or provides printed summaries directly, thus eliminating much tedious manual work. The readers and translators require maintenance and, with the market limited to states that have them, the incentive for manufacturers to provide spare parts is limited. In addition, unless a printed record is also provided, it is necessary to interpret the punched tape manually if results are needed in the field or if the translator is inoperative. Although it is not difficult to learn the code, errors are common (*34*).

With the advent of the printed circuit and microchip it has been possible to increase reliability and versatility of the recording systems. A major advantage has been the much lower power requirements, and elimination of recording machinery.

This has greatly reduced the weight and bulk of the machines, set-out time, and the need for field equipment checks, and has increased scheduling flexibility, the number of recording counters that can be transported by a standard pickup or van, and usable coverage counts per person-year.

The use of cassette tapes as a recording medium has provided an inexpensive and convenient method of transporting data, but with some problems with defective tapes and reading problems among different counters and readers. Solid-state recording chips eliminate the need for mechanical tape transporting mechanism, but specialized proprietary reading equipment is required. For field readings it is necessary to have portable translator-analyzers or counters with circuitry, software, and a display device.

Regardless of the reliability of the recording equipment, the road tube or other device for detecting the passage of a vehicle continues to be an essential and critical part of the system. The principal advantages of the pneumatic tube are: (a) relatively low cost, (b) portability, and (c) ability to be set out and picked up by one person with hand tools (a heavy hammer and a pry bar for driving and pulling spikes). Disadvantages are: (a) it must be kept dry on the inside and tightly sealed to prevent moisture from entering the impulse detecting mechanism; (b) it is sometimes difficult and time-consuming to achieve the proper combination of tube length and impulse adjustment so that accurate counts are obtained, particularly where volumes are high and speeds low during some hours and volumes low and speeds high during others with several lanes to be counted; (c) it is difficult to set the tubes during heavy traffic; (d) tubes are prone to ripping loose or tearing when a vehicle slides its wheels when crossing; (e) most road tubes count axles, with two impulses causing one count, so that multi-axle truck combinations may produce a count of two or more vehicles; (f) at volumes exceeding about 1,000 vehicles per hour, some impulses are simultaneous or blocked so that some vehicles are not counted, and as the volume increases the undercount proportion

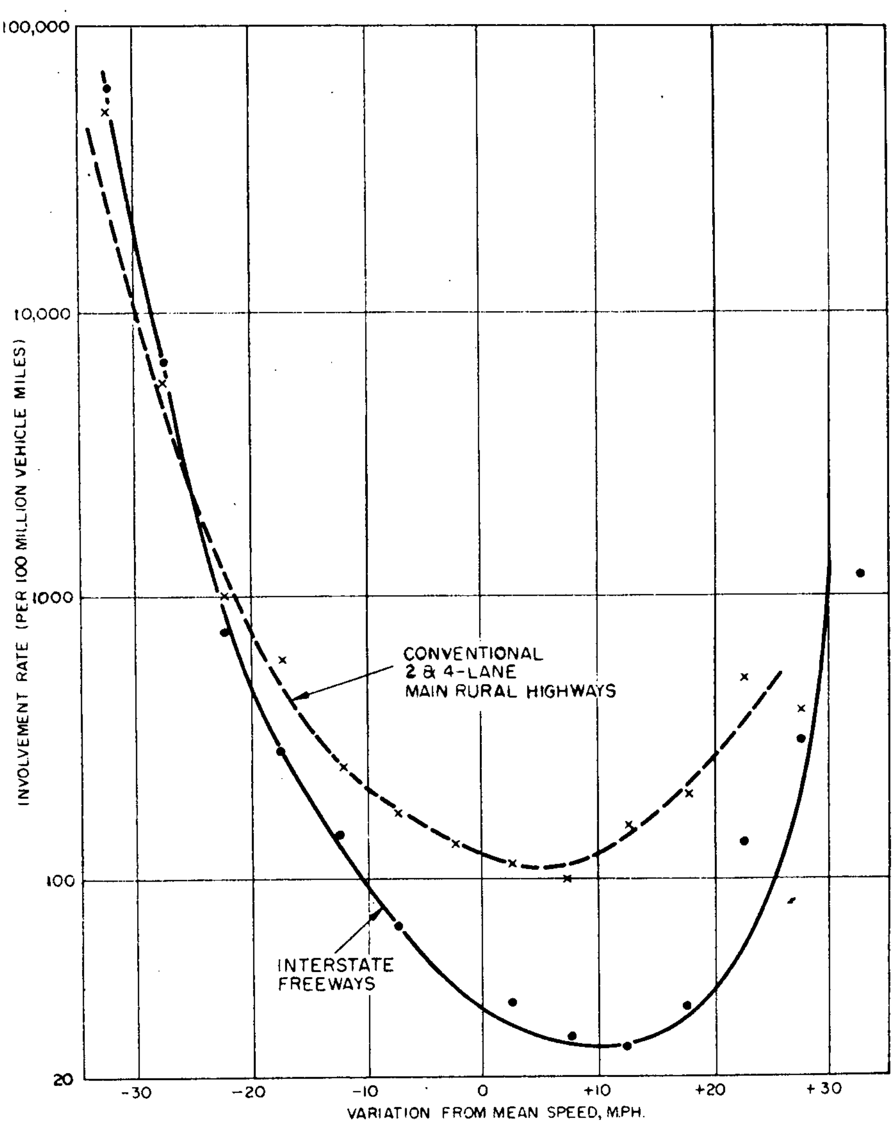
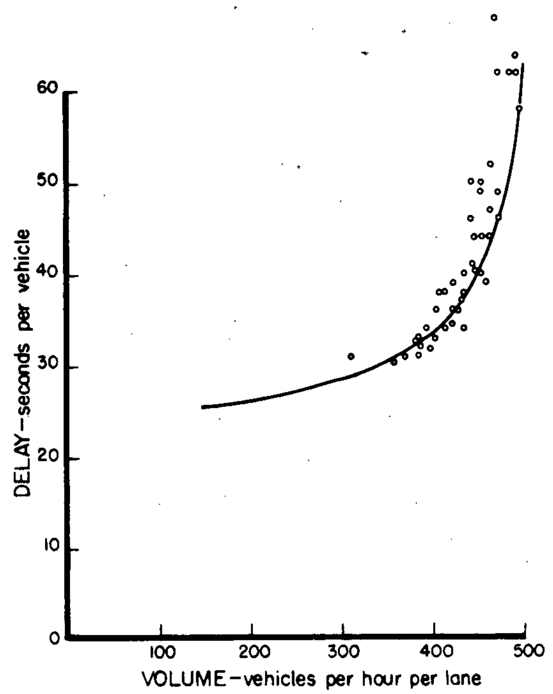


FIGURE 3 Accident involvement rate by variation from mean speed on study units (*28*).

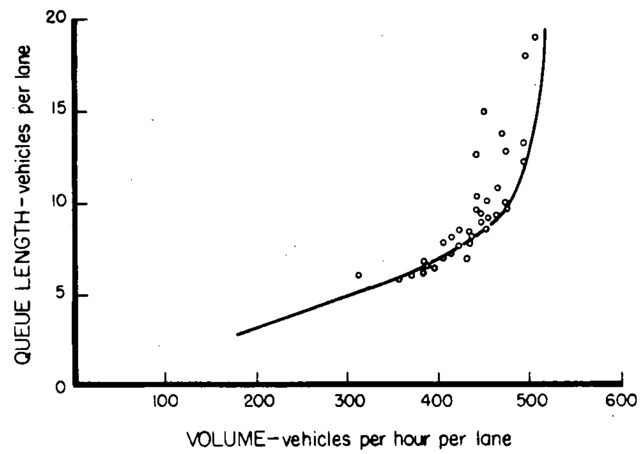
increases; and (g) for more accurate estimates, it may be necessary to conduct manual counts and develop correction factors. Because these biases are within the error of the ADT estimate, this is not usually a major concern. If a correction is not made and the data are used in estimating vehicle miles, an underestimating bias will result for the highest volume facilities, whereas low and moderate volume facilities with a high proportion of truck combinations will be overestimated.

Table 2 summarizes traffic volume count practices of states and other agencies. Approximately 98 percent of traffic volume counting machines reported by the agencies are air tube counters. Table 3 gives the number of count sites at which counts were made. Comparing the two tables shows that there are considerably more machines than count sites. Examination of the survey responses (Appendix Tables A-1 and A-3) indicate that there may be several situations that contribute to this high ratio. Some agencies have a relatively large number of machines for use in counting all lanes separately at interchanges or intersections, which are considered a single site. Others use road tube counters for long-term counts at specific locations such as entrances and exits to parks, stadiums, and other attractions during the open season. Some obsolescent road tube counters have been retained as backup.

Table 3 shows that the Interstate system, with generally higher volumes, is counted more intensively than other mileage. For the Interstate, practically all counts are directional so that two



Delay vs volume, west leg (90 sec cycle, 0.34 split).



Queue length vs volume, west leg (90 sec cycle, 0.34 split).

FIGURE 4 Delay and queue length vs. volume (*32*).

TABLE 2

TRAFFIC VOLUME COUNT PRACTICES

Item	No. of States	No. of Other Agencies	Total Users	Number of Items in Use by States	Others	Total
Air tubes	38	8	46	298,681	3,965	302,646
Inductance loops	37	8	45	3,686	832	4,518
Other (treadles, magnetometer, photocell, radar)	3	7	10	11	1,225	1,236
Total count sites and locations	38	14	52	302,378	6,022	308,400

sites would be required for each link between interchanges. In addition, entrance and exit ramps are often counted and are separate sites. The need for reliable VMT figures for federal-aid apportionment, pavement monitoring, and the relative importance of the Interstate may all contribute to these intensive counting programs.

ELECTRONIC VOLUME COUNTERS

Electric Eye

In the 1930s, "electric eyes" (i.e., photoelectric cells) were developed and used for continuous count stations. Although the technology remains, it is now used primarily for gate operation and other similar functions. A beam of light was projected across the road and reflected by a set of mirrors to a photoelectric cell. The interruption of the light beam by a passing vehicle for a preset time caused the counter to actuate. The data were recorded by electromechanical printing on adding machine tape.

Conditions for proper operation of electric-eye counters are similar to those for many permanent counters today. They include: (a) careful site selection and installation; (b) electric service; (c) an isolated location where pedestrian traffic was nil; (d) adjustment for height, to minimize double actuation caused by space between sections of a combination, or misreading owing to sun, headlights, signs, etc.

Disadvantages were: (a) the electric-eye installations were relatively expensive; (b) they tended to miss vehicles when two or more interrupted the beam at the same time; (c) they were subject to vandalism by the covering of a lens; (d) heavy rain, snow, and mud or slush on a lens caused malfunctions; (e) the adjustment of time between interruptions and duration of the light interruption for actuation was critical and variations in the speeds of passing vehicle increased the difficulty; (f) high traffic volumes, particularly on multi-lane roadways, resulted in undercounts; and (g) monthly or more frequent visits were required to collect data tapes and check for proper operation.

Advantages were: (a) with power from a utility pole it was possible to provide heat in cold weather for improved reliability, (b) the mechanisms were generally very carefully made for reliable operation over long periods, and (c) with proper maintenance and monthly visits to pick up the tapes, reliable and consistent data were obtained, thus establishing the feasibility of continuous counters.

The first 1,000 or so continuous count stations established throughout the United States during the 1930s and 1940s were predominantly of this type. Although the list of disadvantages and problems is substantial, many of them are characteristic of continuous-count stations regardless of the hardware. For example, large variations in speeds, volumes, and vehicle mix are continuing problems. Telemetry would eliminate the need for monthly or more frequent visits for electric-eye counters, just as it has for more modern types of equipment.

Magnetometer

The magnetometer probes, which became generally available for continuous-count stations in the 1950s, operate by detecting a change (induced by a passing vehicle) in the magnetic force patterns provided by the magnetic poles of the earth. These continue in use and have been found to function satisfactorily in some situations where inductance loops (discussed in the next section) do not. Customarily the magnetometer is encased in a

TABLE 3

TRAFFIC VOLUME COUNTS BY HIGHWAY CATEGORY

Item	Highway Category: Interstate	Other State and Arterials	Other Roads and Streets	Total
35 States				
Miles	27,604	366,110	1,369,769	1,763,483
Count sites	18,865	153,578	74,372	246,815
Miles per site	1.5	2.4	18.4	7.1
13 Other Agencies				
Miles	17,922	36,561	29,530	84,013
Count sites	1,500	3,621	2,032	7,153
Miles per site	11.9	10.1	14.5	11.7
All 48 Agencies				
Miles	45,526	402,671	1,399,299	1,847,496
Count sites	20,365	157,199	76,404	253,968
Miles per site	2.2	2.6	18.3	7.3

metal or plastic cylinder $1\frac{1}{2}$ to 2 in. in diameter and about 2 ft long and tightly sealed with waterproofing. The two leads are also sealed and insulated (*35*).

Advantages of the magnetometer are: (a) it is an electronic device that requires no mechanical impulse sensor; (b) it detects vehicles rather than axles; (c) it can be tuned to detect vehicles having a wide range in size, from bicycles to truck combinations; and (d) with permanently installed conduit under the pavement it can be easily removed for repair or transfer to other sites.

Disadvantages of magnetometer probes are: (a) leads must remain absolutely dry as any change in impedance causes malfunction; (b) sensitivity to small variations in field characteristics, such as those caused by discarded metal objects or changes in ambient electrical fields, may require frequent recalibration; (c) it is important that sites be well drained because changes in ground water level are believed to require recalibration in some instances; and (d) access on the shoulder for removal is usually necessary so that probes can be removed for resealing and calibration (*35*).

Inductance Loops

The inductance loop consists of a loop of heavy wire buried about 1 to 2 in. below the pavement surface with a separate loop in each lane. Typically the loop occupies 6 to 8 ft of a 10- to 13-foot lane and extends 30 inches in the direction of travel. The loops are placed by using a concrete saw to cut grooves in the pavement of the desired depth, fitting in the wire or cable, and sealing it with a mastic. Each end of the wire extends out to a junction box or the counter housing where it is connected to the terminals of the recording mechanism (*36*).

In operation, a voltage is applied to the inductance loop so that a magnetic field is created, as compared to the magnetometer, which depends on the earth's magnetic field. A mass, particularly of metal, passing through the field causes a change in voltage that can be detected and measured. The change in voltage over a short time interval can be observed on a cathode ray tube. The circuitry is designed to analyze the shape of the trace, including the space between peaks, their height and duration, so that patterns representing vehicles in the traffic lane can be sorted out from spurious signals (*37*).

The advantages of the inductance loop are: (a) it is suitable for almost any location; (b) it is resistant to vandalism; (c) it is probably the simplest of all permanent-type systems to install; (d) it is suitable for either battery power or standard 110 V A.C.; (e) the loops, as an integral part of the pavement, are reasonably durable; (f) unlike air tubes, which count axles, the inductance loop consistently counts vehicles in a wide range of sizes, from a motorcycle to truck combination, as one vehicle; (g) by having properly placed loops in each lane, over or under counting is minimized in comparison with road tubes, even at high volumes and variations in speed; and (h) once installed, portable recording equipment can be conveniently and safely connected and disconnected so that inductance loops are suitable for seasonal or coverage count locations.

The principal shortcomings of the inductance loop are: (a) careful location, installation, and frequent tuning are required to ensure that the magnetic field is responsive to vehicles of various sizes in the intended traffic lane; (b) magnitude of current flux must be maintained within calibrated limits; (c) when tuned for small vehicles such as motorcycles, trucks in an adjoining lane may be recorded; (d) calibration and sensitivity are influenced by the number of turns, lead-in wire size, conduit (length, type of material, and configuration), metal in the roadway (reinforcing, underground pipes, an accumulation of beer cans, etc.), and circuitry characteristics; (e) lane closure is required for installation; and (f) failing or substandard pavement usually causes the failure of loops and count operation. Many of these problems are more closely associated with traffic signal actuation than with loops used for counting. As with most count systems, it is desirable to select sites where traffic speeds do not vary greatly, where lane changing is at a minimum, and where there is adequate space for safe access to the control box (*38–40*).

Reported Use of Counting Equipment

Survey data indicate that there are more than 4,500 inductance loop traffic count sites (Table 2) and more than 1000 speed monitoring sites (Appendix Table A-7) using inductance loops. There may be some overlap because the speed monitoring data include a volume count for the site. Based on these numbers, it appears that practically all continuous count sites now use inductance loops.

Response from 37 states indicated that there were more than 156,000 sites at which mechanical accumulators were customarily used for counting (Table 4). The four types of equipment capable of recording by hour or other period are used at more than 50,000 locations. Table 5 shows that a one-hour recording period is used most extensively where available. With the advent of the new small solid-state counters, it may become economical to use such equipment for coverage counts. The saving in lost counts, elimination of errors resulting from manual keying, and earlier availability of analyzed results may offset the higher initial cost of equipment.

CLASSIFIERS AND SPEED-MEASURING EQUIPMENT

Vehicle classifiers and speed-measuring equipment are discussed together because the latest equipment for automated classification also obtains speeds. This electronic equipment was developed and marketed primarily to provide for speed monitoring as required for implementing the nationwide 55 mph speed limit. The equipment senses axle number and spacing, thus providing a classification count of vehicles having various axle configurations. In earlier years various other equipment was developed to aid in both classification and speed measurement.

Automated Vehicle Classification and Speed Monitoring

Automated equipment is favored because it can operate continuously for a long period and because it is consistent in recording what is sensed. Most existing automated classification is based on sensing the passage of axles at two closely spaced locations along the road. A spacing of 44 ft was used in the 1930s through the 1950s when air tubes were used as axle detectors. The distance traveled in 1 sec at 30 mph is 44 ft and such spacing, or a multiple thereof, aided manual calculation.

TABLE 4

TYPES OF TRAFFIC VOLUME COUNT RECORDING EQUIPMENT AND NUMBER OF SITES AT WHICH EACH TYPE IS CUSTOMARILY USED

	Number of Sites		
Item	35 States	9 Other Agencies	Total
Mechanical accumulators	156,736	121	156,857
Printed tape	25,734	1,320	27,054
Punched tape	19,275	2,801	22,076
Cassette tape	3,232	93	3,325
Solid state	1,554	978	2,532
Other (photo, video)	65	43	108
Total	206,596	5,356	211,952

An error of 1 ft caused by the rubber tube bouncing back and forth amounted to less than 2.5 percent and was considered acceptable. At low traffic speeds, a vehicle's speed sometimes changed within the spacing, and the spacing between vehicles was sometimes less than 44 ft. Both of these factors caused erratic data.

Modern equipment uses spacing of about 6 ft or less, making it feasible to correctly identify all axles of a multi-axle vehicle (*41*).

Automated equipment measures vehicle speeds and determines number of axles and their spacing. Because the majority of vehicle classifications are based on axle arrangement, this provides speed distribution data by vehicle type.

The 13 FHWA vehicle-classification categories were selected partly on the basis of commercially available automated classification equipment. Tests of this equipment showed that acceptance logic could be developed to correctly classify 90 to 95 percent in each large truck category. Because spacing and number of axles are the criteria for classification, passenger cars, light pickups, and vans are grouped together based on 10-foot spacing. Similarly, two-axle six-tire trucks are included with large pickups and vans (*42*).

Equipment has been tested that uses inductance loops, a "tape switch," and an algorithm to determine the height or mass of the vehicle and the track of the vehicle. (Details of the algorithm were not available when this synthesis was prepared.) This makes differentiation possible between autos with trailers and large combinations having similar axle configuration. Differentiation between dual tire and single tire, and between wide track and narrow track will improve the proper identification of large passenger vehicles and small trucks. Tape switches and coaxial cables that can make these measurements have been developed, but they are short-lived under traffic.

Some automobiles and vans are so nearly alike in wheel arrangement and size that it is sometimes impossible to differentiate between them with currently available automatic equipment. In addition, the difficulty of tuning the inductance loops to detect mopeds and light motorcycles and not detect vehicles in adjoining lanes continues to be a problem. The placement of the tape switch is also critical. At some installations it has been glued to the road surface. Because it is about ½ in. high it is conspicuous and subject to damage if vehicle wheels skid over it. A more durable method of installation is to glue it in a slot that positions it just below the road surface. A satisfactory arrangement was found to be two inductance loops 1.35 m (52 in.) × 2.8 m (109 in.) spaced 200 mm (7.8 in.) apart. In TRRL research, an axle detector was placed between the two loops. The resulting data were fed into a microprocessor. The analysis provided speed, axle spacing, overall wheelbase, front and rear overhang, and overall vehicle length (*41, 43*).

Vehicle Classification and Speed-Monitoring Practices

Table 6 shows that radar and spaced inductance loops each account for about 38 percent of the speed-monitoring devices in use by the states, although among other agencies radar is by far most often used.

Table 7, based on FHWA data for states only, shows that from 1984 to 1985 speed-monitoring installations using loops tied into A.C. utility power increased from 448 to 461 while tubes nearly doubled. From the equipment data obtained from the survey (Appendix Table A-7) it may be inferred that many A.C. utility connected installations are capable of continuous operation and can provide volume and vehicle classification, as well as speed. The 1,974 battery-powered loop installations usually have permanently installed loops and the battery-powered recording mechanism is moved from one location to another.

Table 8, which is based on FHWA data reported by states, shows that 20 states were using automated vehicle classification in October 1985.

TABLE 5

USE OF RECORDING INTERVAL OPTIONS

Item	35 States	11 Other Agencies	Total
Use of Optional Time Intervals			
Frequently	1	1	1
Occasionally	10	0	10
Rarely	20	8	28
Never	4	2	6
Not available	2	0	2
Intervals Customarily Used			
1 hour			
Usually	27	6	33
Sometimes	6	0	6
Never	1	3	4
15 minutes			
Usually	3	3	6
Sometimes	20	3	23
Never	10	4	14
Cumulative (set-out to pick-up)			
Usually	17	0	17
Sometimes	3	3	6
Never	14	6	20

TABLE 6

SPEED MEASURING EQUIPMENT USED FOR MONITORING (NOT ENFORCEMENT)

Item	37 States		9 Other Agencies		Total	
	No.	%	No.	%	No.	%
Radar	1,014	38.0	1,149	69.1	2,163	49.9
Spaced air tubes	579	21.7	2	0.1	581	13.4
Spaced inductance loops	1,039	38.9	37	2.2	1,076	24.9
Other	37	1.4	475	28.6	512	11.8
Total	2,669	100.0	1,663	100.0	4,332	100.0

LATERAL POSITION

At least three methods have been used to obtain lateral positions of vehicles: detectors on the roadway, detectors placed in moving vehicles, and the use of aerial photographs. Detectors on the road were used in the 1930s and 1940s by the forerunner of the Federal Highway Administration and by some states and universities to obtain information on the lateral position of vehicles in lanes and as affected by roadside objects to aid in the design of highways. Indeed, the present standardized width of lane (12 ft) was developed with the aid of these studies.

The current use of tape switches for lateral placement measurements utilizes one switch stretched across the traffic lane at right angles to the direction of traffic and a second switch at a 45-degree angle beginning a few feet beyond the first switch. The time differences between the passage of the left and right front tires of the vehicle over both switches is used as the measure of the lateral position of the vehicle. This method is reliable and very precise. This principle can be used to determine tread width also. Under high-volume freeway conditions and a reasonable proportion of trucks, these tape switches will stand up to traffic for two to three days in dry weather if they are properly placed on the pavement. Thus for short-term studies they are adequate and need to be renewed only once for before-and-after studies (*44*).

Lateral position may be obtained from the same aerial photographs used for acceleration-gap headway studies using the coordinate system. An example of the use of aerial photography for lateral position of buses is described in a report by Daniels and Adams (*45*). They used cameras mounted atop an overpass over the New Jersey Turnpike to obtain lateral positions of 96 in. and 102 in. wide buses traversing the Turnpike. Here the precision of measurement was extremely important because of the small differences in width of the buses of interest. The study showed that in general both 96 and 102 in. wide buses centered themselves in the lane so that the decrease in clearance to other vehicles was caused primarily by the added width of the bus, which is 3 in. on each side. Also, there was no difference in variation in placement within the lane for the 96 and 102 in. wide buses.

Measurement of lateral placement for moving vehicles has been accomplished in Australia and elsewhere with the aid of cameras or video cameras mounted atop moving vehicles (*36*). These cameras scan a white edge line or center line and the angular displacement from the center line is translated in terms of lateral displacement of the vehicle from that particular line. These data, together with speed and distance data, can be used to calculate gaps, headways, and other typical measurements for moving vehicles in conjunction with the lateral placement of the vehicle as affected by various traffic conditions.

TRUCK WEIGHING

A reasonably accurate frequency distribution of the axle and gross weights of trucks has long been essential for cost-effective planning, design, and operation of the nation's highway systems. Such information is needed to establish priorities for highway construction, thickness of pavement structures, design loadings and resultant designs of bridge superstructures and substructures, and frequency and thickness of pavement resurfacing. When coupled with information on available truck power, weight information is employed to determine highway gradients and need for climbing lanes. Weight information is also used to compute truck accident rates and allocate highway taxes equitably. For example, weight and travel information for heavy trucks was used to compute mileage-based accident rates for various weights and types of trucks. These data showed that, for all weight classes, doubles or twin trailers have a higher accident involvement rate than singles, and empty trucks have higher rates than loaded trucks (*46*).

With the coming of the industrial revolution it became desirable to develop large platform scales that could weigh an over-the-road vehicle, a team of horses, and a wagon. By the time motor trucks were in use, large platform scales were available for weighing trucks loaded with grain, coal, gravel, and other commodities. By weighing the vehicle when empty to determine the tare weight, it was possible to determine the weight of the commodity carried. These scales used knife edges for balancing with a series of lever arms and counterweights to determine the weight. A true and rigid foundation was required, and, while accurate, they were expensive. Usually they were maintained by a dealer in grain, coal, etc., and could be used by others for a fee.

TABLE 7

SPEED MONITORING DEVICES IN USE BY STATES (FROM FHWA DATA)

Power Source	Loops		Tubes		Total	
	No.	%	No.	%	No.	%
October 25, 1984						
A.C. (utility)	448	16.2	0	0.0	448	16.2
D.C. (battery)	1,974	71.2	349	12.6	2,323	83.8
Total	2,422	87.4	349	12.6	2,771	100.0
October 29, 1985						
A.C. (utility)	461	24.6	0	0.0	461	24.6
D.C. (battery)	547	34.5	670	35.8	1,317	70.4
Solar	94	5.0	0	0.0	94	5.0
Total	1,022	64.2	670	35.8	1,872	100.0

TABLE 8

CHARACTERISTICS OF AUTOMATED VEHICLE CLASSIFICATION EQUIPMENT AND SITES (FROM FHWA DATA, OCTOBER 1985)

Type of Detector	Year	States Using	Units No.	Units %	Sites[a] No.	Sites[a] %	Sites per Unit
Air tubes	1984	10	157	66.3	3,440	92.1	21.9
	1985	12	303	55.2	3,491	91.1	11.5
Inductance loops	1984	6	43	18.1	37	1.0	0.9
	1985	5	91	16.6	80	2.1	0.9
Tube and loop	1984	1	6	2.5	20	0.5	3.3
	1985	1	6	1.1	20	0.5	3.3
Tube and tape switch	1984	1	31	13.1	240	6.4	7.7
	1985	2	149	27.1	241	6.3	1.6
Total	1984	16	237	100.0	3,737	100.0	15.8
	1985	20	549	100.0	3,832	100.0	7.0

[a]Sites may be understated because some states did not report sites and portable equipment can serve many sites.

It was generally considered impractical to direct vehicles to one of these scales for enforcement or weight surveys, although where scales were located on a main truck route, this was sometimes done. Because enforcement and survey weighing was concerned with the weight of each axle, it was necessary to obtain a separate reading as each axle came on to the platform. This was time-consuming because most scales required the manual adjustment of two poises.

Static Weighing

With the Hayden-Cartwright Act and the intensified planning survey activities of the late 1930s, Load-O-Meters were developed and became commercially available. These were small platforms about 2 ft square, 3 in. high, and weighing about 40 lbs that could be placed in front of the vehicle wheel with a 2 or 3 ft wedge-shaped ramp so that the vehicle could drive up on to it. Inside the "loadometer" as it was known, was a heavy spring steel lever that the operator gradually deflected by turning a small geared crank until the wheel was barely lifted. The weight determined by the number of turns was read from a dial in the machine to give the wheel weight directly, although not as accurately as provided by a platform scale. With a crew of 4 to 10 and 4 or 5 loadometers so that all the wheels on one side of a combination could be read simultaneously, it was possible to weigh at the rate of 1 vehicle per minute, or better. The wheel weights were doubled to obtain axle weights. From the mid 1930s this was the procedure used for annual "Loadometer Surveys." For survey operations at a number of locations it is often the only feasible and economical procedure for obtaining planning data that associates axle weights with ownership and operating characteristics (*47*).

For enforcement purposes on truck routes, segmented platform scales were developed that weigh all axles of a combination simultaneously. Over the years these scales have been automated to provide dial readout, printed weigh tickets, and computation of axle group configurations to identify violations based on single axles, axle groups, and gross weight. This equipment is often installed at weight enforcement stations on the Interstate, and where feasible, on other truck routes also. Where feasible and available, enforcement stations on the Interstate and on other truck routes are used for the biennial weight survey, but loadometers or other portable scales are used for weight surveys on most non-Interstate routes (*48*).

The aircraft industry developed load cells with electrical strain gages for weighing each wheel of an airplane for use in determining center of gravity and total weight. These could be calibrated to provide reliable static weights. As this technology became widely available after World War II, highway scales based on electronic strain gages were developed that could feed data directly to a computer or microprocessor so that weights and violations could be determined almost instantly.

The advantages of static weighing are: (a) very accurate and precise weights can be determined; (b) with the vehicle stopped, it is possible to obtain precise dimensions; (c) other characteristics of the vehicle, such as turbo charger and anti-skid brakes, can be determined; (d) the driver can be interviewed to determine origin/destination, private or for-hire, commodity for some vehicle types, etc. (these data can then be associated with the axle weights of the vehicle and its routing); and (e) portable scales are often the only economical means of obtaining weight survey data on low-volume and bypass routes.

The main drawback to static weighing is that vehicles must be stopped. This is expensive for the truck operators. Disadvantages are: (a) a special site is often necessary so that the operation can be conducted safely with respect to the weigh crew, the trucks, and the remainder of the traffic; (b) the number of sites are limited and become well known to truck operators who plan any overweight operations to bypass the scales or travel when the scales are closed; and (c) adequately designed weigh stations require additional right-of-way and are expensive to establish and operate. Where loadometers are used, additional disadvantages are: (a) weight readings are time-consuming and subject to error; (b) they are a hazard to the field crew because of shifting loads, off-track wheels, and weak tires; (c) the shifting and placing of scales and ramps is physically exhausting; and (d) a large crew is required.

Weigh-in-Motion

A separate NCHRP synthesis is available entitled *Use of Weigh-in-Motion Systems for Data Collection and Enforcement* (*21*). Therefore, this synthesis gives only a brief overview of WIM.

Until 1950, fixed platform scales and portable wheel weighing devices (loadometers) were used by state highway departments to obtain weight information. Beginning with the pioneering research of Normann and Hopkins of the Federal Highway Administration in 1950 (*49*), systems to weigh vehicles in motion (WIM) began to augment fixed scales and loadometers (*50, 51*).

In 1975, the Federal Highway Administration's Federally Coordinated Program of Research and Development showed that it was feasible to employ highway bridges to weigh vehicles in motion (*50, 52*). In recent years, increasing use has been made of bridges to weigh trucks (*51, 53*).

WIM systems are also used to sort likely overweight vehicles for enforcement purposes; at present their precision is not sufficient for direct enforcement applications. Platform or portable scales are employed to confirm overweight vehicles and resulting specific enforcement actions.

WIM systems in use in the United States include slabs or plates with strain gages or other types of load cells to measure loads, capacitive mats, strain gages attached to bridges, and piezoelectric cables set into slots in the roadway. FHWA data show that as of January 1987, WIM equipment was in operation in 44 states (Table 9)(*54*).

Advantages of WIM operations are (a) most overweight vehicles do not bypass monitoring sites because vehicles are not stopped and operations can be conducted without personnel or equipment in view of truck drivers; (b) a large sample of weighed vehicles is obtained representative of all vehicles in the traffic stream and properly defined seasonal, hourly, and other time-related relationships can be obtained; (c) there is minimal hazard to the operating personnel and passing traffic; (d) data are read directly into computer storage, thereby eliminating human error, permitting immediate analysis for legal vehicles to be bypassed at enforcement scales, and providing an immediate indication of bridge formula overloads and other excesses; and (e) the axle weights obtained are the actual dynamic forces applied to the pavement as the vehicles travel at highway speeds and may be more useful than static weights for pavement design and monitoring.

Disadvantages of WIM operations are (a) information on driver and vehicle attributes requiring interview or close examination is not obtained; (b) weights of individual vehicles and axles are different from weights obtained by static weighing raising a question of accuracy; (c) except for instrumented bridges, a permanent installation may cost $10,000 per lane at each site (this is feasible for truck routes requiring operation one or more times each year, but not for low-volume sites operated once every three to five years); (d) instrumented bridges, although most economical and least conspicuous, tend to be less reliable and consistent; (e) portable WIM transducers require placing a mat on the pavement, thereby heightening the awareness of knowledgeable drivers; (f) existing road test data correlating pavement performance with axle weights is based on static weights and there may be reluctance to accept the weights of moving vehicles for design, and (g) a certain proportion of unusable data results from vehicles straddling lanes and from other erratic driving.

VEHICLE DIMENSIONS

Vehicle dimension data are of concern for several reasons. Vertical clearance for vehicles passing under structural members, horizontal clearance, overall length, wheelbase, and overhang are all of concern. The federal-aid regulations of 1916 provided that bridges, viaducts, and underpasses would have clear width of "16 ft and clear head room of not less than 14 ft for a width of 8 ft at the center" (*5*). Length and width are related to pavement and shoulder width, design of interchange ramps, parking spaces, toll booths, and for enforcement of length and width limits.

TABLE 9

WIM EQUIPMENT IN USE (JANUARY 1987)

State	Equipment Type[a]	State	Equipment Type
Alabama	GR, RAD	Minnesota	IRD, SR, Piezo
Alaska	GR	Mississippi	GR, RAD
Arizona	GR	Missouri	GR
Arkansas	SR	Montana	GR
California	S-A, SR	Nevada	RAD
Colorado	GR	New Mexico	RAD
Connecticut	SR	New York	GR
Delaware	S-A	North Carolina	BWS, GR, WW[b]
Florida	GR, IRD, RAD	North Dakota	SR
Georgia	RAD, SR	Ohio	BWS[b], SR
Hawaii	S-A	Oklahoma	RAD[b]
Idaho	BWS[b], GR, RAD[b], S-A[b]	Oregon	IRD, BWS
		Pennsylvania	S-A, SR
Illinois	GR, SR	South Dakota	GR, c
Indiana	SR	Tennessee	SR
Iowa	BWS, Piezo	Texas	RAD, SR
Kansas	BWS	Utah	BWS[b]
Kentucky	GR, RAD[b]	Virginia	RAD[b]
Louisiana	RAD	Washington	BWS, S-A, Piezo
Maine	IRD, c	West Virginia	SR
Maryland	BWS, SR	Wisconsin	BWS, IRD, SR
Massachusetts	S-A	Wyoming	GR, RAD
Michigan	IRD, WW	Canada	IRD

[a]BWS = Bridge Weighing Systems
GR = Golden River
IRD = International Road Dynamics (CMI-Dynamics)
Piezo = Piezoelectric cable
RAD = Radian Corporation
S-A = Siemens-Allis (PAT)
SR = Streeter Richardson
WW = Weighwrite (CMI-Dynamics)

[b]Removed

[c]State's own bridge device

Size regulations include limits on length, width, height, and overhang. The height, length, and overhang limits are relatively easy to check at enforcement stations. At many enforcement stations, distances from the front wheel scale position is marked off on the pavement or on guardrail or other devices so that violations involving length, axle spacing, or overhang can be conveniently identified. Automated equipment has been developed that can make these measurements with the vehicle in motion. It is basically the same as the equipment used for speed monitoring and automated classification.

Increasing vertical clearance under a bridge increases bridge costs, whereas deficiencies in clearance increase transportation costs. For federal-aid highways, a minimum vertical clearance of 14 ft has been standard for many years. Most main line Interstate routes have a minimum vertical clearance of 16 ft. Many structures remain throughout the country with less vertical clearance. The commodity determines the maximum feasible height of load for vehicles. Very light commodities, some construction equipment, and military equipment benefit from very high clearances. In general, equipment can be designed to fold or retract to meet clearance standards. Light commodities, such as straw, empty crates, etc., can be loaded to conform to known limits. In any case, there is some need for determining the proportion of loads that might be above various increments of height so that economically sound vertical clearance standards can be established. Vertical clearance is checked at many weight enforcement stations by means of an overhead cable with dangling baffles or tassels. This can also be accomplished electronically using a beam of light and a photoelectric cell, which read as "go" or "no go."

Maximum vehicle width of 8 ft (96 in.) for trucks has prevailed for many years. Efforts are under way to increase this to 102 in. Transit buses have been using a 102-in. width since the mid 1970s, and trucks have been allowed extra width for mirrors. On the Interstate, and certain other routes with wide lanes and shoulders and no pedestrians, a truck width of 102 in. causes no particular problems and has been permitted since 1981. In narrow streets, through-truss bridges, tunnels, and other constricted passages where pedestrians or bicyclists may be encountered, it is more hazardous. As a result "wide loads," often up to 12 ft, and sometimes greater, are allowed but require special permits, and under some conditions, escort vehicles. The permits often limit travel to Interstate and other specified routes during daylight, non-rush-hour periods.

Horizontal dimensions are also checked at many weight enforcement stations. Width measurements are more difficult to check because the lateral placement of the vehicle is variable. Hanging wands, a bank of electric eyes, and sonar have all been used with varying success.

Overall length and body or load length related to axle location is related to three principal concerns: (a) the time and distance required for one vehicle to pass another, (b) off-tracking, and (c) overhang.

The time or distance for a vehicle to pass a slow-moving long truck combination is particularly apparent to other drivers on long upgrades. On narrow roads this can be both irritating and hazardous if drivers are tempted to pass without adequate sight distance. If the operator ensures a power-to-weight ratio adequate to maintain reasonable speed and highways are designed with reasonable grades and adequate passing opportunities the problem can be minimized (*55*).

Off-tracking occurs when a vehicle makes a turn and the rear wheel track is inside the track followed by the front wheels. This is one reason that on curving ramps at interchanges, wider pavement is required than on the straightaway. For straight trucks, the longer the vehicle the greater the off-tracking. For combinations, the amount of off-tracking is proportional to the wheelbase of individual units or the distance from the fifth wheel to the rear axle of a semi-trailer. A combination consisting of a tractor, a 27-foot semi-trailer, and a 27-foot full trailer will off-track substantially less than a tractor and 45-foot semi-trailer, although the two combinations may have the same overall length. Axle spacing and overall length are obtained at weight enforcement stations and during truck weight studies. With these data, reliable estimates of off-tracking can be computed for use in design and developing regulations (*56*).

Overhang is the distance the body or load extends beyond the forward or rear axles of a truck or the units of a combination. For example, many motorized cranes are designed so that they can travel over the highway with the boom lowered and extending out in front of the vehicle. This forward overhang arrangement makes it possible for the driver to see the end of the boom and judge how close it may be to obstacles. When turning, the end of the boom will sweep a wider arc than the track of the front wheels. Front overhang is used to advantage in the case of transit buses. The front overhang makes it easier for the driver to get the front door close to the curb when the approach is partially blocked by parked vehicles.

When turning, the rear overhang on a straight truck or bus will sweep a greater arc than the rear wheels, but because the rear wheels off-track inside the front wheels, it is seldom that rear overhang will sweep an arc greater than the front of the vehicle. Exceptions are articulated buses and pole trailers with a very long rear overhang that may be hazardous to pedestrians and other vehicles when making sharp turns. For example, if the pole trailer is attached to a pintle 5 or 6 ft behind the rear axle of the truck, rather than mounted on a fifth wheel over or in front of the rear truck or tractor axle, the end of the pole may sweep an arc outside the track of any part of the vehicle. This can be particularly hazardous on city intersections because the end of the poles may move faster than the truck when completing a 90-degree turn.

ROAD INVENTORY, PHOTOLOGGING

Information on the extent and characteristics of the highway systems is necessary for management. Road inventory is closely related to the collection, analysis, and uses of traffic data. It is discussed because roadway characteristics have been used as a basis for stratifying traffic count samples and because VMT are usually estimated for various categories of highway. Road inventory is a separate subject however.

Agencies responsible for the administration of highways usually develop procedures for keeping track of mileage in various categories. In 1904 the Office of Public Road Inquiries made the first national road inventory (*4*). This showed that some jurisdictions had reliable data whereas other had no records. A follow-up inventory in 1909 by the renamed Office of Public Roads provided data on mileage by highway type. The Federal-Aid Road Act of 1916 provided that to receive federal aid a state must have a highway department and that post-road mileage in each state would be a factor in apportioning funds. The Federal Highway Act of 1921 established a federal-aid system not to exceed 7 percent of the mileage in each state, thus requiring an inventory of total mileage. The act also provided that when this mileage was improved, additional mileage could be added to the system. In 1932 this was modified to allow addition of 1 percent when 90 percent of previously approved mileage was improved. Thus, basic inventory data was a crucial part of highway administration from the beginning.

Federal program development and monitoring requires a limited amount of basic data. During the last 10 years this has included an exact inventory of structures and rail crossings. For other program development studies, such as cost allocation, reliable estimates of the mileage having various combinations of pavement, right-of-way, traffic, and other characteristics are required. Federal program monitoring requirements vary depending on what program characteristics are of concern. The exact amount of mileage in each federal-aid system and the location of every highway-rail crossing illustrate one level of effort. Sampling of speed distributions for the monitoring of 55-mph speed limit enforcement illustrates another.

For federal purposes, aggregate mileage data without exact location are often sufficient. The states, with direct responsibility for managing the highways and streets, recognize a need for more detailed data. Examples are the location for each combination of surface type, pavement width, traffic volume, accident location, etc. on each state highway. In some cases the detail may be linked to state legislation or particular local concerns. For policy and planning purposes aggregate amounts of mileage in certain categories are often sufficient, but for developing construction and maintenance programs it is necessary to know the exact location of a road section requiring particular treatment, reconstruction, or other action. Traffic volumes on road sections are used in setting priorities. Numbers of accidents help to identify problem areas and, when associated with other roadway characteristics at high-accident locations, help identify hazardous characteristics.

Straight-Line Diagrams

With the Hayden-Cartwright Act of 1936, all states were strongly encouraged to develop comprehensive road inventory programs. Most states used a straight-line diagram to record and present the data. These were usually large construction-plan-size sheets with the road centerline represented by a straight line across the top at a large scale such as 10 in. to 1 mile, 1 in. to 1000 ft., etc. The centerline was typically in a band 2 or 3 in. wide in which political boundaries, intersecting roads, stream crossings, rail crossings, etc., could be depicted. Below this centerline band were a number of parallel lines, each of which was identified with a particular attribute such as traffic, accidents, surface type, number of lanes, pavement width, pavement condition, sight distance, horizontal alignment, vertical alignment, structures, traffic control devices, shoulder type and width, right-of-way width, utilities in the right-of-way, abutting land use, sufficiency rating, etc. (*57, 58*).

Customarily the original sheets were maintained in the road inventory office. Copies were made, usually at reduced scale through photo reduction, for use throughout the highway department. Copies were also provided to the field road inventory crews for updating. Where sight distance was obtained, this required a crew of four, with two in each of two vehicles. For most other data, a crew of two in one vehicle was customary. The original inventories were very time-consuming, often requiring knowledgeable, well-trained and highly motivated personnel to obtain reliable sight distance, alignment, and structure dimensions. Field crews usually marked new data and changes directly on their copy. This was then returned to the office where the originals were updated, revised traffic and new construction data from other sources were added, and new copies were produced each year.

Advantages of straight-line diagrams are: (a) they present a large number of data items in a concise form and facilitate comparison of all data items depicted, (b) copies can be annotated by each user to suit particular needs without being fed back into the system, and (c) users having a file for several years can easily make comparisons over time for their own annotated data items as well as for the universal items.

Disadvantages of straight-line diagrams are: (a) a limited number of data items established and defined in advance; (b) the file for all arterial or primary mileage in a state can be huge, requiring significant floorspace for storage; (c) occasional users must often travel far from their work areas to obtain access; (d) when conducting an analysis involving only a few data items, such as sight distance and traffic volumes at rail crossings, it may be necessary to leaf through every single sheet, a time-consuming task that may discourage use of the data; and (e) odometer readings may vary from year to year and often conflict with survey distances with resulting adjustments and equations creating confusion.

Road Inventory Requirements

Several aspects of road inventory data collection and analysis require particular care to ensure reliable results. Reported distances between identifiable points along a route may vary from year to year as a result of different interpretation of starting and ending points, construction projects that reduce or eliminate curves, variation or error in odometer reading, and new and more reliable surveys, among other reasons. Where measurements are biased high or low over a route, differences can be substantial. Data by category is also a problem. For example, pavement width may be recorded to the nearest foot. One year a field crew may measure the width at a particular location and find that it is 22.4 ft wide, then judge that the next several miles are the same width and record it as 22 ft. Several years later another crew may measure 22.6 ft at another location and show 23 ft for several miles. Is the pavement actually wider? For traffic management, distances to the nearest 0.01 mile may be more than adequate, but for structures or construction projects, precision to 0.001 mile may be attempted. Major discrepancies must be resolved but sometimes a small difference in distance can become a major concern. Because the people who can be depended on to obtain reliable inventory data find such discrepancies particularly bothersome, considerable time can go into resolving such situations, although in many cases it may have little significant effect on the uses of the data.

Control Sections

For analysis purposes it is often desirable to compare sections over a period of time, particularly before and after improvements. To facilitate such comparisons the "control section" was devised. One approach was that the control section termini should be relatively permanent locations such as county lines, major stream crossings, etc. Another was that the control sections should be defined as logical, or recent or expected construction projects. The basis for determining control section termini frequently resulted in a large number of criteria to meet the needs of various users. County and other political boundaries were important to some users; changes in traffic volume, surface type, number of lanes, and separate sections for all major structures were needed by others. As a result, there could be a large number of control sections of only a few tenths of a mile in length. The required compromises often produce inconvenient or almost unusable data for some users, or the creation of several different inventory systems that become difficult to correlate after several years (*59*).

Photologging and Automated Road Inventory

Photologging is a procedure for systematically acquiring a series of photographs at uniform intervals along a highway. In addition to the view of the highway, additional equipment is customarily provided that superimposes the mileage reading and other data into the margins of the roadway view. NCHRP Synthesis 94 (*60*) provides a complete documentation of photologging for road inventory that will not be summarized here.

Photologging also provides a source of traffic data that is often overlooked because it is less accurate than conventional procedures. It is possible to obtain useful estimates of traffic volumes and speeds from photologs.

Although the procedures for obtaining these data from a moving vehicle are well documented, reports on the use of photologs for this purpose were not located. A 1954 report based on tests in England described the procedure (*61*), and a 1957 report on a variety of street sections in the Chicago area having a range of operating speeds and volumes established reliability values for volume estimates (*62*). The volume is estimated by counting the number of vehicles met by the photologging vehicle as determined from the photographs for a link and dividing this by the time between the first and last photograph on the link. This is then multiplied by the appropriate ratio to provide an estimate of the hourly volume in the direction opposite to that traveled by the survey vehicle. Ordinarily, doubling provides a satisfactory estimate of hourly volume, which can be expanded to ADT using appropriate factors. Care should be taken in counting vehicles in the last several photos on the link to avoid including oncoming vehicles that do not actually meet the survey vehicle during the time interval. The Chicago study showed that with a correction for overtaking vehicles and vehicles passed, a period of 5 minutes, and a volume of between 5 and 10 vehicles per minute, an error of 14 to 20 percent could be expected in 68 percent of the cases.

Speed is determined using the floating vehicle principle. The length of the section and time of travel is determined from the first and last photos on the link. The number of vehicles passed by the survey vehicle is subtracted from the number overtaking the survey vehicle, and this difference is divided by the estimated volume per minute for the link. This correction factor is then algebraically subtracted from the time in minutes to traverse the section. If the survey vehicle is traveling slower than traffic, overtakes will exceed those passed and the correction factor will be subtracted from the survey time, resulting in a higher speed than results from the survey time alone.

Extensive investigations of speed, travel time, and traffic volumes were carried out during the early 1950s and reported by Walker (*63*) in 1957. It was shown that spot speeds, such as determined by radar, could not ordinarily be used to estimate a representative travel time over a link. A mean speed determined from spot speeds, termed "time mean speed," is computed by averaging a number of radar or other instantaneous speeds. A mean speed determined by averaging the travel times of a number of vehicles traversing the link and dividing by link length is termed "space mean speed." The time mean speed is based on the sum of the products whereas space mean speed is the product of the sums, and it is difficult or impossible to obtain a representative sample of spot speeds over the length of a link (*63*).

Photologging has several important advantages: (a) it is capable of providing detailed data when they are needed without requiring a predefinition to ensure manual collection in advance for inclusion in a straight-line diagram or computerized system, (b) it provides capability in the office for determining field locations for coverage and classification counts taking into consideration roadway cross section and alignment, poles or trees for securing equipment, exposure to pedestrian traffic, obstructions to observation, etc., and (c) with time and distance recorded, it is possible to obtain immediate estimates of vehicle volume, classification, and speeds for links where field data are not available, with greater reliability the higher the volume and the longer the link.

Disadvantages are that (a) it creates an additional data system to be managed if it cannot establish credibility to consolidate or replace other inventory systems, (b) special equipment is required for viewing, and (c) weather and light conditions may limit feasible photologging to summer when staff is overloaded.

In recent years, video cameras have been used in place of the conventional photographic process providing immediate viewing without processing. Because it is essentially a magnetic image, direct computerized digitization and analysis may become possible adapting pattern recognition technology used for air photo interpretation and for providing recording of other materials (*64*).

Based on reports of users, the most sophisticated field equipment requires an investment of more than $100,000 plus $25,000 to $50,000 for office equipment, readers, etc. Staffing requires one or two persons with photo- or video-logging as a primary responsibility. Per mile costs are reported to range from $10 to $50 depending on detail of data, proportion of urban mileage, and total mileage inventoried. High costs per directional mile are associated with procedures to obtain a sign inventory with every sign readable and to obtain pavement condition data (*64, 65*).

DATA TRANSMITTAL, EDITING, AND RELIABILITY

Once data have been obtained they must be put in a format that is meaningful and useful for an intended purpose. In the case of traffic data this has been found to be critical to producing useful and credible statistics. Problems that have been identified include bias and error in recording the data, errors in interpreting the recorded data, loss of data, delays between recording and presenting data in usable form, costs associated with transmittal media and processing procedures, and inconsistencies in presenting and interpreting data. This section describes procedures currently in use with primary attention to comparisons among procedures. Current procedures range from the use of tally marks to the use of a sensor in the roadway that transmits data to a central computer. There is little need to discuss the history of transmittal technology since nearly every procedure is still in use to some extent somewhere. In addition, transmittal, editing, and reliability checks often overlap.

Transmittal

Manual classification illustrates the most straightforward procedure. The field count person is provided with a recording sheet designed for recording of the data. In the field he or she enters tally marks in appropriate cells for the vehicle types observed during a prescribed time period. Counts for the most frequent vehicle types are accumulated on mechanical counters and reported on the form at the end of each time period. The recording form is then returned to the office for analysis and thus serves as the transmittal medium. The *Transportation and Traffic Engineering Handbook* (*25*) and various operational manuals provide examples of typical recording forms (*24*).

Field forms have not been investigated in detail for this synthesis, but it is evident that design effort has been directed toward straightforward procedures that will minimize the chance of field error while providing for all the data items needed. In some cases forms are also designed for easy summary or to expedite keying into a computer. In addition to classification counts, manual procedures are used for speed and truck weight data. For these purposes a separate line, or even a separate recording sheet, may be utilized for recording data for each vehicle.

Typical sources of error in manual recording include timing errors where the observer neglects to note that a recording period has ended, confusion as to whether specific vehicles have already been counted, inability to see a vehicle obscured by another vehicle or by weather conditions, marking down the count for one vehicle type under a different vehicle type, illegible or imprecise writing, etc. In addition, neglect of certain data items, such as time, exact location, or lane counted, particularly where several continuation sheets or field crew members are involved, may cause confusion. Confusing or illegible recording might be considered transmittal problems also, particularly where the field observer can interpret them correctly, but the office analyst cannot.

Machine Short Counts

In the case of traffic volume counts, mechanical or electromechanical counters are nearly always used for collecting and recording data. For the small accumulative recording counter it is necessary for the person who sets out and picks up the counters to record the location, the set-out time and meter reading, and the pickup time and meter reading. As indicated by the responses to the survey, accumulative counters are used extensively for coverage counts, with 75 percent of all sites counted with accumulative machines.

Although the importance of accurate recording is recognized in instructions and procedures for accumulative counters, no literature providing information on the frequency and effects of errors in these operations was found. The sensitivity can be judged from hypothetical examples.

Example 1

Assume that the 24-hour volume is 1,200 and that the p.m. peak occurs between 4 and 5 p.m. and has 15 percent of the daily volume (i.e., 180 vehicles). The counter is set out at 4:59 p.m. and picked up at 4:19 p.m. the next day. Actual volume 4:00 through 4:59 = 180. Actual volume 4:00 to 4:19 = 57. Volume missed from 4:19 to 4:59 = 180 − 57 = 123. Thus if the pickup time is recorded as 4:59, the undercount will be 10.25 percent. If the time is recorded correctly and a prorated correction is made based on missing 40 minutes out of 24 hours ($1440/1400 \times 1077 = 1108$), then the undercount error is ($(1200 - 1108)/1200 = 0.0767$ or 7.67 percent. On the other hand, if actual set-out time was 4:19 p.m. on the first day and actual pickup was 4:59 p.m. on the second day, then the errors will be overestimates.

Example 2

If the location is the same as in Example 1, but the pickup is on the third day instead of second day, then the base volume will be 2,400 with an actual error 123 vehicles for a percentage error of 5.125 percent instead of 10.25 percent. If the counter is left out for 5 weekdays, the error of 123 vehicles is just over 2 percent.

Example 3

Assume that the 24-hour volume is 6,000, and that the a.m. peak (8–9 a.m.) has 12 percent of the daily volume (i.e., 720 vehicles). An accumulative counter is set out at 8 a.m. and picked up the next day at 9 a.m. (25 hours later) with cumulative count showing 6,720. A prorated correction of 24/25 would result in 6,451, or an overestimate of 7.5 percent.

These examples illustrate the types of errors that can be expected using accumulative count machines, particularly for coverage counts where hourly patterns are not known, for counts recorded to the nearest hour, or for counts prorated on the basis of time. They also show that by extending counts for 48 hours or more these errors can be reduced. However, extending the time also increases the chances of equipment failures, such as cut road tubes.

Another problem with the accumulative counter is that if the tube is cut or the count interrupted for some other reason before pickup, the data are unusable because it is not known whether the count is for 1 hour or 23 hours of a 24-hour period. Depending on scheduling requirements, field crew performance standards, training, and supervision, there may be a concern that field crews might estimate a count.

Nearly all recording counters provide a count for each clock hour and many record the cumulative count each 15 minutes. This makes possible the determination of hourly patterns and the maximum 60-minute volumes to within 15 minutes of the clock time and, in case of interruption, provides accurate data up to the hour or quarter hour when operation was interrupted. Others have a single adjustable recording time that is customarily set to one hour, but at high-volume locations it may be set for 30 minutes or a shorter period to avoid overflow of the volume count memory or "bin." Shorter settings may also be used to identify peaks or other characteristics in particular situations such as at public events, factory exits, etc. The result will be a large number of recorded times and volumes. Depending on the recording medium, more frequent data collection visits may be necessary.

Although the recording counters have the advantage of identifying the time of interruption so that some of these counts can be used, compared to accumulative counters they have more complex mechanisms, and may fail more frequently. Thus, while the cost of recounting an interrupted count is high, the point of economic balance between a recording and accumulative counter depends not only on the higher cost of the recording counter, but also the proportion of non-usable counts it may produce.

For accumulative counters the usual procedure is manual recording of readings in the field followed by manual keying for computer analysis, or complete manual analysis using desk calculator. The computations include subtraction of start reading from end reading, subtraction of start time from end time, a ratio calculation to obtain a 24-hour volume, and a ratio calculation to convert the 24-hour volume to an estimate of ADT. The transcribing and computation operations are subject to error. In recent years this has been reduced by greater use of computers. The selection of the ratio to convert the 24-hour volume for a particular time to an estimate of ADT is basically a judgment. It may be based on data analysis for earlier years. The determination of reliable factoring procedures has received considerable study. Current FHWA recommendations are for factor groups stratified by functional system (*2*).

Continuous Counts

Data from FHWA (Appendix Table A-6) show 3,889 continuous count sites in 20 states. If operations at all sites functioned for 365 days per year this would amount to about 1.4 million 24-hour counts. The agencies responding to the survey have approximately 300,000 count sites of all kinds, as shown in Table 2. Thus, although only a small fraction of sites are continuous, they probably account for half or more of all 24-hour count data. A principal purpose of the continuous count data is to provide ratios for adjusting short counts to estimates of ADT. The ideal is to identify a continuous count station that has the same "pattern" as the road section where the short count was conducted. Although the volume may be greater or less, the ratio of average annual volume to the 24-hour volume for the period counted should be the same at both locations. Studies have shown that these ratios are similar, but not identical, and that errors in the ratios used can cause both bias and error in the ADT estimates. Thus, although continuous count stations seem overabundant, they may provide a useful capability for identifying variations in patterns.

FHWA data (Appendix Table A-2) show that there are 1,281 sites delivering data by telemetry, with about half in operation for five years or more. Colorado has operated telemetry stations since 1966 and Florida since 1974. Reliability and advantages are well established. A principal advantage is the elimination of all opportunity for human error in transcribing data from initial sensing to computer analysis. Another advantage is prompt notification of malfunction. Customarily all telecount stations are interrogated by computer during the early morning hours when other telephone traffic is at a minimum. Various validity and acceptance checks can be performed by the computer as soon as data are received. Each morning a report is available showing the status of each telecount station. Any inoperative stations or stations delivering suspect data can be identified. Problems are identified within 24 hours and corrective action can often be completed within 24 hours or less, so that no more than 48 hours of count are lost.

Telemetry can be troublesome in that: (a) it is an extensive, complex network providing many opportunities for equipment malfunction including "noise" (spurious current fluctuations) that may prevent certain stations from being contacted, cause errors in the data, cause data to be erased, etc.; and (b) interruptions of telephone service caused by lightning (or other causes) terminates telemetry operations. In most cases, these problems are immediately identifiable so that erroneous data can be identified, if data have been received. In this sense it is "fail safe."

CHAPTER THREE

TRAFFIC DATA ANALYSIS, USES, AND REQUIREMENTS

INTRODUCTION

This chapter deals with the data uses, analysis procedures, and requirements. There are some clearly defined uses of traffic data, often related to specific legislation. Much of the more demanding uses of traffic data result from one-time issues and special studies. In many cases it is necessary to relate several traffic data items to non-traffic measures. Comparisons with vehicle registration, fuel consumption, accident data, costs, and expenditures are frequently necessary, as are comparisons with similar data for other modes. To maintain a capability to deal with unpredictable demands, there are advantages to keeping the data bases at the lowest feasible levels of disaggregation. On the other hand, many special analyses can be avoided if data are summarized and made readily available and understandable to users.

Examples of data collection directly related to legislation are (a) the 55-mph speed monitoring and (b) traffic counting to provide VMT for relating to lane miles on the Interstate for 4-R determinations (*66*). Several states use VMT for certain highway categories for apportionment of state funds. Less specifically defined are FHWA requests for certain data items and programs based on the planning and research provisions of the federal highway legislation.

Other data requirements derive from design procedures, performance monitoring, and warrants for traffic signs, signals, and markings. For example, WIM data may be used to monitor the effectiveness of truck weight regulations and their enforcement, as well as to provide a basis for pavement monitoring and design.

RESEARCH

Traffic data are required for a variety of research activities including those related to traffic, pavements, and bridges. Some of the traffic data are obtained from ongoing acquisition of volume, classification, speed, and weight data. To obtain other data a special research study may be required.

Driver behavior studies have been one of the principal types of special traffic research studies conducted during the past 50 years. Included are studies of speed and lateral placement related to lane width, shoulder width, and lateral clearances to bridges and parked vehicles. These studies have been used to set criteria for lane widths on various classes of highways including lanes 12 ft wide on the Interstate system. It has been shown that this lane width on the Interstate system can accommodate buses and trucks 8.5 ft in width (*67*). These widths are now permitted. Required shoulder widths and bridge clearances have also been determined by studies that show that parked vehicles and structures adjacent to the road need to be at least 4 ft and preferably 6 ft from the edge of the pavement to minimize their effect on passing traffic (*68*).

Studies of gap acceptance and headways at intersections have provided criteria for use of stop signs, yield signs, flashing beacons, and stop-and-go traffic signals. The performance of drivers in terms of speed and headway in advance of intersections on high-speed highways has been used to determine the length of yellow-clearance and all-red intervals, and the need for flashing yellow "signal ahead" signs (*25*).

Information on deceleration rates on speed-change lanes and ramps and at signalized intersections have provided insight into the demand for pavement friction and required friction or skid numbers (*69*).

Speed, acceleration, and lateral position at several points in advance of complex freeway interchanges have been used to evaluate diagrammatic signs. In general, diagrammatic signs were no better than ordinary freeway signing and much more expensive (*70*). The exceptions were at left-hand off-ramps and at complex interchanges where a freeway splits into two freeways. There a diagrammatic sign was shown to be an improvement.

Extension of the findings of the various road tests of pavements and bridges requires continuous information on volumes of traffic and their classification. Replacement of manual with automatic classification of trucks aids this pavement research process considerably as does weighing trucks in motion. Pavement research has provided a better understanding of pavement performance and has improved the reliability of pavement design. Considerable additional research is needed, however, to provide less expensive and more durable pavements.

Bridge research has found that many bridges are susceptible to fatigue failures. Classification counts and truck weighing-in-motion are useful to help analyze the data on structural performance of these bridges.

PLANNING (TRAFFIC DATA ANALYSIS, USES, AND REQUIREMENTS)

Traffic Volume Data

Data on traffic volumes may be the most significant item for transportation planning, with the possible exception of road mileage itself. Traffic volumes are combined with other data to provide rates, such as miles per gallon, miles per registered vehicle, fatalities per hundred million vehicle miles, vehicle miles per capita, etc. When compared to similar data for other time periods, volume data are the basis for monitoring the rate of annual traffic growth, and provide proportions for peak hours and monthly ratios compared to annual averages.

The most comprehensive data are obtained at continuous count stations, often referred to as ATRs (automatic traffic recorders). Data items reported by many states in annual, biennial, and monthly reports include ADT for latest and one or more prior years; average volumes by month and day of week; ratios of average weekday of each month to ADT or the reciprocal; and the volume during the 30th highest hour or for each of the highest 30 hours and every 10th hour through the 100th highest, often with date and time of each. Some states include classification count data showing volumes by vehicle type at ATRs where such data are available. Additional manipulations of the data include percentages and ratios based on the quantitative data (*71–73*).

Several procedures may be used for computing ADT at ATRs. One procedure is to compute a simple average; that is, sum the counts for each of the 365 days counted and divide by 365. The problem with this is that at most ATRs there are some days where satisfactory count data were not obtained, and frequently these will consist of several days in a row. A simple average based on available days counted would tend to be biased. Causes may include malfunctions of all types, roadway construction that interrupts operation, and "special conditions" judged to cause aberrations in the data, which, if included in the regular summaries, would produce misleading results or exclude all data from that ATR from use for any purpose. Where special conditions, such as local nonhighway construction, a one-time auction, etc., cause extremely atypical volumes, the data may be excluded from ADT computation. Although an average could be computed based on 360, 300, 250 days, or whatever days were available, the missing days often tend to skew the result so that the computed ADT is apparently erroneous when used for computing annual change from the previous year, 30th highest hour, or monthly factors.

The traditional procedure for computing ADT tends to minimize the distortions caused by missing days. For each month the average volume for Saturday, the average volume for Sunday, and the average volume for all weekdays of the month are computed. Holidays are sometimes included in computing the average Sunday, and are sometimes treated as the day of the week on which they occur. If data for certain days are missing, the average of available days is in effect substituted. The average monthly daily traffic (MADT) is then computed by multiplying the average weekday by 5, adding to this the average Saturday and the average Sunday, and then dividing this sum by 7. The MADTs for the 12 months are then summed and the sum divided by 12 to obtain ADT.

Because MADT and ADT computations are frequently done by computer, the exact procedures (especially procedures for handling missing or aberrant data) would require investigation of individual computer programs. The literature search did not reveal an analysis of the procedures used or the advantages and disadvantages of particular procedures.

Various procedures have been used for expanding coverage counts (24, 48, or 72 hours or up to 7 days) to an estimate of ADT for the link on which the count was made. The generally accepted procedure is to compute a "monthly adjustment factor" that is judged to approximate the ratio of ADT to the average weekday of the month for the link. If the coverage count is more than 24 hours it is usually adjusted to a 24-hour weekday equivalent. The coverage count is then multiplied by the monthly adjustment factor to obtain an estimate of ADT for the link (*1*, *2*).

The procedure promulgated by Petroff and Blensly (*1*), continues to be effective. It consists of grouping ATRs having similar monthly factors and then attempting to identify, on a map, the road sections likely to have similar patterns. An average factor is computed for each group of ATRs for each month during which coverage counts are made (*1*).

Although procedures are described in references, they are reviewed here to point out some considerations in their application. For simulation, data from ATRs are used and treated as coverage counts to be expanded. In this way, the estimated ADT resulting from the candidate procedure can be compared with the "true" ADT at the ATR.

For example, if 48-hour weekday counts obtained during the months March through October are to be tested, then the count for the first two consecutive weekdays in March at the first sample ATR is expanded to ADT using the candidate procedure. This estimate of ADT is compared with the known true ADT at the ATR, and the error determined by subtracting the true ADT from the estimate. The same procedure is followed for the second two consecutive days in March, and so on for all possible counts of two consecutive weekdays through October. With no missing counts, weeks that do not overlap two different months have four possible pairs of consecutive weekday counts, or about 16 per month.

When tested, the distributions of errors of the estimates of ADT have met the criteria for a normal distribution. Thus, when the standard deviation of the errors is computed, the probabilities associated with the normal distribution are applicable. The mean error is theoretically zero using this procedure, and in practice the calculated mean error is rarely significantly different from zero. If the standard deviation of the error, referred to here as the "standard error of the ADT estimate" or standard error, is 10 percent of the true ADT, it may be inferred that 68 percent of ADT estimates will be within 10 percent or less of the true ADT and 95 percent will be within 20 percent or less.

This example has referred to only a single ATR. It is possible to repeat the procedure for all available ATRs and determine the standard error for each ATR each month. It has been observed that certain months will tend to have significantly higher or lower standard errors, and that ATRs with high ADTs will tend to have lower standard errors. A procedure that is often used in this type of simulation is to compute the error as a percent of ADT at all ATRs being used for the test. Tests usually show the distribution of these percentages to meet the criteria for a normal distribution. This makes it possible to treat the errors of estimated ADTs for all ATRs as a single population and provides a substantial number of observations, or a high n value.

Several candidate expansion procedures can be analyzed using the same simulation procedure. Statistical tests on significance of difference can then be performed to evaluate the relative reliability of the various candidate procedures. The high n values are helpful in determining the effectiveness of alternative candidates.

In using these procedures several points should be recognized:

1. The ranking of candidate procedures is valid in nearly all cases.

2. The actual errors of estimating ADTs on a highway system will probably be greater than indicated by the simulation. This is because the majority of ATRs tend to be at locations where volumes are above the average for the system, because the monthly pattern at the ATRs used for simulation was also used in developing the expansion procedure and monthly factors, and because statistical tests based on year-round count data were used to ensure the grouping of ATRs having similar patterns that is not possible for each road section.

3. The actual differences in reliability of candidate procedures are likely to be greater than indicated by comparing simulation results. The contributing causes are higher ATR volumes, elimination of nonconforming road sections, and year-round data for pattern determination, which tend to make all candidate procedures perform better in simulation than in practice.

4. Candidate procedures involving long ground counts, such as three to five days, are likely to indicate significantly less error than one-day counts, but indicate no significant difference between three and five days because the number of possible observations (n value) within the simulation data is small.

5. Where manual rather than computer procedures must be used, various sampling procedures are used to select simulation data and keep computational time within bounds, with the possibility of introducing additional bias and error. Where feasible it is desirable to use enough data to provide n values of at least 25 to 30 so that true differences are not obscured by a low n value. This may require using data for several years.

In practice, the simulation procedures are effective tools for selecting a procedure. Customarily, several candidate procedures are tested. The most easily administered procedure that is not "significantly worse" than other candidate procedures is selected for use.

The HPMS procedure is based on an initial stratification by functional system. ATR expansion factors are then examined to determine if any functional systems have more than one expansion factor, or if the factors for different functional systems are sufficiently similar so that two or more functional systems can be combined. Typically the result is a new stratification that includes two or more pattern groups on the rural Interstate, the grouping of all other rural arterials and collectors into one or two regional pattern groups, and two or three pattern group strata for the urban functional systems. Reports of simulation study results for the HPMS (Highway Performance Monitoring System) procedure were not found from the literature search.

Based on experience with simulation studies to determine the standard error of the estimate, it is likely that in most states the results for the two procedures will not be significantly different. For mileage having ADTs of 2,000 or more, it is expected that estimates of ADT have a standard error of estimate of less than 15 percent at the 0.95 probability level. The HPMS procedure has several administrative advantages. It appears more logical statistically, particularly when an objective is to obtain annual estimates of VMT for each functional system in each state that can be compared. Such comparisons are necessary at the federal level in developing policy, and in some cases for apportioning certain funds among states. It is desirable that comparably based VMT estimates are used. Another advantage is that volume data for each functional system are identified from the data collection stage with the corresponding functional system. This eliminates conceptual uncertainty. For states with comprehensive counting procedures, it simply requires reworking of available data.

Vehicle Miles of Travel (VMT)

Vehicle miles are estimated in various ways. For state, regional, and national totals, the VMT value is almost always an annual total. For urban study areas an average weekday VMT value is often used. For individual routes and highway systems VMT values may be either average daily, average weekday, or annual.

Vehicle mile values are almost always used for comparative or relational purposes. (An ADT value of 20,000 has meaning by itself while a value of 200,000 VMT has meaning only in relation to some other value.) The change in total VMT from year to year for a state or other area provides an easily understood indication of annual change in travel. When VMT is divided by registered vehicles or licensed drivers to give miles per vehicle or miles per licensed driver, a basis for comparison among areas or other categories is provided. Accident rates are customarily expressed in terms of fatalities or involvements per 100 million vehicle miles. Vehicle miles by truck type provides a basis for estimating ton miles of freight hauled.

It is often desirable to compare urban areas, highway systems, and states on the basis of vehicle miles. The method of estimating VMT can then become critical, particularly when funds are to be apportioned on the basis of VMT. Customarily, VMT for the Interstate and other arterials can be computed by multiplying the ADT for each link times the link length in miles, summing the products to obtain a value for average daily VMT and then multiplying by 365 if an annual value is desired. This is possible where estimates of ADT are available for each link. In many states local mileage is seldom counted, and even in states with a local road count program, 5 to 10 years may pass before all counties in a state have been counted. Similarly, count data are meager for local urban streets. Various estimating procedures are used to estimate total VMT for areas and for systems where counts are rare.

One procedure is to estimate total VMT for a state on the basis of registered vehicles and an average miles per registered vehicle. Values for miles per licensed driver, and miles per gallon of fuel are also used. The VMT for the mileage where count based figures are available is then subtracted from the total and the remainder VMT is assigned to the local systems. The VMT for each system is then divided by the mileage of the system and by 365 to obtain an average ADT figure. The percentage distribution of VMT by system is also calculated. The average ADT and percentage values are then examined and adjusted for consistency. For example, a percentage of VMT on local mileage of less than 8 percent or more than 16 percent would seem questionable. Average ADT for local rural is expected to be substantially lower than for local urban or rural collector. On the other hand there is often no basis for judging whether an ADT of 60 or 120 is more realistic for local rural. The difference between 8 and 16 percent of VMT and between 60 and 120 ADT is equivalent to a 100 percent difference in VMT for that system.

Mileage per licensed driver has been estimated with measurable statistical reliability from the Nationwide Personal Transportation Studies conducted by the Bureau of Census under contract to FHWA/DOT (*74*). The difficulties with these data are that they are based on home interviews in detail by occupation and it has been discovered that data for very high-mileage drivers, such as truck drivers, is underrepresented because they are seldom home or do not actually have homes as such. In the case of miles per driver, per vehicle, or per gallon, some part of the travel is outside the home state and there is travel by drivers from outside the study state or other area. This does not balance out in many states and urban areas because travel in some recreational areas may be largely by out-of-state vehicles. Furthermore, many metropolitan areas overlap more than one state and have commuting and shopping patterns that change from year to year with development, industry, and employment shifts as well as with changes in the transportation system.

Classification Counts

Classification counts provide the data for estimating the proportions of trucks and other vehicle types for intersections, individual links, systems, etc. It is one element in estimating pavement loadings in terms of EAL, estimating ton-miles hauled, and other values related to different vehicle types. For example, in some recreational areas the change in proportion of out-of-state vehicles from one year to the next provides an early indicator of recreational activity and revenue. For highway cost allocation and developing taxing structures it is an important data item.

HIGHWAY PERFORMANCE MONITORING SYSTEM AND STATE DATA BASES

The HPMS is being, or has been, implemented in the majority of states. As indicated previously, it provides a means of integrating the various roadway data items for a sample of roadway links or sections. This provides a useful data base at the national level and for some of the larger states. Many states have data bases that include most of the HPMS data items and are in the process of developing the software to link the HPMS and other data bases (*2, 16*).

Highway Performance Monitoring System (HPMS)

In the responses to the survey, only two states mentioned analysis or study effort directed toward HPMS. These were in response to a question on topics related to this synthesis that were of special concern. On the other hand, responses to questions on equipment used for data storage and on systems and software indicated that a majority of states were in the process of modifying their computerized data system in some way. Many were converting to dedicated minicomputers for data storage and analysis of traffic counts, classification data, speed monitoring, or WIM data.

Survey responses, titles on study reports, and discussions with state and FHWA staff indicate that in many of the larger states responsibility for various data items is dispersed among various organization units. Traffic volumes are generally a planning responsibility; classification counts may be a primary responsibility of a planning, traffic operations, or design unit; speed monitoring is often the responsibility of a traffic operations unit; and WIM may be a planning, research, or pavement design responsibility. The mileage logs and system records appear to be a planning responsibility in most but not all states. In implementing HPMS, some states have established units with that as their primary responsibility, while others may assign coordinating responsibility to an individual or organizational unit as a primary or collateral duty.

The diversity of computer systems and organizational arrangements associated with various data items, as well as the special requirements of some HPMS data items, have tended to add to the difficulty of fully implementing HPMS in all states. Because of the diversity of state administrative procedures, size, and issue priorities, no "recommended best" organizational approach to implementing HPMS has been identified.

The purpose of HPMS, to provide a data base for the roadway-related data most frequently needed by FHWA for policy development and response to legislative issues of concern to Congress, is being fulfilled. In some states a continuing special effort is required to provide the data in HPMS format, and not all HPMS data items are regularly available.

State Data Bases

Many states have specific legal requirements that define certain data requirements. In other cases, long-established administrative procedures are difficult to change, particularly where historical comparisons and relationships to local political jurisdictions are involved. Classification of road mileage is the data item primarily affected. For administrative purposes, every classification subject to different funding sources must be identifiable. As a minimum, all states identify (a) the Interstate system, (b) a state system, and (c) other mileage. In most states there are specific funding and other administrative distinctions related to rural and urban characteristics and to traffic volumes, and requirements related to each class of federal-aid funds.

Responses to the survey showed that the related issues of economical pavement design, monitoring, rehabilitation, protection, and highway cost allocation are prevalent. These issues involve planning staff for both data collection and policy development, as well as other staff responsible for design, enforcement, and research. Because the legislative response to these issues can have substantial economic impacts on the trucking industry and various political subdivisions in most states, data collection and analysis procedures are subject to challenge by interest groups. One response is to try to obtain the most comprehensive data possible within budget constraints. This may contribute to the extensive WIM programs in some states.

Responses to the question on distribution and timeliness of traffic-related data would seem to indicate that regular prompt delivery of extensive data is not a high priority. A number of states publish a monthly traffic count summary and a traffic flow map or log regularly and fairly promptly, but more detailed traffic data are often available only by special analysis or in limited-distribution internal reports.

Using the pavement design and cost allocation issues as an example, it becomes evident that all categories of traffic data are involved. The estimate of equivalent single axle loading

(EAL or ESAL) for a road section usually involves a forecast or projection of past ADT trends to a future design year, the use of classification count data to estimate the proportion of various vehicle types, and the use of truck weight data to estimate the EAL. These are also the key data items required to allocate the highway improvement and maintenance costs, usually at the subsystem level, by traffic categories, to the various classes of vehicles.

DESIGN DATA

Nearly every type of traffic data is used in some aspect of design. In addition, design-hour volume (DHV) and directional split are special data items used almost exclusively for design. Continuing traffic volume, turning movement, speed, classification, and WIM data provide basic information needed to design new highways; relocate, reconstruct, and modify existing ones; and resurface highway pavements and redeck highway bridges. Examples include geometric design, timing of signals, and channelization of intersections (*75*).

To properly design the geometrics of a highway requires estimates of prevailing operating speeds to select an appropriate design speed useful to coordinate the several elements of design: curvature, sight distance, gradient, etc. Speed data collected to monitor the current 55 mph nationwide speed limit is of little value for design purposes because they do not include the entire distribution of speeds and do not distinguish free flowing speeds. The design-speed standards are established and revised in connection with revising design manuals. Periodic speed surveys to establish trends on highways that are constructed to a range of standards and that operate at various levels of service aid in revising design-speed standards. Speed data for existing facilities also aid in determining appropriate design speeds for new projects. The projected traffic volumes also influence the selection of design speeds. Trend data on traffic volumes and origin and destination information are essential in estimating these traffic volumes (*25*).

Traffic volume information is also used to determine the number of lanes, lane width, shoulder width, gradient, need for climbing lanes, and required passing sections. The number, proportion, and type of trucks projected to use the new or reconstructed highway are also employed to establish many of these design requirements. They are also used to determine ramp curvature and width, need for escape lanes in mountainous terrain, pavement thickness, and other design elements.

The presence of pedestrians, bicyclists, recreation vehicles, older or handicapped pedestrians, and school children can affect geometric and operational design. Many of these requirements will also affect the need for separate pedestrian signals. Signal timing is affected by prevailing speeds of traffic. Introduction of one-way streets is often dictated by increasing traffic volumes that cannot be handled on existing two-way streets. Parking prohibitions are also frequently dictated by increasing traffic volumes.

Turning-movement studies and sometimes small-area origin and destination studies are essential for proper design of channelization at complex intersections. Approach speed information is useful to time the signals and aid in decisions as to whether special skid resistant surfaces are required.

Traffic Data for Design

The DHV is related to, and is sometimes considered synonymous with, a projection or forecast of the 30th highest hour in the design year in terms of passenger car equivalents. This is often based on analysis of continuous-count data for locations considered representative of the project. In most states historical trends have been established that show DHV to be in the range of 10 to 20 percent of ADT. Directional split during design hour may range from 60/40 percent to 80/20 percent. The percent of dual tire vehicles, or the K factor, is a projection or forecast based on classification count data (*75*). The basis of forecasting EAL, discussed in a previous section, requires axle weight frequencies, classification count, and ADT data.

The computation of design factors based on projections of available traffic data is a routine procedure. Several states have developed computer procedures that can be used to compute these values for every section in the traffic log. In addition to providing design data, this provides a basis for forecasting future deterioration in levels of service and sections likely to experience congestion as V/C (volume to capacity) ratios increase. Similarly, EAL can be estimated and projected by computer for each section and provides a basis for judging the relative rate of pavement rehabilitation requirements among different road sections.

Although computer-projected design values provide comprehensive and comparable data for all road sections in an easily used form, they do not take into account fully the likely effects of future improvements on adjoining sections, congestion of parallel routes, major highway facilities on new location, or development of new traffic generators. In addition, classification count, WIM, and peak-hour data may be extrapolated from data collection locations substantially different from the project under design. Turning-movement data for intersections is sometimes critical for proper traffic operation. As a result, site-specific data are usually collected as a project approaches the design stage. Depending on the organization of the agency, this may be considered a route planning or design responsibility.

Traffic Data for Pavement Design

Current pavement design guides use historical and base-year truck weight data to compute average ESAL values (*21*). These values are combined with classification, volume, and truck loading data to estimate total ESALs for the design period. However, many pavement designers believe that the ESAL growth rates and truck loading data are not accurate. The availability of more accurate data, such as can be obtained from WIM equipment, will result in a better understanding of how pavement performance is related to traffic loading and environmental conditions and in improved pavement design procedures (*21*).

TRAFFIC DATA FOR TRAFFIC OPERATIONS

Traffic operations include traffic engineering and related low capital improvements that improve the level of service of operating highway facilities. Included are progressive timing of signal systems, channelization, striping, and similar techniques that do not involve major construction projects. On the other hand, some TIPs (traffic improvement projects) can involve major investments in control systems and expensive staffing. Remotely controlled ramp metering on freeways and interconnected centrally controlled signal systems for large street grids require expensive control installations, communications networks, and computer systems. Experienced professionals are required for monitoring, maintenance, and intervention to deal with accidents and other daily unanticipated abnormalities.

To facilitate traffic flow requires the collecting, processing, analysis, and use of enormous quantities of information on the presence, passage, speed, and position of vehicles. Much of the information is obtained "on-line" in real time and used immediately. Other information is obtained for planning and operation of street networks of traffic signals, for freeway control, for tunnel control, and for other purposes.

Traffic Operations Design Data

For design of TIPs, the same basic data are needed as for other design projects. Greater emphasis is likely to be placed on traffic variations over short time periods such as 15 minutes, 5 minutes, or individual signal cycles. Turning movements, vehicle occupancy, time of arrival of transit vehicle, quitting time for employment centers, exit time for major entertainment and sport arenas, pedestrian volumes, and operating-speed fluctuations are often required. For major TIPs, traffic monitoring and adjustment may be a continuing activity (*25*). The resulting data are often useful for other research and planning studies.

Traffic Actuation

Sophisticated TIPs often use detectors to monitor system operation and modify signal timing and other control settings. A simple example is the traffic-actuated signal at an intersection programmed to remain green for the major street until a vehicle arrives on the minor cross street. For freeway ramp metering and freeway monitoring, inductance loop detectors are customarily used to actuate ramp meter signals, as well as to monitor volumes and speeds on numerous sections of a freeway and connecting street system. A computer may receive and analyze these data and modify signal settings in accordance with previously programmed software.

The actuation devices are similar to inductance loop traffic-counting equipment and similar data are obtained. Although the accumulation of these data in the same format as traffic-count and speed-monitoring data provides useful trends in some instances, it is not the general practice for several reasons. Data collected at successive intersections tend to be repetitious with respect to volumes, hourly patterns, and, to a lesser extent, speeds. Thus only a few detectors (of the many that are installed) will provide more data than can be economically processed. In addition, the traffic operation system operates more effectively as the time lapse between detection and modification of signal setting is minimized. Thus, any computer routine that delays response time for data storage or transfer, even by only a few seconds, may be counterproductive.

Traffic Signal Systems for Street Networks

Three key parameters are available to control a city street network controlled by traffic signals: cycle length, split, and offset. Cycle length is the time in seconds from the beginning of green on the main street to the instant when green begins again on the main street. It is often about 60 seconds but may be as low as 40 seconds and frequently exceeds 100 seconds.

The split is the allocation of the green time to each street and is typically about 60/40; i.e., 60 percent of the green time to the main street and 40 percent to the cross street. Split times depend on the relative capacity of each street and the traffic demand.

The offset is the difference in time between the beginning of green at one intersection and the beginning of green at any intersection downstream (or elsewhere in a network). The offsets determine the possible speed of progression of a platoon of traffic traveling along a city street.

Control of a network of traffic signals requires that all of the intersections operate on a common cycle length. Large networks are often subdivided into smaller ones, and in this case, each subdivision must operate on a common cycle length. An attempt was made to operate a network with variable cycle lengths at individual intersections—it was not successful and travel time increased substantially (*76*).

Determining the proper cycle length, splits, and offsets requires information on traffic volumes, platoon speeds, turning movements, and other data. The needed information is collected manually, through automatic recorders placed on the street, or as part of the control system with needed traffic information transmitted directly to traffic control headquarters.

The traffic information is then provided as input to one of several simulation-type computerized programs that calculates the appropriate cycle length, splits, and offsets for a given set of traffic conditions. Based on the continuing collection of traffic data *or* the time of day associated with certain traffic conditions, the signal timing is changed in an appropriate fashion. The traffic information collected may also be used for other traffic and planning purposes including improvements to the traffic simulation programs.

Freeway Surveillance and Control

Highway agencies are using various methods to prevent freeway congestion. These include continuous monitoring of key traffic parameters—especially speed, volume, and density. Based on analysis of these parameters (particularly density), the ramps that feed the freeway can have the entering traffic limited or even stopped and diverted elsewhere. To be effective, ramp control should be implemented *before* congestion occurs and be operated in a manner that will prevent such congestion from taking place. Appropriate traffic data are needed to achieve these goals. Many areas, including Dallas, San Francisco, Los Angeles, Houston, Chicago, Long Island, Portland, Northern Virginia, and Hanshin (Japan), utilize some form of ramp metering or ramp control to help minimize freeway congestion.

In addition to ramp control, data collected from freeway surveillance detectors are used to warn motorists of lower speeds and congestion resulting from accidents, construction, ice and snow conditions, and so on. For this purpose, variable message signs are generally included in ramp metering projects.

Special Types of Traffic Control

Traffic data are also employed for special types of traffic control. Tunnels are an expensive type of highway construction and thus even a small increase in traffic flow is well worthwhile. Data on vehicle speed, volume, density, and headway distribution are employed to determine optimum values of these parameters to avoid sudden breakdown in traffic flow. A surveillance system provides information automatically or to the tunnel operator to change variable message signs to limit vehicles entering the tunnel. The same surveillance system can detect possible vehicle stoppage and, when combined with TV surveillance, indicate a need for emergency vehicles.

Other special types of traffic control include (a) "You are speeding" signs based on speed detectors, (b) variable message speed signs during wet weather on critical curves, (c) fog ahead signs and speed indications, (d) signal ahead—red, and (e) signal-changing routines based on speed of approaching vehicles.

An advanced type of traffic routing system was developed by the U.S. Federal Highway Administration (*77*) and has been utilized at several installations in Japan and Germany to provide drivers with customized route information. In Tokyo, for example, after taxi drivers key the address of their passenger's destination into a black box, a display shows—at each principal intersection—whether the cab driver should go straight, right, or left, or turn at an angle. To accomplish this feat, the cab has a transmitter that indicates to a detector at the intersection, the keyed destination. The detector is connected to a microcomputer that determines the best route to the destination and the appropriate turn and transmits the information back to the cab display box—all in less than 0.01 seconds. This type of route guidance system also produces information useful for planning purposes, for detection of congestion sites, and as part of a general data base.

The routing indication requires a detailed and extensive data base. The minimum requirement is the typical maze algorithm with data for the shortest time route from each intersection to various destinations. It is possible to run the algorithm in advance, perhaps for different times of day when travel times on particular links and intersections are known to be typically slow or fast. This requires the collection of data relating traffic volumes to travel time for many links and intersections. To reduce collection costs, travel times for many links and intersections can be estimated based on measurements for similar facilities. This basic data set will facilitate travel under "normal" conditions, but rush hours are seldom normal.

To provide routing that is responsive to minute-to-minute changes in traffic conditions, it is necessary to provide sensors that will measure volumes, speeds, or queue lengths on links and at intersections. At first sensors can be placed at a small number of locations thought to be most representative of network operating conditions. As experience is gained, additional sensors can be added as additional bottleneck and other critical locations are identified.

The basic travel-time data in a computer file are valuable for developing TOPICS improvement strategies, as well as freeway needs and locations. The improvement locations to achieve the greatest return on investment through reduced user costs can be determined. Analysis to determine sequencing improvements to maximize travel improvements and minimize travel delays caused by construction is feasible. As sensors are added to the system, additional data on the frequency of substandard operation, blockages, and related problems can be identified by approximate location, time, and duration. The time and frequency of interrogation by equipped vehicles makes possible the identification of critical network locations, and signal priorities can be revised if desired. Very detailed and precise time patterns can be developed for volume, speed, and travel time and similarities or differences over a year, as well as growth trends, can be developed from the data. Thus, the implementation of a routing system requires the collection of detailed data useful for other operational and planning activities, and when operating the system provides a potential data source for even more sophisticated analysis.

Traffic Control Studies

Many of the electronic traffic control systems discussed previously require traffic data for their operation. These same traffic data may be employed for various types of traffic studies, or the traffic information may be obtained by other automated equipment or manually. An example of use of density information for traffic control studies is shown in Figure 5 where the maximum density contour is 80 vehicles per mile per lane (*78*). The contours indicate that during peak hours, congestion occurs because of a bottleneck at about mile 5. If this occurs daily, ramp control upstream of mile 5 or some other remedial measure may be indicated. Such contour maps are particularly useful in determining when ramp control should be initiated—about 4:00 p.m. as shown in Figure 5.

Other types of studies useful for traffic control purposes include (a) origin and destination studies needed to provide information for lane closures, ramp closures, and other purposes, (b) travel time and delay studies to help time signals, control parking, and evaluate improvements, and (c) accident analysis to pinpoint hazardous locations and suggest remedies.

Integrated Freeway and Street Operations

Desirably, the control of freeway and street traffic operations should be planned and executed as an integrated system. Such an integral concept has been accomplished in only a few cities although the concept is becoming more widely accepted.

With such a concept, it becomes possible, for example, to increase the capacity (by parking removal, signal retiming, one-way street operation, and other means) of streets near freeway ramps subject to control and provide alternative routes. Drivers on shorter trips will then use the alternative routes; those on longer trips will queue at the controlled ramp, accepting some delay there if they are assured of a delay-free trip thereafter. If the travel times on the delay-free freeway and slower minor arterial city streets can be stabilized, trip times will be more predictable for drivers and time savings will include not only direct delay reduction but the added time per trip drivers had previously allowed to ensure on-time arrivals in the face of possible congestion.

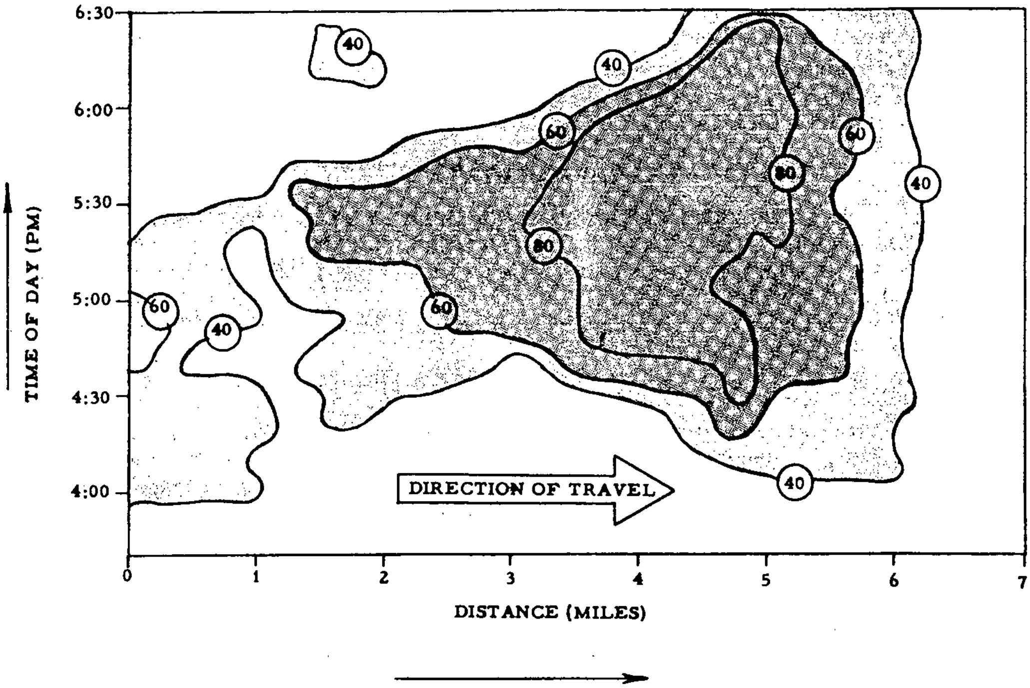


FIGURE 5 Freeway density contour map showing heavy congestion (*78*).

Such integral traffic control planning requires good information relative to trip origins and destinations, volume and capacity studies, turning-movement analyses, travel time, speed and delay studies, and other types of traffic studies. Also needed are projected attendance at special events such as athletic contests, concerts, plays, rallys and demonstrations, shopping sales, conventions, plant shift changes, and other activities that concentrate large numbers of people/cars in a small area. By using such information with appropriate traffic data, modern traffic control and computer technology, and astute analytic judgment, it becomes possible to substantially improve traffic operations on city streets and freeways.

ACCIDENT ANALYSIS

Accident data alone provide a limited view of the real world of traffic hazards. Various types of traffic, highway, vehicle, and driver data are needed to help make sense of the accident information. For example, younger drivers are involved in more accidents than older drivers. Is this because they drive more or simply because of their age and/or lack of driving experience? In fact, as Figure 6 shows, it is due to age and/or lack of driving experience and, as other studies show, it is probably due primarily to lack of driving experiences not to age per se. To obtain the relations shown in Figure 6 accurately, it is necessary to obtain relative travel information by age from roadside interviews and combine this information with age information from accident reports for the *same highways* (*79*).

Another example, in Figure 3, shows that the accident involvement rate is lowest at about the average speed of all drivers and is much greater at *both* higher and lower speeds. To obtain these relations requires speed measurements for a sample of drivers and speed estimates for accident-involved drivers on the same highway (*28*).

Other traffic data required to properly utilize accident information include (a) traffic volume counts to compute accident rates, usually per 100 million vehicle-miles of travel, (b) vehicle classification to compute rates by type of truck, for example, (c) turning movements to compare with angle collision data, and (d) truck weight information to compare accident rates by truck weight.

ENFORCEMENT AND ENFORCEMENT MONITORING

Law enforcement records provide useful traffic data, particularly when related to other data such as speed monitoring, accident, and WIM. When related to particular road sections, useful design or operational data results. In addition, speed monitoring and WIM data may provide guidance toward more effective deployment of limited enforcement staff.

Speeds

FHWA speed monitoring was established in 1973 to ensure consistent nationwide compliance with the 55 mph speed limit. Before that time, surveys had obtained free flow speed distributions at levels of service A and B, often referred to as "desire speeds." Results of the monitoring have been used in all states to judge the effectiveness of enforcement efforts. The monitoring operations are conducted independently of enforcement activities. Survey data showed that radar and spaced inductance loops comprise 50 and 25 percent, respectively, of the 4332 speed-measuring units; most of the remainder were spaced air tubes

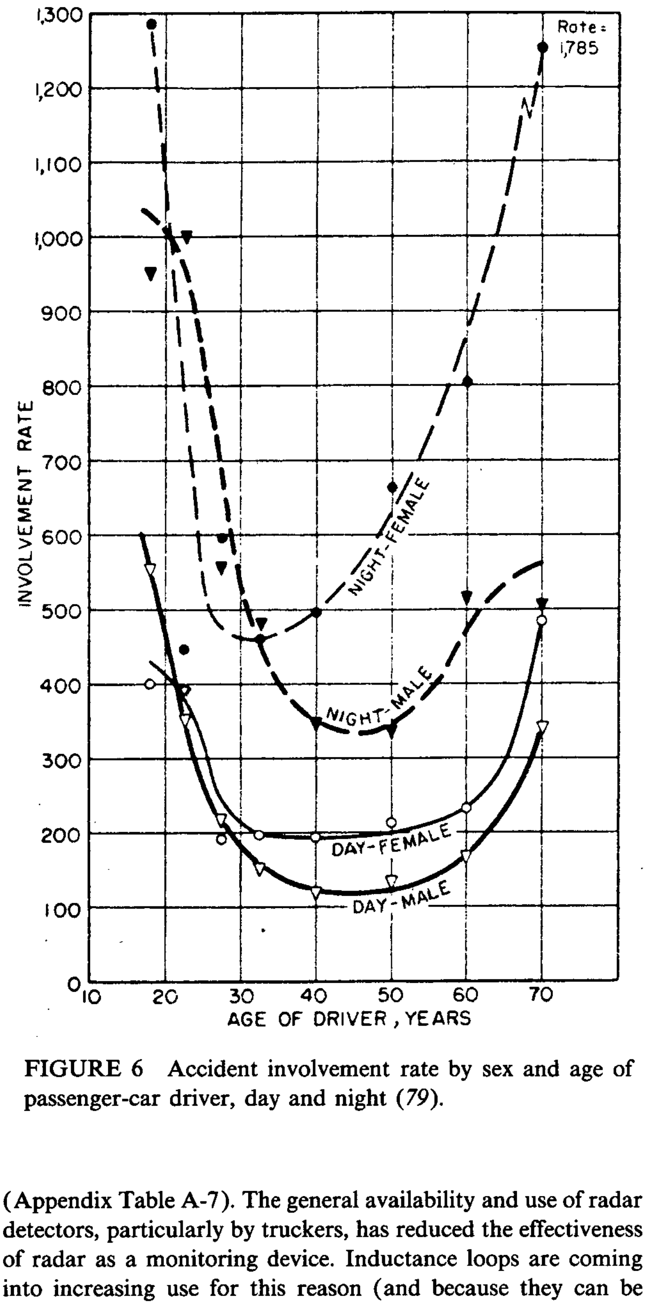


FIGURE 6 Accident involvement rate by sex and age of passenger-car driver, day and night (*79*).

(Appendix Table A-7). The general availability and use of radar detectors, particularly by truckers, has reduced the effectiveness of radar as a monitoring device. Inductance loops are coming into increasing use for this reason (and because they can be automated, accessed remotely, and operated continuously with minimum staffing). Unfortunately, pavement cuts for inductance loops are easily identified by an alert driver, and inductance loops cannot be easily moved to other locations. As truck drivers and others learn the purpose of spaced inductance loops, it is possible that sufficient drivers will slow before passing over the sensors to bias the results. Thus, speed distributions indicated by speed monitoring could be significantly lower than speeds prevailing over the highways in general (*66*). Covering the pavement cuts and the remainder of the pavement surface with a thin overlay should disguise the cuts without affecting the electrical properties of the inductance loop.

Weight Monitoring

WIM devices are used at many weight enforcement stations to expedite the flow of trucks that are below the legal weight limit. This is often done automatically on the approach to the enforcement scales. As the vehicle passes over the WIM detector, the data are analyzed by a computer, and traffic signals are set to green for a bypass roadway if the vehicle is within legal limits. If the WIM data show the truck to be borderline or overweight, signals direct the driver to the enforcement scale where data admissable as evidence in court are obtained. This procedure reduces delay to the majority of legal vehicles and reduces wear and tear on the enforcement scales (*21, 43*).

Use of truck weight data from survey operations where all or a sample of trucks are stopped and weighed have been shown to be biased by elimination of a high proportion of the heaviest overweight trucks. Once the scale location is known to truck drivers (through CB radio or other means), many overweight trucks avoid the station even when enforcement operations are not conducted. Certain data, such as commodity, vehicle condition, origin-destination, class of operation, registered weight and category, and driver demographics can be obtained only by stopping the vehicle.

WIM data provides more representative weight distributions than surveys where vehicles are stopped. Detailed information on the vehicle, load, and driver cannot be obtained, but a good measure of the effectiveness of weight enforcement is provided. Because the overweight vehicles can damage pavement severely and rehabilitation is expensive, this aspect of weight data collection is considered a top priority by some states. Enforcement of vehicle safety regulations involving such things as tire condition, proper running lights, driver duty time, and hazardous cargo laws are sometimes checked at enforcement weight stations. Fuel-tax reciprocity, insurance, and other revenue and economic regulations are checked at ports of entry in many states. Use of WIM combined with AVI (Automatic Vehicle Identification), discussed in detail in Chapter 6, provides a means for expediting properly documented legal weight vehicles without stopping at weight stations or ports of entry, although data on vehicle condition and driver duty time still cannot be obtained.

CHAPTER FOUR

DATA AVAILABILITY TO USERS AND TIME LAGS

INTRODUCTION

Survey questions concerning types of software used and report preparation shed some light on data availability and time lags. It appears that most agencies have only two or three reports that are reproduced in substantial numbers and issued promptly after the end of the data period. Computers are used extensively and it appears that a substantial number of data summaries are provided for limited distribution and internal use or to supply an established FHWA data need.

HARD COPY SUMMARIES AND SPECIAL REQUESTS

Lack of ready availability of widely used existing data will tend to generate an excessive number of requests for special summaries. Indeed, data managers generally recognize the effectiveness of issuing the most needed summaries promptly so that staff effort will not be impeded in providing specially requested summaries.

Responses to the survey indicate that a variety of computer programs are used for data summary. Except for truck weight data where the FHWA package is used extensively, there is no clearly dominant software package. Where personal computers are available, various statistical and spread sheet packages are mentioned, whereas those using larger mainframes depend primarily on in-house FORTRAN and COBOL programs. Most vendors of traffic data acquisition hardware also provide some data summary capability in special summary units or through programs usable on the most generally available personal computers.

The survey obtained an indication of data delivery and availability for those agencies that could respond. Determining numbers of copies produced and date of availability is evidently difficult in many cases. Of the 42 agencies (33 states and 9 others) responding, all prepare a traffic flow map, a traffic count report, or some similar report in sufficient quantity so that some of the most-used data can be provided to users without custom processing. The numbers of copies distributed and the promptness of delivery vary widely among agencies and according to the type of report. Volume data receive the widest distribution, although classification, speed, and weight data are more likely to remain internal and have reports limited to a small number of copies.

Data delivery times range from the 10th of the following month for monthly count data, to close to a year for some traffic flow maps and truck weight reports. Where longer periods are in evidence for comprehensive reports, other internal reports are usually reported as being available sooner. Of the 15 agencies reporting delivery time for annually published reports, 3 indicated 3 months or less, and two-thirds showed 8 months or less.

INTERACTIVE DATA BASE

A feasible alternative to hard copy reports requires accessibility to a large data base on a central computer through computer terminals. In this way, any analyst with the proper access codes can prepare any summary of available data that is desired. It is possible to combine and compare data from a number of very large files. The minicomputer or personal computer (PC), which can be used either as a terminal accessing a large data base or as a stand-alone computer using smaller files on 5 ¼-in. or 8-in. disks, provide the interactive capability using either mainframe or PC software. Of the 39 agencies responding to the survey question on systems and software, at least 8 indicated a system or software that customarily has interactive capabilities. In addition, the FORTRAN and COBOL programs may include interactive features, although these are usually traditional batch-type programs.

Accessibility through several terminals does not appear widespread. Of the 51 agencies responding to a question on traffic-volume data, only 11 reported access by terminals, and of these only 5 reported accessibility from more than one terminal. The widespread and increasing availability of PCs is likely to create a recognition of the value of interactive access to the most-used data bases.

Advantages

A principal advantage of interactive compared to batch processing is the ability to quickly modify a summary to obtain different relationships. Thus, the analyst may (a) compute the quantitative values for a data set; (b) observe an interesting relationship between two data items in a table, then compute the ratios of corresponding entries in two columns; (c) compute each column entry as a percent of the column total; (d) create a mirror image table in which each cell contains a percentage based on the cell entry and the table total; and (e) compute statistical values such as mean, variance, and standard deviation for any variable going from one to the next by typing a few words into the computer. In some cases, software provides for the quick preparation of graphs based on tabular data. Once the analyst has prepared the desired presentation using the display on the monitor, it can be printed out on paper for use. Accessibility of detailed data that can be analyzed in different ways by different analysts may lead to new insights that might not be apparent from traditional summaries. For example, graphic presentations may emphasize significant relationships or inconsistencies that are not apparent in traditional tables.

Disadvantages

One concern with interactive procedures is the tendency for a skilled analyst or a top manager to proceed through a series of intricate analysis steps to produce a simple and easy to understand graph, without recording enough of the intermediate steps so that comparable results can be quickly obtained by another analyst a year later. This requires attentive management.

Under an interactive operation with many users, the data manager is concerned with assuring the currency and reliability of the data base, but is greatly relieved of requests for special summaries. On the other hand, a number of users may see the need for essentially similar summaries, resulting in considerable duplication of effort. As a result of differences in summary formats chosen by different analysts, data users and managers may misunderstand data presented by a different unit.

There is also a concern in large organizations that data providers will become remote from data users with reduced motivation for promptness and innovation to identify and meet emerging data needs. Another concern requiring management attention is the possibility of remote users identifying an error in the data and correcting it to their own satisfaction without all other affected users being notified. It is possible to build in access procedures that will restrict modification of the central data base to authorized data providers. More troublesome is the situation where remote analysts tabulate data, identify an error, correct it in their table, distribute the table, but their results cannot be verified from the original data base.

COMPUTER BATCH PROCESSING

The traditional computer processing procedures involve large mainframes that are fed a program that directs the processing of specific data files. Final output is customarily "hard copy" printed on computer paper. Customarily files are on large disk units or on computer tape stored at the central computer facility. Where the mainframe is not accessible from terminals, or where data are on "write-protected" tapes, it is unlikely that unmonitored changes in data will occur. In addition, the programs are retained so that every time a particular program is run the same procedures will be used, and comparable results produced.

Where a very large amount of data must be accessible to a complex program, such as traffic assignment to a large urban network, the large mainframe computer may be able to accomplish in minutes what would require days on a PC, if it is feasible at all. As a result, there is an incentive to retain the large mainframe capability for some transportation planning purposes.

ORGANIZATIONAL STRUCTURE RELATED TO DATA

A TRB study of data needs and flows identified some differences in organizational structure related to transportation data delivery and analysis (*80*). The increasing use of PCs as terminals capable of accessing many data bases throughout the country has increased opportunities for greater centralization. Conversely, the pervasiveness of PCs and their relatively low cost has increased the feasibility of individual analysts and small organizational units developing very powerful isolated data bases.

The early time-consuming manual procedures for data collection and analysis often resulted in an individual staff member following data from collection through analysis and publication in tabular form, and even through policy analysis. Because of the time lapse and substantial human resources required, several levels of management were often involved in determining details of the data collection and summary procedures. If eight months of effort did not produce usable data, there was little possibility of trying a different approach in time for use. This resulted in an intimate understanding of data strengths and weaknesses by those at or close to the policy level.

As tabulating equipment and the early computers became prevalent in transportation data summary and analysis, it was necessary to utilize the highly specialized skills of computer programmers. Because the computers were expensive and occupied considerable space, it was necessary to assign management responsibility to an organizational unit. Various management arrangements were tried. In some cases the computer unit was responsible only for scheduling users and accounting for the time and services used by each. Organizational units were responsible for training their own programming staff, purchasing and cataloging their own tapes, and budgeting for their computer time on whatever available computer was judged to be best for meeting their needs, including those belonging to other agencies or commercial service companies.

At the other extreme, the computer services staff did all programming and processing for the organization, and no program could be run on the central computer that was not prepared by the staff or modified to meet the specific documentation and procedural requirements of the computer services unit. Because programs were run one at a time in sequence and sometimes required an hour or more to run (particularly when large amounts of data were entered from tabulating cards), scheduling priorities were the cause for much concern and frustration. The programming staff did not depend on the user unit for supervision or evaluation and it was sometimes believed that the programmer was not motivated to expeditiously develop the most effective program from the point of view of the analyst. Occasionally the resolution of conflicts required arbitration by the head of the agency or governor's staff because that was the lowest level at which there was management authority over both the computer service unit and the user unit.

For transportation planning analysis it is sometimes necessary to compare data from a variety of different sources. The roadway-related data are almost invariably available from the highway department. A frequent exception is accident data, particularly for urban areas and non-state mileage, which may go from local police to a state safety agency. Vehicle registrations, tax payments, unemployment figures, school enrollment, and income characteristics are other types of data frequently desired. Most of these data items are developed by other state agencies. Therefore there are advantages to a centrally administered data coordinating activity, which can ensure the timely availability of periodic data and consistent definitions of geography and other common attributes.

Testing different formulas for allocating funds among political subdivisions is a task frequently faced by many states as well as FHWA. Depending on the class of funds and the objectives, it is often desirable to use a wide variety of data series besides mileage-related data. For these studies economic, demographic, geographic, revenue, and environmental data are often required. Some of the data may be produced by non-state or commercial organizations.

Several commercial organizations operate large mainframes accessible to any subscriber. Some of these provide reference search services while others provide data bases of all kinds. Thus any PC user with a modem for connecting to a telephone line can subscribe to the service and access the data. Subscribers are charged according to the time used, the programs used, and the data base accessed. Arrangements can often be made to have special data made available on the system. The analysts can process the data using the services programs and software or read selected data into their own computer for further processing.

Many of the available statistical and spread sheet programs are designed with prompts or cues that help the occasional user to learn the capabilities quickly and use them effectively. As a result, some top managers and policy people are capable of preparing analyses themselves in a shorter time than required to explain their needs to an analyst. In addition, if data are available, they can conduct their analysis at any time of the day or night.

These technical developments may tend to change the organizational requirements for transportation data management. The need for a highly skilled programming staff is less urgent. Much of the traffic count equipment includes software sufficient to produce usable summaries. The automated data entry and edit checks built into much of the present-day data-acquisition hardware minimizes the human key-entry of data. The software available for most PCs makes sophisticated analysis possible with a minimum of training. The units responsible for particular data areas now have the capability of collecting and processing data with little or no dependence on other organizational units.

Where a large central computer is used for integrating a variety of data sets and for providing large mainframe capability to a variety of terminals, centralized coordination becomes necessary for efficient operation. If coordination fails, however, many users will be able to access another data base, or create needed data series from other sources for processing on their PCs.

RESTRICTIONS ON ACCESS, EDITING, AND DISTRIBUTION

Generally, this study found that traffic data are available to anyone desiring the information. The chief concerns with releasing data are that preliminary data may lead to incorrect conclusions on a controversial subject, that data will be misinterpreted, or that data can be manipulated to support alternatives contrary to institutional policy or objectives.

As discussed above, it appears that relatively few states provide access to a central traffic data base through computer terminals. In addition, statistical reports on speed and truck weight data tend to be limited in number and distribution.

A principal management concern in some areas relates to the procedures and level of authority to be exercised with respect to various data series where a centralized coordinated data base is operated. For example, if a state has a road log file showing mile points, traffic counts, estimated ADT, DHV, and EAL for each section, location of each property damage accident, etc., which units should have authority to enter new data, correct data errors, or revise estimated values such as ADT, etc.? If the authorized unit enters new or corrected data, what are the safeguards that will ensure that the corrected data are not erased and replaced by uncorrected data from an older backup file? What are the most effective procedures for notifying users that the "final" files they used three weeks or three months ago have been revised, particularly where there may be hundreds of users? There is a continuing problem of keeping data managers sensitized to urgent and future data requirements. For this synthesis these are identified as issues of which managers should be aware. There appear to be many ways of satisfactorily dealing with them depending more on the size, organization, traditions, and management style of the agency than on available technology.

CHAPTER FIVE

DATA CONCERNS AND EMERGING REQUIREMENTS

INTRODUCTION

The survey identified a number of concerns, but did not reveal any strong consensus identifying one or two particular new concerns or data requirements. Responses to a survey question on areas of special concern show a wide diversity of concerns mentioned by the 19 agencies responding. The efficiency of data collection procedures were mentioned by five states under such topics as "count sampling rates," "undercount or bias," and "data requirements."

Another question was aimed specifically at accuracy of counts, reliability of equipment, and improved scheduling analysis procedures. Fourteen states reported activity in these areas.

The survey question provided an opportunity to indicate what was working well and what needed improvement. From the 22 responses received, enthusiasm for solid-state equipment and telemetry was evident either as a good recent improvement or a needed future improvement. Improved timeliness and software were also mentioned by several respondents.

Committee discussions and presentations at the 64th Annual Meeting of the Transportation Research Board, January 14–17, 1985, were monitored to identify emerging issues, data needs, and technologies. FHWA indicated that it is probable that a shift in truck weight data priorities will deemphasize interview data obtained when trucks are stopped for weighing, and greater emphasis will be placed on obtaining unbiased weight distributions using WIM procedures for pavement and enforcement monitoring as well as for design. A number of advances in WIM technology and data analysis software were reported. A meeting held May 20, 1985 in Atlanta on WIM provided an update on the subject (*81*). It is unfeasible to include those results in this synthesis, although presentations provided up-to-date information on automated classification and speed and monitoring, as well as on WIM.

In opening remarks at a January 1985 session on WIM, Associate FHWA Administrator for Planning, Richard B. Robertson, noted that apportionment of federal-aid funds among the states should be based in part on "usage." This would require consistent reliable estimates of VMT and EAL by state. Thus, estimates of VMT on a basis that would provide comparable results among all states would become critical, as would procedures for developing comparable estimates of single-axle equivalent miles for the appropriate highway systems (*43, 82*).

PAVEMENT DESIGN, MONITORING, AND RESEARCH

The costs of pavement deterioration is a major concern. At the 64th Annual TRB Meeting, in January 1985, 23 of the 212 scheduled formal sessions were related to some aspect of pavement design, monitoring, and research. In addition, various aspects of these issues were on the agendas of a number of committees (*43, 82*).

A major effort is needed to obtain updated, comprehensive, and more reliable data on axle loading characteristics related to pavement performance. WIM obtains a number of instantaneous downward force measurements of wheels on pavement. Although considerable effort has been invested in relating WIM data to static weights transferred through the wheels, it is likely that meaningful stresses on the pavement are more closely related to recorded WIM forces than the static weight. It has been determined that very smooth approaches to WIM platforms improve correlation between static and WIM data. This would seem to imply that a smooth but skid-resistant pavement could endure a greater EAL than a rougher pavement of the same design. Similarly, a vehicle suspension system that damps out extreme oscillations or variations above the static axle weight may cause less damage because of heavy static weight than a lighter axle with more extreme fluctuations. Moisture and freeze-thaw cycles have been identified as other important variables that have not been systematically incorporated into pavement design procedures. The present WIM installations can provide a body of data on axle load frequency distributions at several hundred locations having different climates and pavement characteristics. An organized effort to obtain the needed variables on a consistent basis may now be possible.

BRIDGE DESIGN, MONITORING, AND RESEARCH

Recent improvements in bridge weighing have increased the capability for determining the actual stress cycles in the structural members of bridges. Statistical analysis of the characteristics of the stress cycles produced by different types of trucks has made possible the identification of truck types by axle arrangement (*41, 43*).

The authors point out that:

> Strain records can be analyzed to obtain lateral distribution factors, maximum stresses and impacts, all of which are important in evaluating and rating bridges. In addition, the bridge response can be measured for the relatively rare event of two heavy vehicles crossing the structure simultaneously. The measured bridge load spectra can replace conservative AASHTO rating recommendations in a reliability or probabilistic approach for a rational and consistent evaluation (*43*).

HIGHWAY COST ALLOCATION AND WEIGHT-DISTANCE TAX

The results of the Federal Highway Cost Allocation Study reported in 1982 and the 1984 Congressional mandate for the study of federal weight-distance tax suggest the need for some further data collection and research. For implementation of such a tax a reliable and legally acceptable method of determining the "weight-distance" for which a vehicle is to be taxed and the methods to ensure compliance, must be developed (*83–85*). Determining the differential amounts to tax vehicles of increasing weights is also likely to require additional research and data collection.

TRAFFIC CONTROL

As traffic control systems become more sophisticated with large networks, ramp metering, and large amounts of traffic data sensed, analyzed, and interpreted in real time for signal control, the task of making a permanent record of the data becomes substantial. Nevertheless, such data provide an opportunity to analyze very detailed time patterns. Until this is attempted, the feasibility and possibilities with regard to more reliable traffic estimating procedures are unknown. With the ever increasing computer capability at reduced costs, it would seem possible to identify detailed characteristics that could improve traffic estimates by small increments. A number of small increments might possibly accumulate to substantial improvement at small cost.

ENFORCEMENT

The speed-monitoring program was designed to monitor the 55-mph national speed limit for use by states in monitoring the effectiveness of police enforcement and by FHWA in determining which states, if any, should be subject to sanctions because of ineffective enforcement (*66*). The WIM data provide a means of monitoring the effectiveness of weight enforcement, and federal participation in WIM installations is customarily predicated on this use of the data.

Enforcement of seat belt requirements and driving-while-intoxicated laws are two additional areas of concern. Automated means for monitoring the extent of compliance with these laws have not been developed. Based on available technology it may be possible to develop procedures for automated monitoring in these areas.

Seat belt use for front-seat occupants can be recorded using video cameras mounted on sign bridges, overpasses, and other locations. It seems likely that computer programs to analyze the video image could be developed so that the seat-belt use and non-use "signatures" would be correctly determined in the majority of cases. Infrared spotlights may be capable of providing the necessary illumination without glaring in the driver's eyes.

Similarly, with currently available technology for remotely recording vehicle wheel path and speed change, it may be possible to develop a "signature" for driving characteristics associated with DWI.

SPEED MONITORING

Reliability and representativeness are the principal concerns related to speed monitoring data. On truck routes in particular, the use of radar detectors and CB radios by drivers results in almost immediate slowing of a substantial proportion of traffic as soon as radar monitoring or enforcement operations are started. Use of spaced road tubes or other highly visible sensors also causes some drivers to slow, thereby changing the speed distribution. A valid concern is that states that monitor speeds with visible radar or spaced road tubes are reporting a lower proportion of vehicles exceeding 55 mph than are actually the case. Use of permanently buried detectors causes little or no bias in speed distributions (*66*).

ACCIDENT ANALYSIS AND EXPOSURE RATES

Accident analysis results often suggest changes in established procedures and expenditures that do not directly improve mobility. Efforts to measure the effectiveness of accident countermeasures are nearly always influenced by other variables and there are difficulties in obtaining reliable measurements. The 55-mph national speed limit, for example, reduced mobility, and was accompanied by a decrease in the economy and the proportion of drivers under age 24. It may be argued that each of these phenomena would tend to reduce the fatality rate, but the contribution of each alone is difficult to determine in a way that is acceptable to the different analysts, not to mention the advocates and opponents of particular countermeasures.

NCHRP Synthesis 91 (*86*) provides a comprehensive explanation of the situation and notes that accident files, highway files, and traffic files are location specific, whereas vehicle files and driver files are not.

Accident Location Accuracy

This is a continuing problem that requires conscientious effort by a number of people, often under emergency or other adverse conditions. It is an essential element in linking accidents with highway characteristics. An effective highway location reference method, preferably tied to a photologging program, is essential.

The accident data must be carefully edited to create a computer file in which the analyst may have confidence. The roadway file must have sufficient traffic and inventory data on the sections at and leading to the accident site, so that meaningful highway-related contributing conditions can be identified and measured.

Accident Data

Reporting detail required to identify significant contributing factors can involve one or more pages of forms for each of the elements. As a result, ensuring consistent, complete, and accurate reporting is a significant management problem. There is a continuing concern for balancing the need for data against an understandable form that can be completed quickly and accurately. Details of accident reporting are discussed in Synthesis 91 (*86*).

Traffic Data for Accident Reporting

Traffic volume data, particularly ADT for all system mileage, should be in a computer file based on a location reference system compatible with the system used for accident reporting. Because traffic volume data are usually for the previous calendar year and are often based on counts that are two to five years old, a computerized process is desirable for updating traffic data in accident files, to provide traffic data for the time of the accident. Because traffic growth has been moderate in recent years, concern for a 2 to 8 percent difference caused by annual change in an estimated ADT with a standard error of 10 percent or more tends to have low priority. For some analyses, the traffic volume at the time of the accident, such as a five-minute volume converted to an hourly rate, may be a significant contributing factor. Unfortunately, accurate estimates of such values are not usually available.

Accident Rates

For accident comparisons year to year, between age groups, between highways with and without control of access, and between areas of the country, VMT estimates are used to provide rates per 100 million vehicle-miles. The most widely used VMT-based rate is annual fatalities per 100 million vehicle-miles for the nation.

With more than 40,000 fatalities and about 1.5 trillion vehicle-miles each year, a small change in rate is probably significant, but there are opportunities for error and bias in both the highway fatality and VMT figures. Fatalities that have nonhighway causes may be classed as highway, and vice versa; fatalities may not be reported because of error, deliberate concealment, or unusual conditions such as floods, hurricanes, etc. Most causes for error remain constant from year to year, whereas others, such as natural disasters, tend to have greater impact in specific years.

Because a difference of 10 fatalities per state would barely produce 1 percent difference in fatalities for the nation, a very substantial year-to-year change in reporting would be required to produce a substantial error.

On the other hand, year-to-year changes and biases in VMT estimates can result from a number of causes. Because count-based VMT estimates are lacking for nearly all local rural and urban mileage, totals must be estimated as discussed previously. The extent to which various elements are used and weighted is a matter of judgment by analysts who change from year to year. If a large state, accounting for 10 percent of total travel, revises its estimating procedure causing a 10 percent change in its base VMT value, this alone can cause a 1 percent difference in the national total. Based on these examples, it may be that a change of 1 percent or less in national fatality rate is due to error and bias, rather than a true change. As far as can be determined, no reliable measure of the error has been published in recent years.

If sensitivity tests indicate the probability of error on the order of 0.5 to 1 percent for these national values, greater error can be expected in comparisons among states, highway systems, and demographic strata.

Accident Sampling Systems

The National Highway Traffic Safety Administration, in cooperation with FHWA, was instrumental in developing FARS (Fatal Accident Reporting System) and NASS (National Accident Sampling System) (*87,88*). The intent was to provide the resources to accurately report greater detail for all fatal accidents and a sample of other accidents. Because of changes in policy on data collection and budget problems, the extent of the effort has varied from year to year.

The expectation of some highway administrators and traffic engineers was that by intensive study of a sample of locations (NASS), it would be possible to identify characteristics of highways that were significant hazards. Because a large number of highway-related variables may contribute to or mitigate against the occurrence and severity of accidents, data for a large number of accidents and locations are required to obtain statistically reliable measures of the positive and negative effects of highway attributes. It appears that these efforts thus far have not conclusively identified additional highway hazards.

The establishment of standard definitions and computerized procedures was an important aspect of this effort. There is a continuing need to combine numerous data bases. Within a state, compatibility among (a) traffic volumes, (b) accidents, and (c) the highway environment has been discussed previously. Because accidents are rare events, particularly with respect to individual highway sections, it is important that data for a number of locations in different states be available to provide an adequate sample for deriving significant conclusions concerning specific combinations of highway characteristics.

Before-and-After Accident Analysis

As resurfacing, rehabilitation, and restoration projects (3-R) have become more important, the need for objectively analyzing potential safety improvements has increased. To undertake these analyses, reliable data are required on the incidence and severity of accidents and on associated traffic volumes (*25*). From these data, accident rates may be computed and estimates developed of reduction in rates resulting from various safety improvements. Benefit-cost analysis may then be projected and safety benefits included in the priority-setting process (*86*).

Before-and-after analyses have been used for many years. In many cases a simple comparison was made of accidents occurring for several years before and after improvements were completed. Sometimes an adjustment for ADT was included, particularly where a numerical decrease in accidents was not observed. Because 3-R projects tend to include more mileage than most other projects, use of ADT makes it possible to compute benefits for alternative projects and programs. Some of the simple before-and-after analyses produce biased results and the Accident Research Manual was developed to improve the quality of accident analyses (*89*).

To undertake analyses, estimates of VMT are important and are required for each section of highway under consideration. From the accident analysis point of view, therefore, it is becoming important to obtain reliable count-based estimates annually. Where improvements induce additional traffic it may be necessary to make annual counts and check monthly factors to ensure reliable estimates of changes in accident rates (*90*).

AXLE LOAD BY LANE

Various studies have shown that on many major routes, the driving lane or lanes show much greater deterioration than the passing lanes. Thus for design purposes it is important to develop reliable estimates of EAL for each lane and, sometimes, for specific ramps, accel/decel lanes, toll booth approaches, etc. The existing WIM technology provides satisfactory data for estimating EAL by vehicle type, but additional data may be required because of variation in the proportions of heavy trucks in various lanes throughout the length of a route. Thus, less expensive automated equipment capable of classification counting by lane would be useful. Because the more lightly loaded vehicles of a given type are likely to occupy the passing lanes a higher proportion of the time, it may be desirable and feasible to use less expensive, and perhaps less accurate, WIM equipment to obtain more extensive EAL distributions for a large number of highway locations (*54*).

CHAPTER SIX

STATE OF THE ART AND IDENTIFIABLE POTENTIAL

INTRODUCTION

This chapter describes new technologies and procedures with promise for highway information collection and analysis. Several of these have been demonstrated to be technically workable. Others, such as pattern recognition and optical disc technology, are used extensively in other fields but are used only to a limited extent for traffic data collection and analysis. Cunagin et al. (*91*) provide detailed information on current development and operation of portable sensors for traffic data collection, such as tape switches, piezoelectric and coaxial cable, and inductance loops.

HARDWARE AVAILABLE AND UNDER DEVELOPMENT

Automatic Vehicle Identification (AVI)

Roadside equipment capable of interrogating passive transponders mounted on trucks is being tested at several locations in Oregon and other states. The transponders have been mounted on 200 trucks belonging to 21 firms operating in Oregon (*92*). The transponders provide a unique identifying number when interrogated. The location, date, time, direction of travel, speed, axle weights, and vehicle number are fed to a central computer. The companies owning the trucks can interrogate the state's central computer and retrieve all data for their own vehicles, but not for those belonging to others. Most companies participating in the tests are pleased with this ability to find out where their vehicles are traveling. State analysts can prepare weekly summaries for all transponder-equipped trucks operating in the state (*41, 43, 92*). Further testing planned for Interstate highways from Washington to Texas has resulted in the name "Crescent Study." The Crescent Study expects to have 10,000 vehicles from 200 companies equipped with transponders (*92*).

In addition to recording location, time, speed, and weight for individual vehicles, with sufficient roadside monitoring locations it would be possible to monitor travel time, hours on duty, down time, and vehicle miles of travel. With additional circuits it would be possible to feed the odometer reading to the transponder. This would make possible accurate weight-distance taxing and prorating of fuel tax under the International Registration Plan and similar compacts. In many states the interrogating device can be located at ports of entry; thus it would be possible for the transponder-equipped vehicles to bypass the entry station whereas vehicles without transponders would be required to stop for the usual paperwork. This would provide an economic and psychological incentive for participation in the automated program.

Automated Classification

Automated equipment can operate continuously for a long period and is consistent in recording what is sensed. Most existing automated classification is based on sensing the passage of axles at two closely spaced locations along the road. The latest equipment uses spacing of about six feet or less, making it feasible to identify all axles of a multi-axle vehicle correctly. Automated equipment now measures vehicle speeds and determines number of axles and their spacing. Because the majority of vehicle classifications are based on axle arrangement, this provides speed distribution data by vehicle type.

As discussed previously, TRRL has tested equipment that uses inductance loops and a tape switch to determine the height or mass of the vehicle and the track of the vehicle (*41*). This makes possible differentiation between autos with trailers and large combinations having similar axle configuration. Differentiation between dual tire and single tire and between wide track and narrow track will improve the proper identification of large passenger vehicles and small trucks. Tape switches and coaxial cables have been developed with the capability of making these measurements, but they appear to be short lived under traffic. The TRRL analysis showed that speed, axle spacing, overall wheelbase, front and rear overhang, and overall vehicle length could be obtained automatically (*41*).

Vehicle "Signature" for More Accurate Bridge WIM

The traces produced by each transducer used in a bridge weighing system were analyzed and compared with the axle arrangements of the vehicle involved. Distinctive sets of trace patterns were identified (*54*). Using this set of information, termed the "signatures," it was possible to develop programs that consistently identified vehicles in the traffic stream by vehicle type (based on axle arrangement as well as axle weight) with a high degree of reliability.

Algorithms have been developed for efficiently checking data related to an identifiable condition or event among a large mass of similar data to develop the signature for the condition or event of interest. Masses of data can then be systematically examined for patterns of data for which a signature has been established. A match indicates the presence of the specific condition or event.

Indications are that these procedures have been successfully tested to provide finer vehicle type identification than is possible when based on axle spacing alone. In the case of WIM and AVC, the data can be derived from inductance loops, strain gages, sonar, radar, road tubes, piezoelectric coaxial cable, and so on. The details are considered proprietary by manufacturers. From reports of TRRL studies, it known that different body types and types of loads influence the response patterns of inductance loops (*41*).

WIM

The Transport and Road Research Laboratory in Crowthorne, England has been working with a French manufacturer of piezoelectric coaxial cable containing a highly compacted lead ceramic powder. As a load is applied by a tire rolling across the cable, an electrical charge is generated that varies with the load. The characteristics of these variations have been analyzed. Correlation with wheel weights and vehicle characteristics have been developed. Repeatable results have been achieved with an improved algorithm providing a standard deviation of about 10 percent (*43*).

Irregularities in the road surface, particularly rutting in wheel tracks, causes inconsistencies. In addition, rigorous quality control is required in many phases of the construction and assembly of the cable. As a result, the cable will be fairly expensive. Future increased demand and development of more economical fabricating techniques can reduce costs significantly.

Reliable portable WIM equipment would provide the capability to determine the characteristics of heavy vehicles at different locations along a truck route and the associated EAL values. It is postulated that design economies could be achieved by identifying areas of lighter loading on routes being designed for very heavy truck traffic. It would also provide the research capability of associating axle loads more exactly with the performance of particular traffic lanes in short pavement test sections (*36, 43*).

Optical Disk Technology

The permanent storage and retrieval of random access graphic or digital records is now possible and commercially available. The graphic information is etched on a metal disk using a laser beam that creates pits of varying depths and shapes. This is then covered by a transparent plastic protective layer. A laser beam focused on the pits can then read the data back from the disk (*93*).

It is possible to record up to 14 billion pits (roughly equivalent to bits on a digital basis) on one side of a 12-in. disk, or about 2000 megabytes of digital data. More than 50,000 video or photo frames can be stored on one side. Degradation from frequent read back, environmental factors, and scratches in the surface of the protective coating (which are not recognized) is negligible compared to other electronic storage media. It is capable of storing both digital and graphic data from a record such as a photograph. In this way it is possible to catalog for computer search, analysis, and summary, digital captions and related data such as provided by photologs.

Laser disk technology has been used extensively in the entertainment industry for creating a disk from which both music and video sequences can be played. Computers have been used to enhance musical recordings, interpret air photos, and aid in engineering drafting. For traffic data, this suggests that analysis of video road logs and video tapes of traffic movement and traffic operations could be automated. Whether existing software can be adapted to traffic analysis, or whether custom programs are required, was not determined (*94*).

Using present industry standards, the quality of photo images produced from the disk is comparable to the best quality video image. Where higher resolution is required, the catalog data can be used to identify the file containing the original plans, the photo negative, or other source. By using more tracks per image, the technology is available to obtain extremely high resolution. The "industrial" readers cost about $3,000, whereas home readers are under $1,000 and some of limited capability may be available for under $500. The cost of preparing one disk for use from paper files is on the order of $3,000 with the cost reduced for video tapes or computer tapes.

COMMERCIAL COMPUTERIZED DATA BASE

For a number of years, commercial data base services, such as CompuServe, Dialog, and The Source, have provided computer readable files and analysis software to subscribers having computer terminals. As indicated by survey responses, several states have some traffic data in data bases accessible to several computers. The state police and DMV field offices in most states have access to vehicle registration and driver license files through computer terminals.

Of particular value to transportation planners are the efforts of the Bureau of the Census to make available some 1980 Census data on a similar basis. Consideration is being given to procedures for making other Census data, such as the public use files for the 1980 Journey to Work data, the Nationwide Personal Transportation Study, and the Truck Inventory and Use files, available in a similar manner.

With the development of standard software with adequate prompts for the occasional user, such procedures could provide usable data at an early date and without extensive correspondence concerning availability, format, and processing procedures.

IMPACTS OF TELEPHONE DEREGULATION

The questionnaire did not request information on telemetry costs. Because none of the responses mentioned increased line charges as a problem, it appears that with deregulation there have been few substantial increases, and there may have been some decreases. Since deregulation, the local phone company is generally responsible for providing the service up to the jack, and subscribers can use whatever equipment they wish to plug in. Thus, deregulation may actually have decreased problems in some areas.

SATELLITE FEED

Some large states have considered the use of satellites for transmission of telemetry and other data from remote locations. Generally where this is advantageous, such as from Fairbanks to Juneau, the telephone company that provides the necessary service often transmits via satellite. Routing may be different for different calls between the same points, depending on availability and load on land lines, microwaves, and satellites.

STATISTICAL SAMPLING

As discussed elsewhere in the synthesis, there have been no recent improvements in data reliability that can be attributed to statistical studies. Rather, studies have determined that a more convenient or economical procedure is not significantly worse than previous practices. FHWA's HPMS-related traffic counting procedure provides for grouping by pattern group within functional system, rather than by pattern group alone, as originally suggested by Petroff and Blensly in 1954 (*1, 90*). The HPMS data are logically related to the functional systems. Although FHWA requested states to report any statistical reliability studies, results were not available in time for this synthesis.

Tests were made of VMT estimating procedures in connection with NCHRP Project 8-20 (*3*). Reliable count-based VMT estimates for local roads and streets would provide a substantial improvement in planning data, but procedures have not been developed and implemented apparently because of cost and policies discouraging the collection of such data.

Several states have done statistical studies to establish less expensive procedures for obtaining or analyzing data.

New York ADT Estimating

A New York study resulted in a saving in computer time for ADT estimating, validated manual factoring procedures used by some field offices to obtain immediate results for special counts, and identified "best" (maximum similarity of monthly factors) periods for counts (*95*).

The aim of the New York study was to cut traffic counting costs by 30 percent, while doing the minimum damage to the reliability of data and credibility of reported results. This was achieved by eliminating a three-year count cycle on road sections believed to experience slow stable growth and by eliminating seasonal counts to determine the shift of road sections among pattern groups. These changes were supported by a statistical analysis that showed that for the months of June and September the factors for all groups were clustered, and that a total of four groups, compared to the previous eight, provided expansion factors with a coefficient of variation well below 10 percent for most months when counting was likely to be conducted. The error band for monthly expansion factors was somewhat greater than for the eight groups.

It was found that the four groups were associated with rural/urban and access control characteristics. These associations could then be used to help assign road sections to pattern groups for expansion.

Also included in the report are 1-way DHV values (30th highest hour) for each of the pattern groups, only one of which is greater than 10 percent. It is stated that further study of DHV is desirable.

Thus, to achieve economies a trade-off must be made in this procedure using a greater amount of guided judgment and less data to assign road sections to pattern groups, and to omit sections judged to be "slow growth" from the three-year count cycle. The New York study provided guidance to minimize the loss in reliability associated with less data.

Alaska and Washington Statewide Counting

Studies of counting procedures for the states of Alaska (*96*) and Washington (*97*) include statistical procedures that analyze and exploit the advantages of stratification. The results of the Washington study are described in a paper by Ritchie for TRB presentation that provides extensive background and summarizes recent efforts (*97*).

Wisconsin Selection of Representative Weight Sites

A statistical analysis of data obtained at truck weight stations was used to develop a cluster sampling plan to locate weight stations on each non-local functional system (*98*). The values used were the mean gross weight for each vehicle type and its coefficient of variation for each functional system. Counties were used as the basis for cluster selection. It was found that the number of practical locations on a particular functional system within a county was limited by practical considerations.

These considerations included: (a) sufficient truck volume so that the crew is not idle and data are useful for design, enforcement, monitoring, etc.; (b) avoidance of atypical locations; (c) closeness to other traffic stations for correlation of data; (d) workable location with adequate sight distance, space for truck queing and weighing, etc.; and (e) minimum feasibility of trucks bypassing weigh site by use of other routes.

Status of Statistical Studies

The New York and Wisconsin studies were the only statistical studies identified for this synthesis (*95, 98*). The NCHRP Project 8-20 report (*3*) contains a good analysis of a stratified sampling system for obtaining VMT estimates for all systems. It showed that reliable statistically controlled estimates for low volume mileage is relatively expensive, particularly if there is a need to determine which of two areas show the greatest annual growth.

A number of reports of data were received that demonstrated the use of various techniques. Some of these have been mentioned in the text.

Fertile Ground

With the concern for EAL data, there is a need to develop procedures to estimate ADL for road sections where weight data collection is impractical. In connection with the 1957–1962 cost allocation study, some ad hoc analysis indicated that trucks of a given type tended to have similar weight characteristics wherever they traveled, with a few identifiable exceptions (e.g., loaded 3-S2 log trucks on local rural roads were heavier than the average 3-S2). As a result it was judged that by obtaining classification counts on any road section it was possible to estimate weight-related values with adequate reliability for cost allocation. The availability of bridge WIM makes possible the updating and validation of this judgment, and a basis for developing a statistically controlled estimating procedure acceptable to designers and other users of ADL and weight-related data.

As stated in the New York study of DHV factors, development of a standard method for deriving this value is worthwhile (*95*). The use of existing 30th highest hour values requires judgment, since any level of service may be occurring during the 30th hour on particular facilities.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Traffic sensing and recording technology is experiencing rapid advances. Breakthroughs are proceeding rapidly in WIM and solid-state data recording. Computer analysis technology and the use of minicomputers is well established, but has not yet been fully implemented and exploited.

Data needs remain largely unchanged in terms of data items needed for design, program monitoring, and policy development, but new concerns change the emphasis and the amounts of data required. Six data items have accounted for practically all roadway data collection since the early 1930s or before. These are (a) vehicle volume, (b) vehicle characteristics, (c) vehicle speed, (d) axle weight, (e) accidents, and (f) origin-destination. An additional essential data item is mileage, although this is not strictly a traffic data item. The time intervals, details of characteristics, and association among the data items has become more complex. The 1970s saw emphasis on speed data related to fuel conservation while the 1980s have experienced emphasis on axle weight related to vehicle characteristics in connection with cost allocation and pavement design and monitoring.

Since the 1930s when comprehensive traffic data collection was implemented by all states, labor costs have increased much more than equipment costs. From a statistical sampling perspective, the result has been that spatial sampling costs have increased while temporal sampling costs have decreased. This suggests that procedures should be aimed at exploiting the extensive time series data from the relatively few road sections where continuous data collection is under way. Detailed analysis of relationships may lead to procedures that improve the reliability of estimates for the many road sections where short counts are rarely obtained.

Relative cost and the need for particular types of data indicate that manual traffic counting and interviewing will continue to be an essential element in transportation data collection. Although it is conceivable that equipment can be developed to automatically determine the use of seat belts, distinguish between mini vans used for passenger and cargo transportation, or determine turning movements at an intersection, it is unlikely that the cost of set up and operation will be less than manual procedures.

RECOMMENDATIONS

Most of the recommendations that result from this synthesis would fall in the category of "keep up the good work and try to do it a little faster."

Continuous count data have been obtained on an hourly basis for decades, but little analysis has been done in an attempt to generalize long-term relationships. For example, an association between 30th highest hour and DHV has long been recognized. The data could be analyzed to determine how and why the 30th highest hour increases in absolute value and decreases as a percent of ADT over time, usually accompanied by a decrease in level of service.

There is need for an efficient generally accepted procedure for estimating ADL for any road section. Use of portable WIM equipment promises the capability of obtaining sample axle weight data for low-volume roads.

There are possibilities of reducing the costs of volume counts through refinement of expansion procedures to reduce the frequency of ground counts. With greater availability and reduced costs of computer processing, it may be economical to use extensive historical ATR data and more complex expansion procedures, so that ground counts 3 to 10 years old can provide ADT estimates of acceptable reliability.

Pattern recognition procedures offer possibilities for improving the efficiency of expansion procedures using the permanent station and other available data to produce reliable estimates from minimal link data. Pattern recognition is a step beyond regression and cross classification, because it searches out variables useful for identifying a particular condition. For example, it may be that in estimating ADT for road sections in a particular category, a 10-year-old count in combination with data on improvements, population, weather data, demographic trends, etc., can produce a better estimate of ADT than a current-year count expanded by a questionable pattern group factor. For a similar section in a different population density area, it may be that the relationship of 8 a.m.- to 10 a.m.-volume to the 24-hour volume in the 10-year-old count and the CPI are key items. The analysis to identify these patterns is extensive and requires data for a number of similar road sections for which true data for the dependent variable are available. The extensive historical ATR data for the nation as a whole combined with reduced computer costs may make such pattern recognition analysis possible.

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APPENDIX

DETAILED DATA OBTAINED FROM SURVEY AND FROM FHWA

Data in the following tables were obtained from responses to a 1984 survey of states, provinces, and other highway agencies and from data in a computerized inventory maintained by FHWA (22). Because of continuing updates in equipment and aquisition of new equipment, these data may change over time.

TABLE A-1

COUNT SITES BY EQUIPMENT MANUFACTURER

	Airtube		Inductance Loop		Other		
Agency	Make[a]	Sites	Make	Sites	Make/Type	Sites	Total
Alabama	SA	6,000	GR, SA	174			6,174
Arizona	SA	700		49			749
Arkansas	KH	12,700	SA	24	SA (magnetometer)	2	12,726
California		5,900	Saf, [b]	600			6,500
Connecticut	SA	5,500	SA	38			5,538
Delaware	SA	1,600	SA, Sar	86			1,686
Florida	SA	8,400	Sar	87			8,487
Georgia		25,375		107			25,482
Hawaii	LS, SA	300	SA	5			305
Illinois	SA	19,150	SA	175			19,325
Indiana	SA	5,500	SA	44			5,544
Iowa	LS, SA	9,290	SA	106			9,396
Kansas	SA	7,787					7,787
Louisiana	FP, LS, SA	6,200		25			6,225
Maryland		1,300		42			1,342
Massachusetts		1,744		91			1,835
Minnesota	SA	13,000	SA	117			13,117
Mississippi	SA	4,000		30			4,030
Nebraska	KH, SA	4,052	SA	43			4,095
New Jersey	FP, SA	1,715	FP, SA	76			1,791
New Mexico	SA	1,700	SA	57			1,757
New York	FP, LS	7,300	FP, GR	453			7,753
Ohio	FP, KH, SA	3,350	SA	150			3,500
Oregon	KH, LS, SA,	7,342[c]		107	Magnetometer	8	7,457
Pennsylvania	SA	3,500	SA	67			3,567
Rhode Island	SA	10	SA	32			42
South Carolina	KH, SA	13,500	SA	21			13,521
South Dakota	KH, SA	1,372	SA	69	SA (magnetometer)	1	1,442
Tennessee		9,916		35			9,951
Texas	SA, Unitech	43,000	FP, SA	146			43,146
Utah	FP	1,200		72			1,272
Vermont	LS	600	LS	60			660
Virginia	KH, SA	49,878	SA	66			49,944
Washington	FP, LS	2,281	GR, SA	65			2,346
West Virginia	SA	2,400	SA	142			2,542
Wisconsin	FP, KH, LS	6,809		158			6,967
Wyoming	GR, LS, SA	3,750	GR, Saf,	51			3,801
District of Columbia	FP, GR, LS	560	FP, GR, LS	16			576
Alberta Rec. & Parks	KH, LS	32	FP, LS, M&K	20	SA, Scientific Dim.	21	1061
Alberta Trans. Systems			GR, LS, Int.	234			234
Nova Scotia	SA	380	SA	20			400
N. W. Territories		12	FP, LS	20			32
Ontario	FP, GR, LS	1,770		450	Photocell, probe	100	2,320
Saskatchewan	LS	880	LS	30	Radar, photocell	25	935
Durham, N, C.	SA	200					200
Wilmington, N. C.	Econolite	411	SA	23			434
Illinois Tollway		280		35	Treadle, photocell	35	385
Kansas Turnpike					Treadle	16	16
West Virginia Turnpike					Treadle	5	5
Total		302,646		4,518		1,236	308,400

[a]FP = Fisher-Porter; GR = Golden River; KH = KayHill; LS = Leupold & Stevens; SA = StreeterAmet; Saf = Safetran; Sar = Sarasota

[b]Conga, DetectorSyst, 3M

[c]Even years; 5,089 in odd years.

TABLE A-2

AUTOMATIC TRAFFIC RECORDING EQUIPMENT AND SITES (FHWA, OCTOBER 1985) (22)

State	Make, model and sensor	Number of units	Number of sites	Number with telemetry	Power type	Year of first use
Ala.	Golden Rv. 331 loop	13	13	13	solar	1983
	" " 331 "	33	33	33	AC	1982
	Streeter-Rich. 505-A loop	41	41	41	AC	1980
Alask.	Golden Rv. GR331 tube/loop	3				1985
	" " GR357 loop	2				1985
	Leupold-Stev. 7951-2 probes	3	3		AC	
	" " 7952-2 probes	23	23		AC	1977
	Streeter-Rich. MR	11	9		AC	
	" " MR103B tube	9	15		DC	1975
	" " MR202B magnetom.	3	3		AC	1975
	" " RCHT tube	4			DC	1956
	" " 101A tube	30	800		DC	1976
	" " 103A probes	13	14		DC	1971
Ariz.	Golden Rv. loops	25	25	25	AC	1984
	" " 0331 loops	53	3	3	AC	1982
Arkan.	Streeter-Rich. RC magnetometer	2	2		AC	1980
	" " 141 loops	24	23		solar	1980
Cal.	Fischer-Porter 1544 loop	200	200		AC	1961
	" " 1546 tube	100	100		DC	1961
	Leupold-Stev. 7551 tube	100	100		DC	1978
	" " 7552 loop	100	100		AC	1978
	" " 7553 tube	100	100		DC	1978
	" " 7554 tube	100	100		DC	1978
Colo.	Golden Rv. GR0340 loop				AC	1966
	" " GR0340 loop				AC	1976
Conn.	Streeter-Rich. MR101 tube	150	1,100		DC	1973
Del.	Sarasota VC1900	31	31		AC/DC	1984
D. C.	Fischer-Porter tube	26	550		DC	1968
	Golden Rv. GR0331 loop/tube	43	29		solar	1982
Fla.	Digital Equip. 11/23+	1	1	9	AC	1974
	Hewlett Pack. 2100A	1	1	80	AC	1974
	Safetran DPC	100	80	80	AC	1974
	Sarasota VC1900	18	9	9	DC	1984
Ga.	Streeter-Rich. 505 loop	74	69	69	AC/DC	1978
Hawaii	Streeter-Rich. MR101 tube	20	200		DC	
	" " MR103 "	9	5		DC	
	" " MR111 "	21	200		DC	
	" " 141-A	12	10			
	" " 505A loop	3	1	1	DC	1978
	" " 505B loop	4	4	4	DC	1982
Idaho	Golden Rv. GR0334A loop	2	2		AC/solar	1985
	Streeter-Rich. 141 loop	10	11		solar	1980
	" " 202MR loop	26	30		AC	1977
	" " 206T loop	6	12		AC	1962
	" " 505B-1 loop	24	22	22	AC	1980
Ill.	Fischer-Porter 1544 loop	9	8		DC	1963
	" " 1544 loop	104	73		AC	1963
	" " 1544 loop	4	3		solar	1963

TABLE A-2 (continued)

State	Make, model and sensor	Number of units	Number of sites	Number with telemetry	Power type	Year of first use
Ind.	Streeter-Rich. MR101-A tube	12			DC	
	" " MR101-B tube	101	4,800		DC	
	" " MR112B loop	29	14		DC	1978
	" " MR202A loop	17	1		AC/DC	1976
	" " MR202B loop	37	27		AC/DC	1971
	" " 141-A loop	4	2		AC/DC	1982
Iowa	Streeter-Rich. 505C loop(?)	69	69	69	DC/solar	1983
Kan.	Fischer-Porter 1544 loop	60	51		AC	1963
	" " 1544 magnetom.	2	2		AC	1963
	" " 1544 loops	3	3		solar	1963
	" " 1546 tube	3	3		DC	1967
	" " 1546	12				1963
	" " 1546 loops	3	1		solar	1967
	K-Hill portable new tube	42	37			1974
	" " old tube	67	37			1957
	" " unknown tube	3	3		DC	
	Leupold-Stev. 7052 loops	1	1		solar	1980
	" " 7052 loops	23	15		AC	1980
	Streeter-Rich. JR160 tube	108	37			1978
	" " MR101 tube	20				1978
	" " 161-2 loops	2	2		DC	1980
	" " 206 loops	8	8		AC	1957
	" " 206 magnetom.	2	2		AC	1957
	" " 206-4 loops	9			DC	1957
	" " JR160 tube	108	37			1978
Ky,	Fischer-Porter 1544 loop	65	55		AC	1962
	" " 1546 tube	196	45		DC	1962
	Stevens PPR2 7551-1 tube	26	45		DC	1981
	" PPR2 7551-2 tube	14	45		DC	1976
	" PPR2 7553-2 tube/loop	28	45		DC	1976
	" PPR2 7952-2 loop	7	2		AC	1982
La.	Fischer-Porter 1546 w/Sarasota	35	20		solar	1985
	Leupold-Stev. PPP-2 w/Sarasota	25	16		AC	1960
	Streeter-Rich.	20	20	1	solar	1985
Maine	Stevens 7951-1 tube	14	280		DC	1979
	" 7952-1 loop	18	11		AC	1979
	Streeter-Rich. MR101B tube	27	1,674		DC	1977
	" " MR202 loop	12	5		AC	1977
	" " RCHT tube	43	2,666		DC	1967
	" " 206 loop	22	14		AC	1966
Md.	Streeter-Rich. MR103A tube/loop	100	400		DC	1970
	" " MR103B tube/loop	150	600		DC	1978
	" " MR202 loops	100	42	7	AC	1978
Mass.	Fischer-Porter loops	46			AC	1968
	Leupold-Steve. class loops	14	1		DC	1983
	" " P/PUN loops	34	1		DC	1981
	" " P/PUN loop/tube	73	48		DC	1967
	Streeter-Rich. 101-AB loop/tube	84	49		DC	1974

TABLE A-2 (continued)

State	Make, model and sensor	Number of units	Number of sites	Number with telemetry	Power type	Year of first use
Mich.	Computer Automatn. ALPHA16 loop	7	2	2	AC	1974
	" " LSI-2 loops	4	1	1	AC	1976
	" " 808 loops	13	2	2	AC	1969
	Safetran 801-803 loop	46		7	AC	1970
	Mich. Inhouse loop	61	61	61	AC	1981
Minn.	Streeter-Rich. 505C loop	120	120	17	AC	1984
Miss.	Streeter-Rich. MR loop	63	44	1	solar	
	" " RC-H loop	15	15		AC	
	" " 141-4 loop	11	11		solar	
Mo.	Fischer-Porter 1544 loop	65	38		AC	1962
	Golden Rv. 331 loop	21	21	21	AC	1985
	" " 334 loop	40	40	40	AC	1985
	" " 340 loop	2	2	2	AC	1985
Mont.	Streeter-Rich. MR212 loop	29	28		AC	1977
	" " MR214 loop	4	4		AC	1981
	" " 206	14	11		AC	1964
Neb.	Streeter-Rich. 505-C loop	9	9	9	AC	1985
	" " 505-C loop	35	35	35	solar	1985
Nev.	Fischer-Porter 1544 loop	4	2		AC	1976
	" " 1546 loop	1	1		DC	1975
	" " 1546 loop	1	1		DB	1981
	" " 1546 loop	6	6		DC	1976
	Golden River 331 loop	3	3	3	solar	1982
	" " 331 loop	1	1	1	AC	1983
	" " 331 loop	2	2	1	solar	1985
	" " 331 loop	1	1		solar	1984
	" " 331 loop	3	3		AC	1984
	" " 331 loop	4	4	4	solar	1983
	" " 331 loop	8	8		solar	1983
	" " 334 loop	2	2		solar	1983
	" " 334 loop	2	2		solar	1985
	" " 334 loop	1	1		solar	1984
	" " 334 tube	2	2		solar	1984
	" " 334 tube	2	1			1984
	" " 334 loop	1	1		solar	1984
	" " 334 loop	2	2	1	solar	1983
	" " 334 loop	1	1	1	solar	1982
	" " 334 tube	1	1		solar	1983
N. H.	Leupold-Stev. 7551-1 tube	1	12		DC	1976
	" " 7551-2 loop/tube	17	187		AC/DC	1976
	" " 7552-2 tube	4	48		DC	1976
	" " 7945-A loop/tube	5	16		AC/DC	1980
	" " 7951-2 loop/tube	19	152		AC/DC	1980
	" " 7954-2 loop	4	4		AC/DC	1982
	" " 8263 loop	13	13		DC	1984
	" " 7554-2 port. tube	4	48		DC	1979

TABLE A-2 (continued)

State	Make, model and sensor	Number of units	Number of sites	Number with telemetry	Power type	Year of first use
N. H.	Streeter-Rich. MR103A tube	10	120		DC	1974
	" " RCH loop/tube	32	153		AC/DC	1962
	" " RCHETA loop/tube	6	39		AC/DC	1969
	" " RCHT tube	27	324		DC	1964
	" " 202-1 loop/tube	6	61		AC/DC	1972
	" " 206 loop/tube	8	30		AC/DC	1963
	" " 206T loop/tube	3	25		AC/DC	1967
N. J.	Fischer-Porter loop	47	47		AC	1974
	Streeter-Rich. tube	54	1,500		DC	1974
	" " tube	59	1,500		AC	1974
N. M.	Streeter-Rich. MR103 loop/tube	29	1,500		DC	1965
	" 505A loop	102	57	62	AC	1975
N. Y.	Leupold-Stev. unk. mod loop	1	1	1	AC	1982
	" " 7051 loop	6	10		DC	1976
	" " 7051 tube	57	12		DC	1976
	" " 7054 loop	14	10		DC	1977
	" " 7954 loop	2			DC	1976
N. C.	Streeter-Rich. 202 loop	81	62		AC	1972
N. D.	Streeter-Rich. 505C loop	43	40	40	AC	1978
Ohio	Streeter-Rich. 141-A4 loop	50	149		AC/DC	1983
	" " 141-4 loop	60	51		AC/DC	1983
Okla.	Traffic Data Syst. DFC824 loop	52	44	44	AC	1976
Oreg.	Streeter-Rich. MRP202 loop	6	3		AC	1973
	" " MR121B loop	30	22		AC	1980
	" " 206 magnetom.	8	8		AC	1937
	" " 206 loop	101	82		AC	1937
Penn.	Streeter-Rich. 505C2 loop	2	2	2	solar	1984
	" " 505C2 loop	59	59	59	AC	1984
R. I.	Streeter-Rich. 141-4 tube/loop	35	70		AC/DC	1981
S. C.	Streeter-Rich. 202B loop	29	20		AC	1972
	" " 214B loop	2	1		AC	1980
S. D.	Golden Rv. GR331 loop	57	50	50	solar	1984
	K-Hill Flow tube	100	2,205		DC	1969
	Streeter-Rich. 163 tube	32			DC	1985
	" " JR tube	100	1,530		DC	1947
	" " MR202A1 tube	29	(in storage)		DC	1975
	" " 101B1 tube	51	765		DC	1977
	" " 103B1 tube/loop	47	47			1977
	" " 202A tube	31	(in storage)		DC	1974
	" " 202B1 tube	4	(in storage)		DC	1977
Tenn.	Streeter-Rich. MR101 tube	33	900		DC	
	" " 141-4 loops	39	34	12	solar	
	" " 141-4 tube/loop	140	9,150		DC	
Texas	Fischer-Porter 1546 tube?	197	82		AC	1963
	Sarasota VC1600 loop?	110	29	29	AC	1985
	Streeter-Rich. 505C loop?	55	40	40	AC	1983
Utah	Streeter-Rich. 505C loop	76	72	70	solar	1982
Vermt.	Leupold-Stev. PFR2 loop	55	55		DC	1970
	" " PPR2 tube	39			DC	1970
Va.	K-Hill JR tube	100			DC	
	Leupold-Stev. PR tube	18			DC	

TABLE A-2 (continued)

State	Make, model and sensor	Number of units	Number of sites	Number with telemetry	Power type	Year of first use
	Streeter-Rich. JR tube	100			DC	
	" " 101A,B tube	129	5,140		DC	
	" " 102-A loop	20	80		DC	1978
	" " 141-A loop	25	114		DC	1984
	" " 141-A tube	37	1,200		DC	1984
Wash.	Fischer-Porter 1546 loop	2	2		AC	1974
	Golden Rv. 331 loop	20	20	20	AC	1983
	" " 334 loop	32	32	32	DC	1983
	" " 340 loop	14	14	10	solar	1983
W. Va.	Streeter-Rich. 101 tube	85			DC	1972
	" " 103 loop	3			DC	1971
	" " 103-A loop	11			DC	1975
	" " 103-B tube/loop	18			DC	1978
	" " 202 loop	54	38		AC	1973
	" " 202 loop	13			DC	1973
Wisc.	Streeter-Rich. 505B loop?	90	70	70	AC	1981
Wyo.	Golden Rv. GR0331 loop	9	9	9	AC	1982
	" " GR0331 loop	21	21		DC	1983
	" " GR0331 loop	7	7	7	solar	1983
	Safetran DPC-824 loop	62	48	48	AC	1977
	Streeter-Rich. 505C loop	3	1	1	DC	1985
Total	51 States (incl. D.C.)	7,351	44,120	1,281	494 solar sites	

TABLE A-3

SCHEDULING OF VOLUME COUNTS BY HIGHWAY CATEGORY

	Interstate			Other State Routes			Other Roads and Streets		
Agency	Miles	Counts	Mi/Count	Miles	Counts	Mi/Count	Miles	Counts	Mi/Count
Alabama	824	212	3.9	9,900	3,830	2.6	3,000	2,450	1.2
Arizona	1,163	4,924	0.2						
Arkansas	541	900	0.6	15,564	4,300	3.6	60,949	7,200	8.5
California	2,260	2,050	1.1	12,923	4,450	2.9			
Connecticut	523	1,746	0.3	3,379	2,166	1.6	15,632	1,594	9.8
Delaware	41			921			4,318		
Florida	1,266	476	2.7	11,464	7,914	1.4	86,258		
Georgia	1,181	475	2.5	16,831	17,60	1.0	89,969	7,240	12.4
Hawaii	36	18	2.0	1,000	3,001	3.3	3,100	101	31.0
Illinois	1,711	740	2.3	15,596	11,428	1.4	118,920	7,239	31.0
Indiana	1,122	733	1.5	10,209	3,029	3.4	80,405	1,584	50.8
Iowa	1,050	1,227	0.9	9,069	1,111	8.2	102,364	2,836	36.1
Kansas	630	1,207	0.5	7,550	3,936	1.9	4,500	2,644	1.7
Louisiana	684	80	8.6	15,726	4,000	3.9	45,000	12,000	3.8
Maryland	1,100	179	6.1	4,000	41	97.5	24,000	753	32.9
Massachusetts	562	80	7.0		320			400	
Mississippi	686			9,630			9,395		
Nebraska	482	90	5.4	9,406	2,760	3.4	82,013	1,002	81.8
New Jersey	340	195	1.7	1,909	856	2.2	31,622	684	42.2
New Mexico	1,000	300	3.3	11,400	1,000	11.4	65,750	400	164.4
New York	1,490	400	3.7	14,680	4,000	3.7	93,376	2,000	46.7
Ohio	1,293	40	32.3	17,923	101	177.5	91,688	57	1,608.6
Oregon	720	263	2.7	6,842	7,709	0.9	6,152	4,334	1.4
Pennsylvania	1,100	350	3.1	4,600	5,400	0.9	400	250	1.6
Rhode Island	70	13	5.3	976	27	36.1	5,209	2	2,604.5
South Carolina	756	430	1.8	39,171	6,525	6.0	23,337	6,525	3.6
South Dakota	679	162	4.2	7,196	1,073	6.7	75,340	202	373.0
Tennessee	1,029	296	3.5	9,031	7,118	1.3	73,691	2,502	29.5
Utah	805	322	2.5	4,900	550	8.9	40,400	200	202.0
Vermont	200	18	11.1	2,323	635	3.7	2,628	600	4.4
Virginia	1,002	29	35.5	52,037	44,500	1.2	12,597	5,000	2.2
West Virginia	479	70	6.8	33,268	2,058	16.2	2,837	414	6.9
Wisconsin	578	580	1.0	11,343	2,800	4.1	96,173	3,600	26.7
Wyoming	916	250	3.7	5,466	3,000	1.8	31,787	300	106.0
District of Columbia	12	10	1.2	428	600	0.7	672	150	4.5
Alberta Trans. Sys.	14,500	450	32.2	15,500	50	310.0			
Nova Scotia	697	100	7.0	6,112	300	20.4	9,000	75	120.0
N.W. Territories				1,366	16	85.4	767	4	191.8
Ontario	249	320	0.8	3,728	1,900	2.0	16,156	1,000	16.2
Saskatchewan	1,975	400	4.9	9,707	1,200	8.1	2,230	100	22.3
Durham, N.C.					85			115	
Wilmington, N.C.								50	
Milwaukee, Wisconsin	68	0					1,374	687	2.0
Illinois Tollway	158	211	0.7	98	69	1.4			
Kansas Turnpike	187	14	13.4	50	1	50.0	3	1	3.0
W. Virginia Turnpike	88	5	17.6						
Total	45,526	20,365	2.2	402,671	157,199	2.6	1,399,299	76,404	18.3

TABLE A-4

EQUIPMENT FOR RECORDING AND STORING TRAFFIC VOLUME DATA

	Mechanical Accumulator		Printed Tape		Punched Tape		Cassette Tape		Solid-State			
Agency	Make[a]	No.	Make	No.	Make	No.	Make	No.	Make	No.	Other	Total
Alabama	SA	5,000	SA	1,000					GR,SA	174		6,174
Arizona	SA	1,000							GR	400		1,400
Arkansas	KH	12,400	SA	350					SA	24		12,774
California	SA	1,500			FP,LS				Sar	10		1,510
Connecticut			SA	5,500					SA	24		5,524
Florida	SA	8,400							Saf	87		8,487
Georgia	SA	3,800	SA	192	LS				SA, b	89		4,081
Hawaii			SA		LS				SA			
Illinois	SA	19,000	SA	325	FP	82						19,407
Indiana			SA				SA					
Iowa	SA		SA		LS				SA			
Kansas	SA	7,750	SA	37								7,787
Massachusetts			SA	1,700	FP,LS	134						1,834
Minnesota	SA	11,000	SA	2,000	SA	117						13,117
Mississippi		3,500		500				400				4,400
Nebraska	KH,SA	1,030	SA	2,822								3,852
New Jersey	SA	545	SA	c	FP,SR	1,715	SA	29				2,289
New Mexico			SA	1,700					SA	57		1,757
New York					FP,LS	7,700			GR	13		7,713
Ohio	KH	3,200			FP	300	SA	200				3,700
Oregon	KH	395	SA	90	LS	36						521
Pennsylvania	SA	3,500					SA	2,500				6,000
Rhode Island			SA	20					SA	42		62
South Carolina	KH,SA	13,500	SA	126								13,626
South Dakota	KH,SA	1,372	SA	70			SA					1,442
Tennessee	MR,SA	9,916					SA	80				9,996
Utah						1,000				72		1,072
Vermont			LS	c	LS	660						660
Virginia	KH	44,278	SA	5,610					SA	56		49,944
Washington					NR	2,281	SA	3			65	2,349
West Virginia			SA	2,542					SA	117		2,659
Wisconsin	KH	2,000	SA	150	FP,LS	4,800						6,950
Wyoming	GR,LS,SA	3,650	SA	1,000			LS	20	GR,LS,Saf	79		4,749
District of Columbia					FP,LS	450			GR	310		760
Alberta					LS	400			GR	100		500
Nova Scotia			SA	400			SA	75				475
N.W. Territories	FP	4			LS	16						20
Ontario		5	FP,LS	1,470	SA	3	GR,LS	750				2,233
Saskatchewan	LS	80			LS	880			GR	2	40[d]	1,002
Durham, N.C.			SA.	200						125		325
Milwaukee, Wisconsin			MR,SA	434							3[d]	437
Illinois Tollway		32		280		35				1		16
Kansas Turnpike			e	1		35	f	15				16
Total		156,857		27,054		22,076		3,325		2,532	108	211,952

[a]FP = Fisher-Porter; GR = Golden River; KH = KayHill; LS = Leupold & Stevens; SA = StreeterAmet; Saf = Safetran; Sar = Sarasota

[b]Mitron

[c]Number included under Punched Tape.

[d]Time lapse

[e]Talker-Cooper

[f]Kennedy

TABLE A-5

ANNUAL PERSON-DAYS REQUIRED FOR EACH TYPE OF VISUAL COUNT

Agency	Volume	Vehicle Type on Link	Turning Move-ments	Body Type	Pedes-trians	Occup-ancy	In/Out State	Seat Belt Use	Delay/ Queuing	Person-days	Total Sites	Person-Days per Count
Alabama	450	1,020	450	230			10		20	1,160	120	9.7
Arizona	1,200	300	418	50			300			1,968	218	9.0
Arkansas		150	240		40				10	440	250	1.8
California			100							800	450	1.8
Connecticut		200	30							230	34	6.8
Florida		1,000								1,000	245	4.1
Georgia		816	65			95				976	77	12.7
Hawaii		95	40							200		
Illinois		250	950							2,200	1,015	2.2
Indiana		540								540	49	11.0
Iowa		260	2,150		2					2,440	2,930	0.8
Kansas	880	200	200			10	200			1,080	87	12.4
Louisiana	900	60	80	60						1,100	6,000	0.2
Maryland			870		870		40			910	700	1.3
Minnesota		607		607						607	315	1.9
Mississippi			260		10	20				300	170	1.8
Nebraska	750	750	910		30				30	750	360	2.1
New Jersey	324	555	324		300		555			771	418	1.8
New Mexico	485	315	170	485			485		3		485	
New York		25	530		250	10			10	575	450	1.3
Ohio	300	1,300	3,000	60	20	10				4,800	3,500	1.4
Oregon	x	x	x							480	158	3.0
Pennsylvania	900	900	600							1,200	1,500	0.8
Rhode Island		66	95				66			166	274	0.6
South Carolina		256	100		5			2		377	267	1.4
South Dakota	60		2		3				10	75	61	1.2
Tennessee	2,367	290	2,077							2,367	3,623	0.7
Texas	x									3,000	400	7.5
Utah	260		24							284	90	3.2
Vermont		27	169			12				872	125	7.0
Virginia	916	8,300	130			50				9,396	5,404	1.7
Washington	276		100	276	10	2				388	376	1.0
West Virginia	520	300	100		2					920	80	11.5
Wisconsin	x	x								314	38	8.3
Wyoming	432	432	276	x	x	x	x	x	x	432	36	12.0
District of Columbia	x	x	x	x	x	x	x	x	x	1,600	800	2.0
Alberta Parks	x					x				640	70	9.1
Alberta Trans. Safety			400	400	400	400		25	50	475		
Alberta Trans. System	x		x	x	x			x		9,888	611	16.2
Nova Scotia		15	60		60					75	56	1.3
N.W. Territories		x	x							120	14	8.6
Saskatchewan	200	50	50	5	5	5	5	5	10	355	1080	0.3
Durham, N.C.			125		5				3	133	125	1.1
Wilmington, N.C.	10		5		5					15	10	1.5
Milwaukee, Wisconsin			17	4	1				2		26	54
Total	11,230	19,079	15,117	2,177	2,018	614	1,661	32	148	63,081	33,925	1.9

TABLE A-6

AUTOMATED VEHICLE CLASSIFICATION EQUIPMENT AND SITES (FHWA, OCTOBER 1985) (22)

State	Make & Model	Sensor	Number of units	Number of sites	Number with telem	Power type	Year of first use
Alask.	Golden River GR341		2				1985
	Leupold-Stevens 8063-2	tube	1	1		DC	1981
Ariz.	Golden River 0348	loop	2			AC	1982
Arkan.	Streeter-Rich. 141	tube	20	100		DC	1982
Cal.	Leupold-Steve. 8061	tube	21	100		DC	1982
	" " 8063	"	10	100		DC	1982
	Streeter-Rich. 140A	tube/loop	6	20		DC	1979
	TDS (Traf. Data Sys.) VCC120	tube	20	100		DC	1976
Colo.	Golden River GR0340	loop	21	21	21	AC	1978
	" " "	"	19	19		DC	1981
Conn.	Streeter-Rich. 141A	tube	1			DC	1982
	" " 550	loop	42	38	38	AC	1982
Del.	Streeter-Rich. 141		36			DC	
Fla.	Streeter-Rich.	tube/tp. sw.	148	240		AC/DC	1983
Idaho	IRD VCLS2	axle/sensor	1	1	1	AC	1984
Ill.	Leupold-Stev. 8061	tube	4	40		DC	1981
	" " 8063-1	"	5	40		DC	1982
Kan.	Streeter-Rich. 141A	tube	6	65		DC	1983
La.	Streeter-Rich. 141A	tube	6	65		DC	1978
Maine	IRD CL 400-4	?	2	7	7	AC	1984
Minn.	IRD	loop	1	1	1	AC	1985
Miss.	Streeter-Rich. 141-4	tube	25	220		DC	?
N. Y.	Streeter-Rich. 401	tube	2	10		DC	1974
	Traf. Data Sys. VLG120	tube	2	10		DC	1977
N. D.	Streeter-Rich 141A-2	tube	21	140		DC	1982
Oreg.	IRD CL400-6.	loop	6	1	1	AC	1984
Penn.	Streeter-Rich. 141-4	tube	145	2,500		DC	1981
Wyo.	Streeter-Rich. 141	tube	14			DC	1985
Total	20 States		591	3,889	69		

TABLE A-7

SPEED MEASURING EQUIPMENT (NOT USED FOR ENFORCEMENT)

Agency	Radar Make	Radar No.	Spaced Air Tubes Make	Spaced Air Tubes No.	Spaced Inductance Loops Make	Spaced Inductance Loops No.	Other Make	Other No.	Total
Alabama			SA	4	SA	30			34
Arizona	Speedset	20				49			69
Arkansas			SA	12	SA	9			21
California			LS	18	Sar	100			118
Connecticut	Kustom Signals	550			SA	25			575
Delaware			SA (incl. under loops)		SA	9			9
Florida				4	Saf, Radian	32			36
Georgia	Decatur		SA			41			41
Hawaii			LS	8					8
Illinois						70			70
Indiana			SA	20					20
Iowa					SA	33			33
Kansas					SA	39			39
Louisiana			SA	100					100
Maryland				2		28			30
Massachusetts					GR	30			30
Mississippi				2		32			34
Nebraska	MPH Industries	70			Sar	34			104
New Jersey					SA	29			29
New Mexico				60		16			76
New York					GR	51			51
Ohio			SA	20	SA	51			71
Oregon	Vinstrom	48			LS	35	IRD WIM	2	85
Pennsylvania					SA	38			38
Rhode Island	CMI	20			SA	12			32
South Carolina	Decatur	20	SA	34					54
South Dakota			SA	21	SA	13			34
Tennessee			SA	58	SA	16			74
Texas			SA	92	SA	9			101
Utah	Kustom Signals	36			LS	24		35	95
Vermont			LS	1	LS	24			25
Virginia	Decatur	200	SA	16	SA	36			252
Washington					SA	33			33
West Virginia			SA	7	SA	27			34
Wisconsin					SA	64			64
Wyoming			LS	100				37	100
District of Columbia	Decatur	50							50
Alberta Trans. Systems	b					7			7
Alberta Trans. Safety	c	642						340	982
Nova Scotia		450	SA		SA				450
Ontario		12		2		30	d	130	174
Saskatchewan	Muni Quip	20							20
Durham, N.C.	Decatur	15							15
Wilmington, N.C.	Decatur	1							1
Milwaukee, Wisconsin	Muni Quip	9							9
Total		2,163		581		1,076		512	4,332

[a] FP = Fisher-Porter; GR = Golden River; KH = KayHill; LS = Leupold & Stevens; SA = StreeterAmet; Saf = Safetran; Sar = Sarasota

[b] Highway Speed Monitor

[c] Kustom Signals; Muni Quip

[d] Permanent-count station telemetry with 170 microprocessors.

TABLE A-8

DATA STORAGE AND TRANSMITTAL EQUIPMENT IN USE FOR TRAFFIC DATA REPORTING

Agency	Large Central Computer[a]	General Purpose Minicomputer	Dedicated Computer	Magtape or Cassette to Computer or Translator	Solid State Memory to Analyzer	Punched Tape to Computer or Analyzer
Alabama	SA					
Arizona	GR	GR	GR		GR	
Arkansas				IBM		
California				170 vol. & speed		
Connecticut			SA/mainframe	SA		
Florida			Saf			
Georgia		SA/DEC				
Hawaii	SA/DEC			SA	LS	
Illinois			Pertec			FP to LS translator
Indiana				SA		
Iowa		UniData/IBM PC				
Louisiana						FP/IBM
Maryland						Print tape/cond.
Massachusetts					GR	FP, LS
Minnesota			SA/IBM PC			LS
Nebraska						Key printed tape
New Jersey				SA		FP, SA
New Mexico		SA				
New York				TI		Envirolab
Ohio				SA		FP
Oregon			IRD WIM/IBM PC			LS/TRS
Pennsylvania						Recordet/card
Rhode Island				SA		
South Carolina				SA	SA	
South Dakota		GR/IBM PC		SA		Card/IBM
Tennessee				SA		
Texas		SA, Sar				
Utah	b		b			FP
Virginia				Sykes		
Washington		GR/IBM PC		SA		FP, LS
West Virginia				SA	SA	
Wisconsin			SA	SA/Amdahl		FP, LS
Wyoming		Saf/Data Gen.	GR/IBM PC	LS	GR	
District of Columbia						GR
Alberta Parks	IBM, Amdahl					
Alberta Trans. Sys.	IBM PC	GR				LS
Nova Scotia					Traff. Comp.	
N.W. Territories						LS
Ontario	Nova	170			GR	FP
Saskatchewan					GR	LS
Milwaukee, Wisconsin						MR

[a]DEC = Digital Equipment Corporation; FP = Fisher-Porter; GR = Golden River; IBM = International Business Machines; KH = KayHill; LS = Leupold & Stevens; SA = Streeter Amet; Saf = Safetran; Sar = Sarasota; TI = Texas Instruments; TRS = Tandy/Radio Shack

[b]Vector Graphic to IBM

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The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the Federal Government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

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