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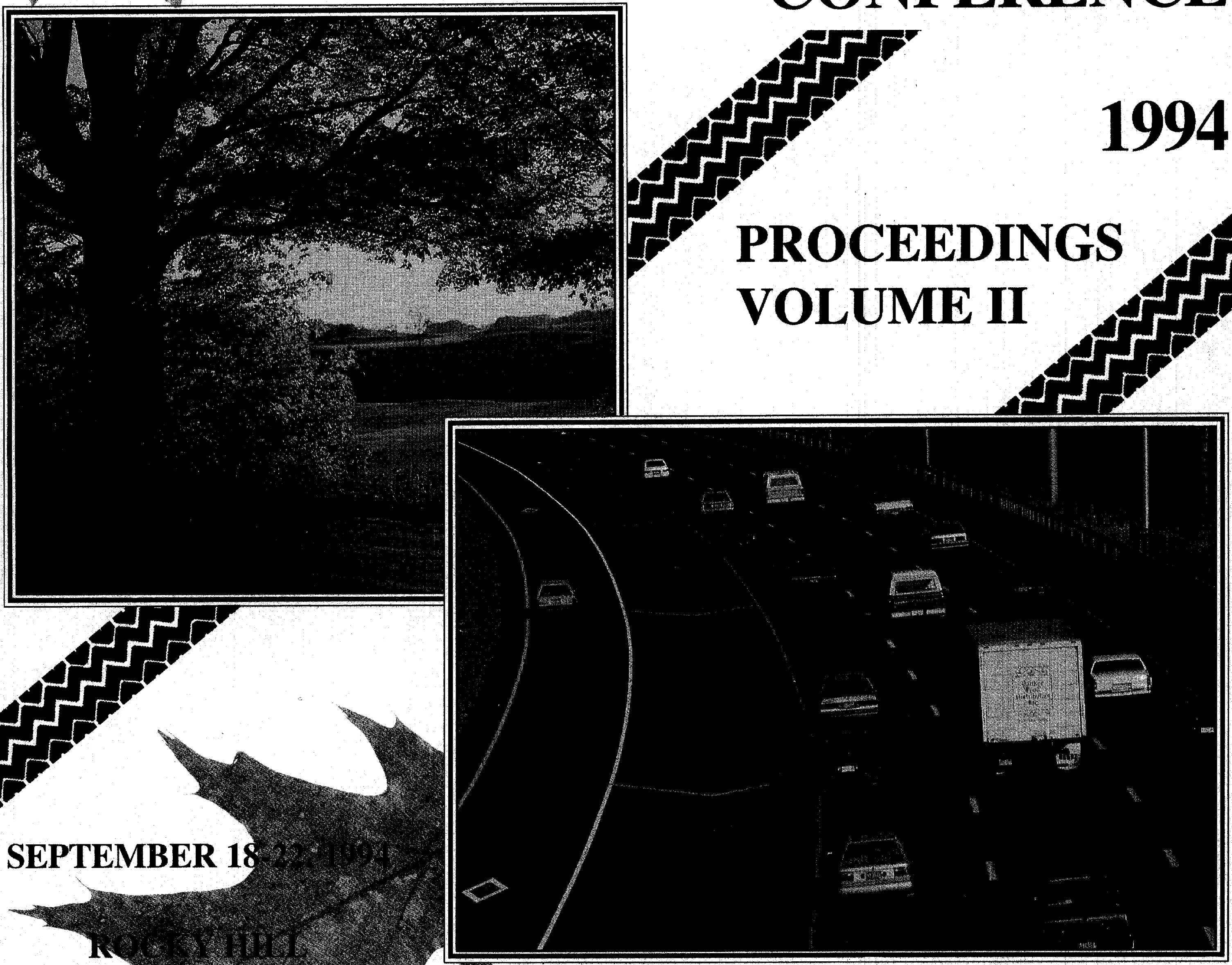
NATIONAL TRAFFIC DATA ACQUISITION CONFERENCE

1994

PROCEEDINGS
VOLUME II



SEPTEMBER 18-22, 1994

ROCKY HILL
CONNECTICUT

Connecticut Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

NATIONAL TRAFFIC DATA ACQUISITION CONFERENCE (NATDAC '94)

PROCEEDINGS

Volume II

Rocky Hill, Connecticut

September 18-22, 1994

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The National Traffic Data Acquisition Conference 1994 (NATDAC '94) was held in Rocky Hill, Connecticut on September 18-22, 1994. A broad range of topics was covered during the conference, including: ISTEA Management Systems, Intelligent Vehicle/Highway System Applications, Geographic Information Systems, Traffic Data Collection Technologies, and Data Quality. Concurrent sessions were held on Traffic Data Collection, Data Quality, Needs and Uses of Traffic Data, and Advanced Data Collection Technology. There were 65 speakers, panelists and moderators involved in the program. Conference participants were brought to three field locations for demonstrations of data collection equipment from 15 vendors. Over 25 vendors also maintained static displays and exhibits at the conference facility for participants to view.

There were 348 registered participants for NATDAC '94 representing over 40 states, the federal government, academia and industry. Fifteen of the participants were from Canada and Europe. The conference was co-sponsored by the Connecticut Department of Transportation and the Federal Highway Administration.

The papers within this publication are a compilation of those presented at NATDAC '94. In order to make the publication manageable, it is divided into two volumes. Volume I contains all General Session papers. Volume II contains all Concurrent Session Papers.

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PREFACE

The National Traffic Data Acquisition Conference 1994, (NATDAC '94) was held in Rocky Hill, Connecticut on September 18-22, 1994. A broad range of topics was covered during the conference, including: ISTEA Management Systems, Intelligent Vehicle/Highway System Applications, Geographic Information Systems, Traffic Data Collection Technologies, and Data Quality. Concurrent sessions were held on Traffic Data Collection, Data Quality, Needs and Uses of Traffic Data, and Advanced Data Collection Technology. There were 65 speakers, panelists and moderators involved in the program. Conference participants were brought to three field locations for demonstrations of data collection equipment from 15 vendors. Over 25 vendors also maintained static displays and exhibits at the conference facility for participants to view.

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Thanks are hereby offered to all the speakers, participants and exhibitors who made the conference an outstanding success.

Charles E. Dougan

Dr. Charles E. Dougan, P.E.
Manager, Office of Research and Materials
Connecticut Department of Transportation

The contents of this report reflect the views of the authors of the papers, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the State of Connecticut or of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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CONCURRENT SESSION, TRAFFIC DATA COLLECTION

National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

SUMMATION: CONCURRENT SESSION, TRAFFIC DATA COLLECTION

Mr. Bill M. McCall
Iowa Transportation Center

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

SUMMATION: CONCURRENT SESSION, TRAFFIC DATA COLLECTION

Bill M. McCall, Iowa Transportation Center

It was my pleasure to moderate Session 1A on traffic data collection. Six great papers have added materially to the national mileage for data collection. [Thomas] Black, Arkansas DOT, presented the new directions path that led his department to enjoy and expand the data collection program and increase quality, while at the same time, reducing the cost of the program about 50 percent.

Anne-Marie McDonnell, Connecticut DOT, presented the Connecticut DOT's experiences with weigh-in-motion. She shared with us a lot of the work that she and her staff accomplished on the highway, and that paper also adds to our thought processes.

Douglas Terhune, Alaska DOT, discussed data collection, in general, and specifically spent some time on a topic that is critical to all of us in that he is comparing the difference between static weight and weights predicted by weigh-in-motion and the differences those pieces of data cause in pavement design. In other words, what does standard deviation mean? Is it an extra inch? Is it an extra two inches? An extra half inch?

John Hamrick, Idaho DOT, talked a little bit about his experience with portable weigh-in-motion and calibration.

Bruce Harvey, Georgia Institute of Technology, discussed the accuracy of the federally sponsored automatic vehicle classification study [involving] nine vendors, and systems. And Bruce has organized his results and ranked the performance of those pieces of equipment. The final report is in the hands of FHWA for final approval, and perhaps will be released in October of this year.

Herbert Weinblatt, Cambridge Systematics, discussed continuous monitoring sites in four states. [He] cautioned us [that] perhaps we are not obtaining the accuracy that we think we have from continuous monitoring sites.

I encourage you to read all these papers. It [was] a good session, and again, must reading for all. Thank you.

INTEGRATED TRAFFIC DATA COLLECTION MANAGEMENT: A NEW DIRECTION

Mr. Thomas F. Black
Arkansas State Highway and Transportation Department

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

ABSTRACT

The title of this paper, *Integrated Traffic Data Collection Management - A New Direction*, refers to an idea which is neither original to me or new. Over the last four years I have discussed this concept to a smaller degree with many people both inside and outside my Department. About four years ago I suggested to one of the Department's field supervisors that we combine the ATR and Speed Data Collection Programs in order to save resources. In response to this the supervisor told me that traffic recorders have been improved to such an extent that it ought to be possible to combine all our permanent data collection programs into one family of sites in order to make maximum benefits from the use of our resources. From this point we began to evaluate the cost of our existing data collection programs and the cost of converting several of the Department's traffic data collection programs into remotely operated coincident data collection installations, in order to estimate the potential costs and benefits.

In October 1992 the Federal Highway Administration published a revision of the Traffic Monitoring Guide (TMG). In the Guide Objectives to this document the following was written:

"The second objective of this guide is to change our perception of traffic counting, vehicle classification, and truck weighing as being separate activities to the recognition of these activities as part of a related set of traffic characteristic monitoring functions. More than being an advocate of a unified approach for the gathering of traffic characteristic data, this Guide provides specific recommendations on the number, extent, and duration of such monitoring. Further, the design of the data monitoring is set up in an interrelated and hierarchical fashion. Truck weighing sessions are selected as a subset of vehicle classification sessions. Vehicle classification sessions, in turn, are a subset of volume counting sessions. This 'nesting' of sessions leads to economies of operation. For example, truck weighing locations will serve to gather a portion of the vehicle class and volume count data called for by the sample design. Similarly, vehicle classification sessions will provide needed volume count data."

As you can tell from these statements taken from the TMG, the FHWA is encouraging the States to move toward more interrelated data collection programs in order to improve both the quality and efficiency of traffic data collection activities. Following publication of this TMG the need for streamlining our data collection programs became even more apparent with the advent of Intermodal Surface Transportation Efficiency Act (ISTEA). The implementation of the six management areas of ISTEA will in part depend on the ability of the States to provide high quality transportation data, and toward that end the streamlining of the existing traffic data collection programs have the potential to save manpower and costs which can be reallocated to ISTEA.

This paper is one approach being implemented in Arkansas to make the Traffic Data Collection personnel more productive by reducing the number of data collection sites needed for permanent data collection programs, eliminating many of the labor intensive data collection activities and replacing them with automatic data collection recorders and automatic data collection, and improving both the quality and quantity of traffic data collected.

DATA COLLECTION IN THE USA

The Scatter-Gun Approach

The nature and size of traffic data collection programs in this country varies significantly from state to state. One characteristic of the programs which seems consistent throughout the country, however, is that the number of programs and data collection needs for those programs seems to gradually be growing for a wide variety of purposes.

Traditional data types normally associated with traffic data collection are volume counts, vehicle classifications, vehicle speed data, and axle weight data. The ways we collect this data has changed with technology and the evolution of the traffic streams on various traffic corridors, however, the data types remain the same.

The demands for traffic data has changed dramatically over the years. Automatic Traffic Recorder (ATR) programs in our states have all gone to permanent remotely operated volume counters and classifiers. Although the numbers of ATR data collection sites may have increased or decreased in any particular state, recent user demands for information from these sites has steadily increased with user demands for accuracy's of ±5%, and even more recently demands of ±3%. The Weigh-In-Motion (WIM) data collection program's roots originate from the loadometer studies which substantially ended nearly a decade ago. Even though the data collected by the loadometer studies and WIM studies may not be exactly equivalent, the needs for larger volumes of axle weight data collected from a more representative cross section of the traffic stream necessitated the application of WIM technologies. The states have been encouraged to achieve WIM accuracy's of ±10% for weight data and in the future may be required to achieve this or greater accuracy's. The Speed Program in many of the states is designed to produce statistics which show that average speeds on certain highways are controlled within a certain range in order to avoid the threat of monetary penalties. Speed data collection reporting is now being extended to include interstate highways with all sites monitored quarterly. The Highway Performance Monitoring System (HPMS) encompasses all these data types as well as hundreds of vehicle classifications annually and pavement roughness data. Add to all these programs, a coverage count program, special needs program, a highway inventory program, a needs inventory program, the Strategic Highway Research Program (SHRP), and many other individual state programs, and a quantification of the state's data collection program begins to take shape.

These programs did not just develop concurrently in recent years, but evolved individually over several decades. Unfortunately, each program was administered by a separate group within FHWA. And, in many of the states individual programs were also administered by different sections. Individual historical and/or random selection processes were used to determine the number and identify locations of data collection sites for each separate program. In addition, independent data processing and report formats were often developed on an individual program basis, even when more than one program used the same types of data. This traditional way of establishing traffic data collection programs for each state amounts to a scatter gun approach which adds a pattern of data collection sites to the state map, Figure I., for each program, and results in an additional new layer of labor, equipment requirements, and methods for each program established.

If traffic data collection continues to evolve in this fashion with the limited resources available, the future of annual traffic data collection in each state may wind up being the determination of which programs get skipped each year.

HOLISM AND PARSIMONY

New Directions For Traffic Data Collection Management

The idea of integrating traffic data collection programs to improve both the quality and efficiency of data collection is not new. Almost anytime State and Federal data collection personnel get together conversations include discussions of the value of relating data collection programs, as well as complaints regarding the failure to consider existing data collection programs when creating new or modifying existing programs. One of the more recent examples of a new program created without significant considerations of existing programs is the SHRP Program.

In the latest Traffic Monitoring Guide, October 1992, (TMG) (Reference 1.) the suggestion of relating permanent traffic data collection programs actually came out of the closet, so to speak. FHWA introduced the concept of Holism, the whole is much more than the sum of its parts, to suggest that program integration was far superior to program separation. And, the concept of Parsimony, the belief that the simplest, most economical, valid solution is the best, to suggest that a reduction in complexity resulting from a simple solution is many times worth the relatively small losses of efficiency or information.

It's obvious from the suggestions being made in the TMG that FHWA has actually been listening to what the states have been saying and are prepared to make adjustments in their thinking to meet future traffic data needs. The conclusions which seem to be made regarding a loss of efficiency and information from the concept of Parsimony may be an overstatement in traffic data collection. The assumption that independently developed traffic data collection programs provide the most reliable accurate data does not consider the purposes behind the programs themselves. Traffic volume, classification, speed and axle weight data are related to the same traffic streams. And these data types are utilized together for highway planning, design, and maintenance applications. By developing separate programs to collect these varied data types, the different types of data are most often collected at separate sites, minimizing the ability to relate the various data types and reducing the reliability of the projections and reports made from the combined data types. By integrating the programs, various types of traffic data can be collected in concurrent highway segments maximizing the ability to relate the various data types and the value and accuracy of the volume, classification, and load data projections. In other words, integrating our data collection programs may result in an increase in the efficiency and accuracy of the projections made from the statistics created from this data, while reducing the relative cost and labor required to collect it.

MULTI-PROGRAM TRAFFIC DATA COLLECTION MAKES SENSE

Many factors affect the state's ability to provide traffic data and highway information for the various users. Innovations and improvements in technology are ever increasing the capabilities and opportunities to operate more efficient and responsive Traffic Monitoring Systems for Highways (TMS/H). Factors influencing this endeavor include the financial resources, personnel available, political considerations, individual program data collection needs, level of technological developments, and willingness of the state to support data collection efforts. Some factors may be affected by other factors, such as the state support and political considerations may be affected by the economic and practical factors disclosed in a justification made for improvements in the traffic data collection program.

As Engineers and Technicians we do not control all the factors affecting the resources available to do this task. However, no one can perform this task without adequate resources, therefore, the justification (Appendix C. & D.) for these programs becomes very important! Fortunately, current social and economic conditions provide us with a lot of justification. Many of our departments have reduction in force policies, and departmental personnel are constantly being asked to find ways to improve efficiency and cut expenses. The way we can reduce the labor force for the work we perform is to make our existing personnel more productive, thereby, reducing the need for additional labor to perform additional data collection for existing programs and the management areas of ISTEA. This can be done through better management of existing resources and the application of modern technology to expand the capabilities of our existing personnel. As our users demand greater volumes of more accurate data and the number of users increase, the application of state-of-the-art technology for integrated traffic data collection programs reduces the cost of data collection by improving efficiency, reducing labor requirements, eliminating duplication, and allowing for improved data collection management. With existing technology and experience available to the states and FHWA, management can be shown how to do the job with existing departmental personnel at a relatively lower cost.

One word of caution here – We can't show management how to do this job for nothing, however, they can be shown how to do it better and at the same time more efficiently. Therefore, let's be careful not to mislead anyone into thinking that adequate traffic data collection is a by-product which can be achieved without any effort or expense. Many state highway department managers are not practicing engineers or technicians themselves and are not interested in the specifics of this job. Therefore, they tend to believe that all the traffic data collection needed will be done according to their orders regardless of the resources provided. In the past short cuts have been taken to satisfy these managers which has led them to look at this activity as a nonprofessional enterprise, and has caused them to develop unreasonable expectations. Let's conduct ourselves in the future in a way that does not add to these unrealistic expectations, and that ultimately provides departmental personnel with the resources and opportunities to do the traffic data collection requested by users.

ISTEA MANAGEMENT SYSTEMS

It's Time For Planning Not Panic

The Intermodal Surface Transportation Efficiency Act (ISTEA), the current Federal highway program, is creating six management systems in addition to the existing traffic data collection programs. These are comprised of the pavement management system (PMS), bridge management system (BMS), public transportation management system (PTMS), safety management system (SMS), intermodal management system (IMS), and the congestion management system (CMS). In addition to these management areas, the current programs and the means by which the traffic data collection is provided for under ISTEA, is the Traffic Monitoring System for Highways (TMS/H). There is not sufficient time to discuss any of these systems in detail in this paper, and any discussion of them would be premature at this time, since they are currently in the process of being designed at the state level. However, the assumption can be made that many of these systems will require additional traffic data over that currently being collected, and all systems will ultimately share traffic data collected with the TMS/H. Initially, the states thought that data for these systems would be collected without any additional cost, however, as the specifics of each system are determined it appears that additional data collection over and above the current traffic data collection activities will be needed. In creating the plan for the TMS/H it is incumbent upon each state to determine how to best utilize existing resources to perform the necessary data collections while minimizing the need to increase data collection personnel and costs.

Maximum integration of the current traffic data collection programs in the TMS/H has the potential to release significant amounts of personnel resources to be utilized in other traffic data collection activities which may be required for these six management areas. The plan for the TMS/H is scheduled for completion along with the six management areas, therefore, the states do not have the luxury of waiting to see what data is going to be requested by each management system before the TMS/H plan is completed. It is crucial that each state coordinate the planning of all the management systems and the TMS/H simultaneously in order to provide the necessary data when needed for all state and federal users. For current planning purposes at the state level the TMS/H should be treated as a seventh management system.

When planning the TMS/H, never overlook any potential uses for the current data being collected so that state forces can avoid duplication of efforts and maximize the benefits of the traffic data being collected. Remember, traffic data is used for planning, design, maintenance, and enforcement. By identifying all beneficial uses for the data collected, maximum benefits of the data collection activities can be obtained and additional sources of financing for equipment and operations may be discovered.

ONE SUGGESTED PROPOSAL

The Bottom Line

With the installation of the SHRP Program in Arkansas it was observed by Arkansas State Highway and Transportation Department (AHTD) personnel that the equipment used could provide data for several traffic data collection programs as well as information for enforcement from integrated traffic data collection sites. A few of the SHRP sites were instrumented and have been operated as integrated multi-program data collection installations to take maximum advantage of the State's equipment investment. AHTD personnel expanded on the experience gained in the SHRP program by investigating the possibility of combining permanent data collection programs, i. e. ATR, WIM, HPMS, Speed Data, etc., into multi-program data collection sites. Since many of these programs are operated primarily with labor intensive technologies, significant reductions in personnel and support costs were immediately identified.

After the publication of the revised TMG, and the announcement of ISTEA, the Department decided to look for new ways to reduce labor and costs. AHTD personnel were asked to propose some cost cutting and labor saving innovations, thereby leading the way to the proposal for the development of integrated multi-program data collection sites. Following the preliminary proposal, the Department prepared a draft plan which combined the ATR, WIM, Speed Data, any associated vehicle classification sites, and most of the SHRP sites into a family of data collection installations which eliminate the less efficient labor intensive methods currently employed.

The basic steps followed in this endeavor are as follows:

1. Because of the traffic history already collected , the ATR sites were chosen for upgrading to multi-program sites.

2. Existing ATR sites were categorized according to highway system in order to identify deficiencies in the coverage of the existing program. (Appendix A.)

3. A statistical procedure, based on axle weight data, was used to select the minimum number of sites needed to sample the state highway system for the WIM Program. (Appendix B.)

4. Additional sites were selected, over the existing ATR Program, from other data collection program sites to complete the proposed ATR and WIM Programs.

5. The sites selected for the ATR and WIM Programs were then reviewed to determine their adequacy for the Speed Data Program.

6. Additional sites were selected from other existing data collection program sites to complete the expanded Speed Data Collection Program.

The final draft program was tabulated and submitted as a proposal for the traffic data collection programs for the ATR, WIM, Speed Data, Quarterly Vehicle Classification, and most of the SHRP Program sites.

The final preliminary proposed traffic data collection program, Figure II., amounts to approximately 50 ATR, 48 WIM, 45 Speed Data, 11 SHRP, 65 HPMS Classification, and 11 Quarterly Classification sites, incorporated into 48 Automatic Weight and Classification System (AWACS) and 17 Automatic Vehicle Classification (AVC) sites. In other words, the equivalent of approximately 180 current traffic data collection sites, most of which are being collected with labor intensive technology, can be replaced by 65 remotely operated traffic data collection systems.

The total benefits of this proposal, however can not be described by a simple comparison of the number of existing sites to those proposed. Each program will be affected in a number of ways.

The type of data collected for the ATR Program will change from continuous volume counts currently being collected to continuous vehicle classification data. Also, this proposal will eliminate the need for on site retrieval of data by AHTD personnel, and provide for the collection of vehicle classification data by telemetry, thereby substantially reducing the labor currently required. All 65 traffic data collection sites will be capable of collecting continuous traffic data adequate for the ATR Program.

The effect on the WIM program is even more dramatic. WIM has been collected in Arkansas and through much of the Country with portable AWACS systems. The portable equipment, support vehicles, state crews, state highway district support, and all necessary field per diem and support is eliminated. Even more important in Arkansas, this proposal converts the WIM data collection from a 90 site three year data collection program, 30 sites per year, to an annual data collection program, at approximately 48 sites with the ultimate duration of each sample increased from 48 hours to 7-days. The comparison of the size of the WIM Program based on the number of sites, 90 to 48, is also misleading. Because of the way data collection sites are numbered for divided highways, the 48 WIM sites proposed actually compares to more than 70 sites under the existing program. In other words instead of collecting about 30 WIM sites annually under the existing program, the state would actually be collecting the equivalent of over 70 sites annually.

The effect on the Speed Data Program is to virtually eliminate portable speed data collection and convert it to remotely operated sites. The Speed Data Collection Program has recently been changed to include reporting of Interstate highways (65 mph) as well as 55 mph routes. Also the entire program has been converted to be collected quarterly rather than part quarterly and part annually. The number of sites in Arkansas has increased from 34 to 45. This proposal would allow the expansion of this program without any addition increases in personnel, and would incorporate it with other programs to eliminate the proliferation of additional data collection sites.

Approximately eleven of these sites are SHRP Program sites in addition to other data collection programs.

The estimated cost of operating the existing data collection programs is approximately $420,000 annually. The revised cost of operating these same programs, with integrated traffic data collection sites, is approximately $293,000 annually. These revised costs include the amortized investment and operating costs for the proposed traffic data collection installations over a ten year design life, personnel, maintenance, and utilities. Since the existing programs are already instrumented no additional costs were included for replacement of equipment with the current programs. Therefore, the cost savings, approximately 30%, for the integrated multi-program sites is a conservative estimate. No value was assessed to this comparison for the increased volume or quality of traffic data collected at the integrated sites.

Some of the advantages to be gained through the implementation of this proposal for integrated traffic data collection management are listed as follows:

1. The operation of AWACS and AVC equipped data collection sites for multi-program use will result in significant cost and labor savings by eliminating duplication of data collection equipment and efforts, and eliminating the labor intensive field operations currently being employed. In Arkansas, as much as 10,000 hours or more of field personnel resources could be saved annually and reallocated to the management systems of ISTEA and other program needs. With the Department's current policy of working toward more efficient operations and minimizing manpower costs, this proposal would further the Department's interests toward achieving these goals.
2. The reduced presence of AHTD personnel and vehicles will eliminate the impact on traffic during data collection activities, and eliminate the associated bias created.
3. This equipment will improve the data collected by allowing for continuous collection of classification data, seven day collection of WIM data on an annual basis, the collection of data during week ends and holidays, and the ability to remotely reprogram and operate permanent traffic recorders.
4. The use of multi-program installations will improve the accuracy and value of the data collected by retrieving classification and WIM data in the same highway sections, improving the ability to relate various data types.
5. This proposal will satisfy FHWA directives by implementing automatic traffic recorders for permanent data collection sites and eliminating duplication of data collection efforts.
6. The implementation of this proposal will provide training and experience for our field personnel which will make them more productive and valuable for the future data collection needs of the Department.
7. The implementation of this proposal would allow the Department to expand the data collection for the Speed Program without additional personnel and minimize the need for additional personnel and equipment to satisfy the data collection needs for the six management areas of ISTEA.

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ATR PROGRAM SITES

Number And Classification

The Traffic Volume Monitoring program recommended in the TMG consists of three major elements.

1. A limited continuous count element
2. A more extensive HPMS framework as the traffic volume sample
3. A very flexible Special Needs element

The ATR sites act as the limited continuous count element of these needs. As a minimum the TMG recommends these seasonal groups for the development of ATR data collection sites.

Recommended <u>Group</u>	HPMS Functional <u>Group</u>
1. Interstate rural	1
2. Other rural	2, 6, 7, 8
3. Interstate urban	11
4. Other urban	12, 14, 16, 17
5. Recreational	Any

The TMG notes that most continuous data collection programs lack a firm statistical base, and states that their design can best be characterized as evolutionary and incremental. It states, "Because of the enormous expenditures made to implement existing continuous programs and their present utility in terms of the data base provided, the intent of this chapter is more towards modifying than redoing. By using as much as possible of the existing framework, cost-effectiveness is improved and modifications to existing programs minimized." It is apparent that the TMG does not recommend scrapping our current data collection programs and starting over. As a result we recommend that we use our existing program as a starting point for a re-instrumentation proposal and recommend random selection of new or additional sites from HPMS sample sections. This will enable us to work towards, what the TMG calls, statistical rigor in our programs while preserving the value and usefulness of our existing data base.

AUTOMATIC TRAFFIC RECORDER SITE ANALYSIS

The TMG indicates that typically monthly variations for urban areas have coefficients of variation under 10%, while rural areas range from 10 to 25%. For our purposes we will use 10% for urban estimates and 15% for rural estimates of the number of ATR sites needed for each ATR group. It is further recommended that the number of sites needed be calculated for Interstate rural, Other rural, Interstate urban, and Other urban, with additional recreational sites added for those identified as needed. The TMG recommends the following equation for determining the number of sites need for each group:

$$D = T_{1\text{-}d/2,n\text{-}1}C/n^{½} \qquad (3)$$

where

D = precision interval as a proportion or percentage of the mean

C = coefficient of variation of the factors

T = value of student's T distribution with 1-d/2 level of confidence and n-1 degrees of freedom

n = number of locations

d = significance level

Using a 10% precision level with 95% confidence, based on Equation (3), the following minimum number of locations are recommended for the number of ATR sites in each group.

1. Interstate rural	12
2. Other rural	12
3. Interstate urban	7
4. Other urban	7

ATR DATA COLLECTION SITES LOG

Currently, Arkansas has approximately 35 active ATR sites distributed in each group as follows:

Field Station	Federal Station	Route	Section	F/C	Location
Rural Sites:	Interstate rural				
01	58-101	I-40	22	01	W. of Pottsville, LM 85.86
02	43-101	I-40	41	01	E. of S.H. 13, LM 183.52
03	47-101	I-55	12	01	N. of S.H. 181, LM 36.98
04	10-101	I-30	14	01	W. of S.H. 26, LM 68.39
	Other rural				
05	20-102	U.S. 79	06	02	NE of U.S. 167, LM 0.13
06	40-102	U.S. 65	16	02	N. of S.H. 114, LM 8.69
07	17-102	U.S. 71	15	02	Mountainburg, LM 12.78
08	64-102	U.S. 65	04	02	0.29 MI.N. of S.H. 235, LM 5.38
09	56-102	U.S. 63	08	02	N. of S.H. 14, LM 10.05
25	03-102	U.S. 62	11	02	W. of Norfork Bridge, LM 8.76
26	02-102	U.S. 82	08	02	E. Ouachita River, LM 3.50
10	42-103	S.H. 22	03	06	E. of S.H. 23, LM 4.07
11	73-103	U.S. 167	16	06	N. of S.H. 87, LM 3.19
12	28-103	U.S. 412	08	06	E. of Cash River, LM 0.62
13	29-103	S.H. 4	05	06	N. of S. H. 332, LM 2.54
27	22-106	S.H. 35	08	06	SE of Monticello, LM 5.79
30	58-106	S.H. 7	15	06	1.09 MI N. of S.H.164, LM 15.86
14	67-104	S.H. 115	03	07	E. of U.S. 167, LM 13.83
15	68-104	S.H. 50	01	07	W. of S.H. 75, LM 1.01
16	27-104	S.H. 46	02	07	SW of U.S. 270, LM 17.82
29	08-107	S.H. 21	05	07	S. of Berryville, LM 15.70
Urban Sites:	Interstate rural				
18	60-121	I-630	21	11	W. of Denison St., LM 2.0
19	65-121	I-540	12	11	N. of S.H. 22, LM 5.36
31	18-111	I-55	11	11	NW of U.S. 70, LM 3.50
33	60-111	I-440	01	11	N. of Ark.Riv.Brdg., LM5.59
34	60-131	I-40	33	11	Lakewood Interchange, LM 154.31
	Other urban				
20	60-122	U.S. 67	10	12	S. of Jacksonville, LM 7.81
32	16-112	S.H. 245	01	12	S. of I-30, LM 4.49
21	60-123	S.H. 10	08	14	W. of Cross St., LM 14.75
22	65-123	U.S. 64	01	14	S. of Ark. River, LM 4.16
28	70-114	U.S. 167B	01B	14	E. of S.H. 7 Spur, LM 3.18
23	73-124	S.H. 36	03	16	W. C/L of Searcy, LM 19.18
24	35-124	Hazel St.	N/A	16	N. of 27th St., LM 1.24

As you can see from the list of Data Collection Sites above, we have been sampling more than the number of Other rural sites estimated and less than the number of Interstate sites. This analysis is only the beginning of the considerations, however, and it does not take any other data collection programs into account. Let's look at the needs of the Weigh-In-Motion (WIM) program and see what the recommended number and distribution of sites would be before considering additional sites solely for the ATR Program.

WEIGH-IN-MOTION TRAFFIC RECORDER SITE ANALYSIS

First, let's use the previous relationships and method to estimate the number of sites needed. Obviously the variation in traffic counts at the WIM sites does not relate directly to the axle weight data being collected, therefore, for a different perspective, axle weight data will be used to get a frame of reference for this analysis.

For the existing WIM Program, the TMG recommends that each state sample, at least, 90 WIM sites over a three year cycle. These sites were to be selected for two reporting stratification levels, 1. Interstate and 2. Other Roads (excluding local functional class or unpaved). One third of these sites were arbitrarily assigned to Interstate highways with the remainder distributed over other classification highways according to their mileage. The TMG recommended that each sample be collected for a 48-hour period once every three years.

The Department is recommending, for the future WIM program, annual data collections at all sites with seven day duration samples and quarterly data collections at specific sites to provide seasonal WIM data. With the more complete seven day samples and the additional seasonal information obtained annually, Arkansas should be able to adequately sample axle weight data at fewer than 90 sites.

WIM data is used to estimate static axle weights for planning, bridge, and pavement design purposes. Since the actual dynamic weights collected are normally not equal to static weights, let's look at the differences between the dynamic and static axle weights to estimate the coefficient of variation of the data. In Arkansas' work in the Demonstration 76 Project, over 700 heavy trucks were weighed both dynamically and statically for comparison. Axle weight data from the four DEMO 76 sites was used to compute coefficients of variation at each of the sites. The values from this analysis is summarized on the next page as follows.

Average DEMO 76 Data Collection Sites	Static (WIM-Static) Gross Weight	WIM Standard Deviation	Sample Coefficient Variation(%)	Size #
I-30 Hempstead Co.	59,606	10,381	17.42	152
Other Highways				
U.S. 71 Benton Co.	53,567	6,908	12.90	228
S.H.29 Hempstead Co.	62,628	8,715	13.92	183
U.S. 82 Ashley Co.	49,192	8,781	17.85	52
Weighted Other	8,697	13.86	463	

Based on this analysis, coefficients of variation of 17.50% and 15.00% were used to estimate the number of sites for the Interstate and Other systems, respectively. Using a 10% precision level with 95% confidence for the student's T distribution along with Equation (3), it was estimated that we need a minimum of 15 Interstate Highway and 12 Other Highways WIM data collection sites.

Although the figures above indicate that fewer Other highway sites are needed to sample Arkansas' state roads, this analysis does not take other factors into account including the type of area, functional classes of roads, and many other considerations pertinent to determining the number of sampling sites needed. It is apparent from the relative number of miles of highway and traffic between the Interstate and Other highway systems, that a larger number of data collection sites will be needed for the Other highway systems than the Interstate systems. The TMG gives more weight to the sampling of the Interstate highways than the Other highways and arbitrarily assigns one third of the data collection sites to Interstate highways. Accordingly, we will initially assign twice the number of data collection sites, thirty, to Other highways and distribute them across the highway systems. In this regard we will follow the recommendation from the TMG and distribute these sites according to AVMT mileage within the Interstate and Other highway systems.

In order to adequately sample any highway system one site is not considered adequate and a few additional sites are needed to provide for interruptions of data collection, for maintenance, and equipment failures. At least three sites should be sampled for each type highway system with no less than 27 sites in operation at all times. Therefore, where the estimated number of sites, based on AVMT, is less that 3 for any system, the minimum number of proposed sites will be recommended as three. The following table shows the minimum number of sites calculated for the Interstate and Other highway systems using the Student's T distribution analysis, and the minimum number recommended for adequate sampling of each highway system based on TMG recommendations and the distribution of sites according to AVMT.

Highway System	1991 AVMT statistics (millions)	Student's T Minimum sites No.	Recommended sample site No.
Rural Interstate	2,830	9	11
Urban Interstate	1,780	6	7
Rural			
Principal Arterial	3,376	3	9
Minor Arterial	2,685	2	7
Collector	4,071	3	4
Urban			
Other Freeways and Expressways	670	1	4
Principal Arterial	2,498	2	3
Minor Arterial	1,641	1	3
	Totals	27	48

ATR, WIM, SHRP, SPEED

Data Collection Sites Log

After determining the number of permanent AWACS sites needed to satisfy the WIM Program, the log of ATR sites previously included in this report was updated to include additional sites already instrumented with automatic traffic recorder for SHRP, WIM, and Speed data collection activities. Sufficient sites were found from the WIM and ATR locations chosen, to instrument the higher classification Speed Data Collection sites, however, some additional locations had to be chosen to satisfy the requirements for the Major Collector and Minor Arterial sites needed. Once this was completed, approximately 65 sites, 50 AWACS and 15 AVC, were chosen as multi-program data collection installations, to satisfy the needs of the ATR, WIM, Speed Data, and most of the SHRP Program sites statewide. This revised ATR, WIM, and Speed Data Collection Sites Log is included as follows:

Field Station	Federal Station	Route	Section	F/C	Location
Rural Sites:	Rural Interstate				
01	58-101	I-40	22	01	W. of Pottsville, LM 85.86
02	43-101	I-40	41	01	E. of S.H. 13, LM 183.52
03	47-101	I-55	12	01	N. of S.H. 181, LM 36.98
04	10-101	I-30	14	01	W. of S.H. 26, LM 68.39
07	U.S. 71	(I-49)	future	01	U.S. Hwy. 71 relocation
		I-40	51	01	1.0 M. E. S.H. 1, LM 240.0
		I-30	11	01	N. of Texarkana
		I-30	22	01	S. U.S. 70 Int., Saline Co.
		I-40	11	01	E. of Ark/Okla State Line
		I-40	32	01	Faulkner Co., Mayflower
		U.S. 65	12 or 14	01	Near Speed Section
	Principal Arterial				
05	20-102	U.S. 79	06	02	NE of U.S. 167, LM 0.13
06	40-102	U.S. 65	16	02	N. of S.H. 114, LM 8.69
08	64-102	U.S. 65	04	02	N.of S.H.235, LM 5.38
09	56-102	U.S. 63	08	02	N. of S.H. 14, LM 10.05
25	03-102	U.S. 62	11	02	W. Norfork Bridge, LM 8.76
26	02-102	U.S. 82	08	02	E. Ouachita River, LM 3.50
		S.H. 1	06	02	N. of White Riv.Br.
		U.S. 167	01	02	South of El Dorado, Union Co.
		U.S. 425	07	02	Old U. S. 81 S. of Pine Bluff
		U.S. 67	11	02	South of S.H. 89, Cabot
39		U.S. 167	10	02	South of U.S. 270, Sheridan
	Minor Arterial				
10	42-103	S.H. 22	03	06	E. of S.H. 23, LM 4.07
11	73-103	U.S. 167	16	06	N. of S.H. 87, LM 3.19
12	28-103	U.S. 412	08	06	E. of Cash River, LM 0.62
13	29-103	S.H. 4	05	06	N. of S. H. 332, LM 2.54
27	22-106	S.H. 35	08	06	SE of Monticello, LM 5.79
30	58-106	S.H. 7	15	06	N. S.H. 164, LM 15.86
		S.H. 29	03	06	Evening Shade
26		S.H. 140	02	06	West of I-55
31		S. H. 27	07	06	North of S.H. 298, Story

46		S.H. 29	01	06	North of Louisiana State Line
46		S.H. 29	01	06	North of Louisiana State Line
69		U.S. 64	09	06	East of Conway
71		S.H. 19	02	06	North of Waldo
Major Collector					
14	67-104	S.H. 115	03	07	E. of U.S. 167, LM 13.83
15	68-104	S.H. 50	01	07	W. of S.H. 75, LM 1.01
16	27-104	S.H. 46	02	07	SW of U.S. 270, LM 17.82
29	08-107	S.H. 21	05	07	S. of Berryville, LM 15.70
52		S.H. 42	05	07	West of I-55
60		S.H. 1	01	07	North of S.H.138
76		U.S. 70	17	07	East of S.H. 302, Brinkley
77		S.H. 13	09	07	South of S.H. 232
78		S.H. 14	12	07	West of S.H. 37, Newport
79		S.H. 10	01	07	East of Greenwood

ATR, WIM, SHRP, SPEED

Data Collection Sites Log

Field Station	Federal Station	Route	Section	F/C	Location
Urban Sites:	Urban Interstate				
18	60-121	I-630	21	11	W. of Denison St., LM 2.0
19	65-121	I-540	12	11	N. of S.H. 22, LM 5.36
31	18-111	I-55	11	11	NW of U.S. 70, LM 3.50
33	60-111	I-440	01	11	N. Ark.Riv. Brdg., LM 5.59
34	60-131	I-40	33	11	Lakewood Inter., LM 154.31
		I-40	33	11	Burns Park NLR
	U.S. 71	(I-49)	future	11	U. S. 71 Benton Co.
		I-40	52	11	West of Miss. Riv. Bridge
		I-430	21	11	North of S.H. 5, Little Rock
	Other Freeways & Expressways				
20	60-122	U.S. 67	10	12	S. of Jacksonville, LM 7.81
32	16-112	S.H. 245	01	12	S. of I-30, LM 4.49
		U.S. 65	15	12	Jefferson Co., Pine Bluff
		U. S.63	06	12	Craighead Co., Jonesboro
	Other Principal Arterials				
21	60-123	S.H. 10	08	14	W. of Cross St., LM 14.75
22	65-123	U.S. 64	01	14	S. of Ark. River, LM 4.16
28	70-114	U.S. 167B	01B	14	E. of S.H. 7 Spur, LM 3.18
	Minor Arterials				
23	73-124	S.H. 36	03	16	W. C/L of Searcy, LM 19.18
24	35-124	Hazel St.	N/A	16	N. of 27th St., LM 1.24
12	28-103	U.S. 412	08	16	Greene Co., Paragould
94		S.H. 255	03	16	Sebastian Co., Barling

Virtually all of the ATR, WIM, and Speed Data sites chosen were selected from existing data collection sites. The 65 data collection sites listed fulfill the needs of the Department for this portion of the continuous count element (ATR), of the data collection program, from existing data collection sites from current programs. Of these 65 sites, 48 are proposed to satisfy the WIM Program. All of these sites fall in or near highway segments currently in use for traffic counts, vehicle classifications, axle weight data, and/or speed data collection, fulfilling the objective of making them relatable to past traffic data collected, thereby, protecting the value and integrity of existing traffic data.

PROGRAM SUMMATION

In order to assess the cost effectiveness of implementing new technology in our current data collection programs, the existing annual operating costs were estimated. These costs included wages and overhead costs, transportation costs, per diem, and equipment operating costs. Not included in these costs were depreciation of existing equipment and replacement costs for obsolete equipment, therefore the costs summarized in this report for the existing programs are conservatively low.

Existing Data Collection Programs

Program	Annual Estimated Costs
ATR	$ 74,080
Speed & Class	74,080
WIM	212,980
SHRP	58,610
Total	**$419,750**

In order to assess the projected costs for operating the data collection programs proposed in this report, operation costs were estimated for the instrumentation of the ATR program, along with any additional sites needed for completion of other data collection programs, and conversion of the data collection sites to multi-program installations. The estimated operating costs include contractor installation expense, equipment acquisition, telemetry equipment, annual maintenance, monthly telephone bills, and an annualized ten year amortization of the total equipment installation cost based on a 6% interest rate over a ten year period.

Proposed Multi-Program Data Collection Program

Expenditure	Annual Estimated Cost
Annual Equip.(@6%)	$187,963
Maintenance (@5%)	74,200
Telemetry	31,200
Total	**$293,363**

As you can see from these estimates, in excess of $126,000 annual savings, approximately 30% of the annual projected field operating costs for these programs, is being projected by the implementation of new technology and the combination of the current data collection sites into multi-program installations.

The installation of this proposal will result in a significant change in data collection and processing. Because of the traffic history collected at each of the ATR sites, all current locations will be maintained without relocation from their respective highway section. Speed monitoring sites will be relocated to ATR sites. WIM sites will also be relocated to ATR sites. Some additional WIM sites, instrumented with SHRP, will continue to be operated in addition to these being proposed. Also, some additional Speed Data Collection Sites will be located at previously existing data collection sites for lower classification highways not adequately represented in the initial sites selected for this proposal.

Although the number of data collection programs being operated is not affected by this proposal, the quality and quantity of the data collected and the number of sites being monitored annually for the ATR and WIM programs would be substantially increased with implementation of this proposal.

The number of ATR sites would increase from approximate 35 existing to 50 as a result of the WIM sites being added, and all highway systems would have adequate numbers of sites based upon the estimates from the previous analysis included in this report. In addition to this change, sampling at these sites would change from continuous count to continuous classification, eliminating the need to perform periodic classifications with portable traffic recorders, thereby, further reducing our reliance on portable labor intensive methods.

The total number of WIM sites would decrease from 90 sampled over a three year cycle to 48 sampled annually. This is not a valid comparison, however, in that under the existing program, divided highways are considered two WIM sites with the traffic data collected directionally, whereas, under the proposed program each divided highway would be sampled as a single site. Since the portable 5150 AWACS traffic system monitors two traffic lanes at a time, 60 lanes of AWACS data are currently collected annually. Under the proposed WIM program the 48 Sites would result in the monitoring of 158 highway lanes annually, or the comparable equivalent of 79 traffic data collection sites when compared to the existing program. Additionally, since this data is being collected with remote instead of portable equipment, the duration of each WIM sample would be seven days instead of 24 or 48 hours under the existing WIM program. Also, this would allow us to collect seasonal WIM data at the same time we collect quarterly classification data at the designated ATR sites, expanding the seasonal traffic information available to the Department.

This proposal also includes the incorporation of the Speed data collection program into our other permanent data collection programs. In the past the Department has collected directional speed data only at 55 mph highways. Annual speed data has been collected at all existing sites with quarterly data collected at selected sites. Most of our speed data has been collected with portable traffic recorders. In the future program all speed data will be collected quarterly, and will be reported on 65 mph as well as 55 mph highways. Under this proposal we would select as many sites as possible from the ATR , WIM, and SHRP program sites, using the criteria from the speed data collection manual, to satisfy the needs of the program. The current Speed Data Program being proposed would be able to satisfy most of the higher classification highways in the State from the sites proposed for ATR and WIM except for an additional 15 sites required on lower classification highways, which comprise the largest mileage in the State. The addition of these 15 AVC sites to this proposal would add additional flexibility to the data collection programs by providing additional locations where traffic volume and vehicle classification data will be available if needed.

It is apparent from the description of the data collection sites proposed, that vehicle classification data available from this program would be adequate to satisfy the needs of quarterly traffic data used at eleven of the ATR sites across the State presently used for preparation of quarterly reports. This existing program primarily uses portable traffic recorders at these ATR sites four times annually, or 44 times a year, to gather data for preparation of this report. The use of remote systems to do this function would eliminate the repeated field labor necessary for this program.

The TMG directs the States to collect approximately one third interstate highway locations and two thirds other functional classification highway locations. The WIM and Speed programs are both site specific and directional, therefore, the instrumentation of one interstate or multi-lane primary highway for multi-program use, could potentially serve as an ATR, vehicle classification, Speed Monitoring, and WIM site. A SHRP site could possibly serve the Strategic Highway Research Program and all the above mentioned programs as well. The implementation of this proposal would result in approximately 50 ATR, 65 vehicle classification, 48 WIM, 11 SHRP, and 45 Speed Monitoring sites capable of remote operation and automatic data retrieval. It is apparent that nearly all of our permanent annual data collection needs for the ATR, Speed Monitoring, WIM, and quarterly traffic reports, in addition to the SHRP program, could be met and/or exceeded by the implementation of Automatic Weight And Classification (AWACS) and Automatic Vehicle Classification (AVC) Equipment. Therefore, by converting a portion of the present permanent data collection sites to multi-program installations, the AHTD should be able to accomplish this objective with fewer permanent data collection sites than are presently needed with the existing programs.

PROGRAM JUSTIFICATION

The application of AVC and AWACS equipment at these sites will result in some changes to the current data collection programs. The ATR program will be satisfied by the collection of continuous classification data, rather then continuous traffic counts with periodic classification data. This means that the adjustment factors computed over the State would be based on more complete data including data for week end and holiday periods. It will also result, however, in the necessity to process significantly larger volumes of classification data transmitted into the office by telemetry. The WIM program will result in every site being collected annually rather then on a three year cycle. This will make it unnecessary to adjust WIM data, and allow the collection of seven day data rather then 24-hour samples currently being collected. The automation of the Speed Data Collection Program will allow the AHTD to increase the number and duration of samples without increasing the personnel for the program. While this proposal will certainly significantly reduce the AHTD staff needed in the field to collect data for these programs, it will result in additional staff needs in the office to manage the retrieval of data with telemetry and the processing of data for inclusion in the AHTD traffic data bases. The collection of classification and weight data in the same highway segments will improve our ability to track both traffic and truck weights, and more dependably relate truck weights to traffic classifications statewide for better quality planning and design data. Modern practices and equipment will also enable us to meet the goals of truth in data and increased accuracy's being proposed for the Highway Performance Monitoring System (HPMS) and Environmental Protection Agency (EPA) goals.

Another important factor is the effect this proposal will have on the present and future labor demands for the data collection programs. The current field labor requirements would be reduced by thousands of hours a year, and the enhanced capabilities of the remotely operated automatic traffic recorders mean that the equipment can be operated from the central office rather than by dispatching field personnel, saving time, money, transportation, and labor. It also should be pointed out that the future expansion of the Speed Program, the addition of the SHRP program, and the creation of the six management areas of ISTEA with their additional data needs, can not be achieved with the Department's current technologies without hiring addition personnel. Therefore, modern technologies which allow us to combine data collection for multiple programs afford the opportunity to operate these programs while reducing the need for the hiring of additional field personnel and the avoidance of significant increases in the associated costs of labor, transportation, and overhead.

The disadvantages of continuing our data collection activities using current practices for the ATR, Speed Monitoring, and WIM, programs are as follows.

1. The current equipment and practices being used are highly labor

intensive and inefficient when compared to the new equipment and practices being developed.

2. The current portable data collection practices being used by the AHTD at most permanent data collection sites are limiting in that they only allow the collection of a limited amount of classification data and, make it extremely difficult to collect data during holidays and week ends.
3. The presence of AHTD personnel and support vehicles during the collection of WIM data affect the traffic and create some bias of the data.

The advantages of implementing the use of AWACS equipment and the development of multi-program sites are as follows.

1. The operation of AWACS equipped data collection sites for multi-program use will result in significant cost and labor savings ($126,000+ per year) by eliminating duplication of data collection equipment and efforts, and eliminating the labor intensive field operations currently being employed. Since the operation of these programs involve at least seven people, as much as 10,000 hours or more could be saved and reallocated to more productive use in field data collection with future program needs. With the Department's current policy of working toward more efficient operations and minimizing manpower costs, this proposal would further the Department's interests toward achieving these goals.
2. The reduced presence of AHTD personnel and vehicles will eliminate the impact on traffic during data collection activities, and eliminate the associated bias created.
3. This equipment will improve the data collected by allowing for continuous collection of classification data, seven day collection of WIM data on an annual basis, the collection of data during week ends and holidays, and the ability to remotely reprogram and operate permanent traffic recorders.
4. The use of multi-program installations will improve the accuracy and value of the data collected by retrieving classification and WIM data in the same highway sections, making them directly relatable.
5. This proposal will satisfy FHWA directives by implementing automatic traffic recorders for permanent data collection sites and eliminating duplication of data collection efforts.
6. The implementation of this proposal will provide training and experience for our field personnel which will make them more productive and valuable for the future data collection needs of the Department.
7. The implementation of this proposal would allow the Department to expand the data collection for the Speed Program and management areas of ISTEA while minimizing the need to hire and equip additional field personnel.

The many advantages and improvements to the AHTD's data collection efforts are apparent. However, the primary justification of this proposal is to demonstrate how the combination of multiple ongoing data collection programs can be achieved in an efficient cost effective manner to meet the future needs of the states and FHWA. It will demonstrate how existing state personnel can be made available for other data collection needs created by ISTEA by making the Department and its' personnel more productive. Nationwide, this may be the first state wide effort to streamline entire data collection programs by making maximum use of the existing data collection program sites rather than proliferating data collection sites across the states for each independent program. It may also be the first attempt to make radical improvements in the overall quality of different types of data by making traffic count, vehicle classification, axle weight, and speed data all relate to the same highway segments. It definitely demonstrates the ability to maximize the cost effectiveness and efficiency of modern data collection equipment by making each installation serve the needs of multiple data collection programs, rather than invest in different kinds of data collection equipment and/or labor intensive portable equipment to be used at scattered locations over the state.

FIGURE 1
Arkansas Current Traffic Data Collection Programs

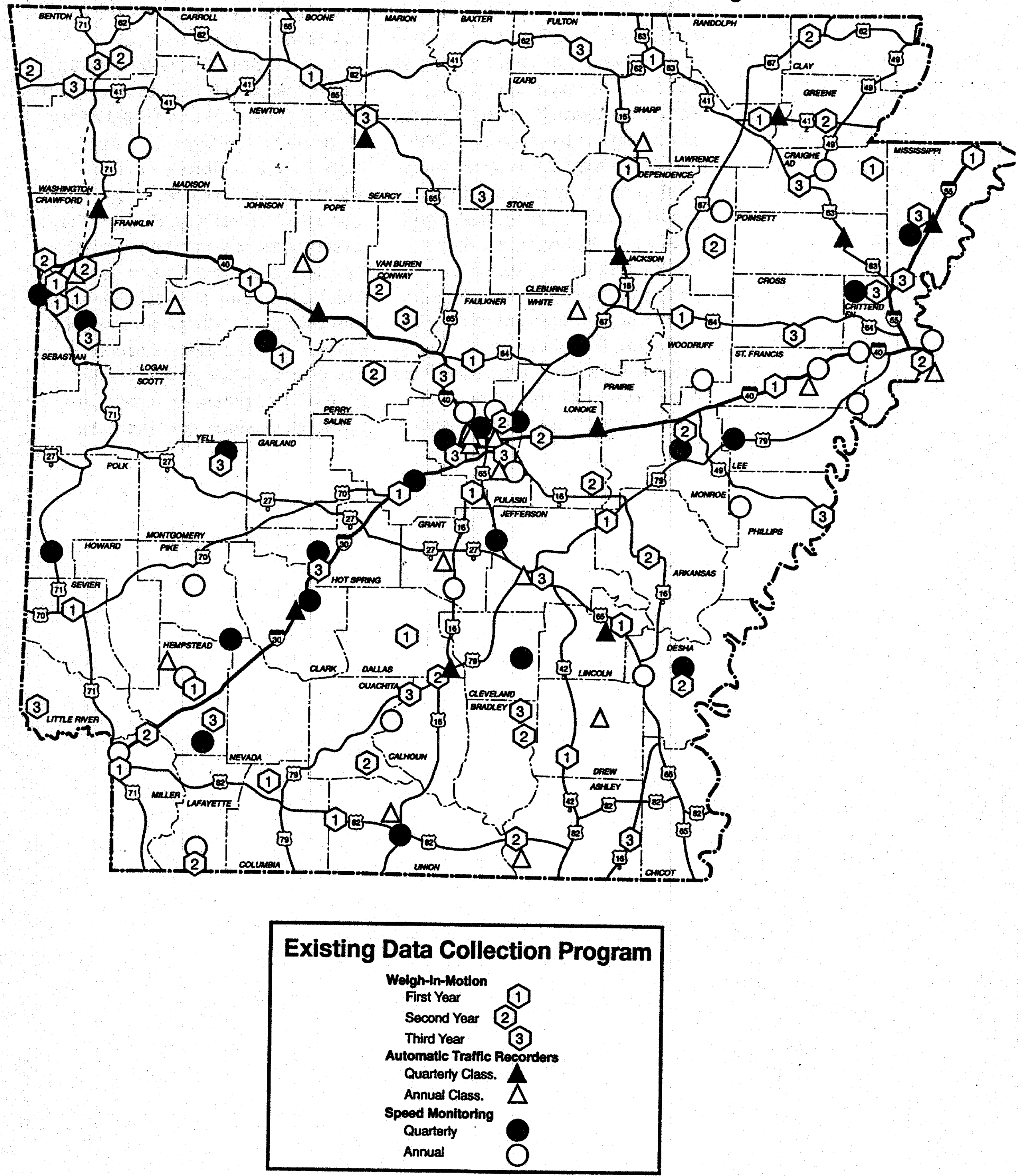
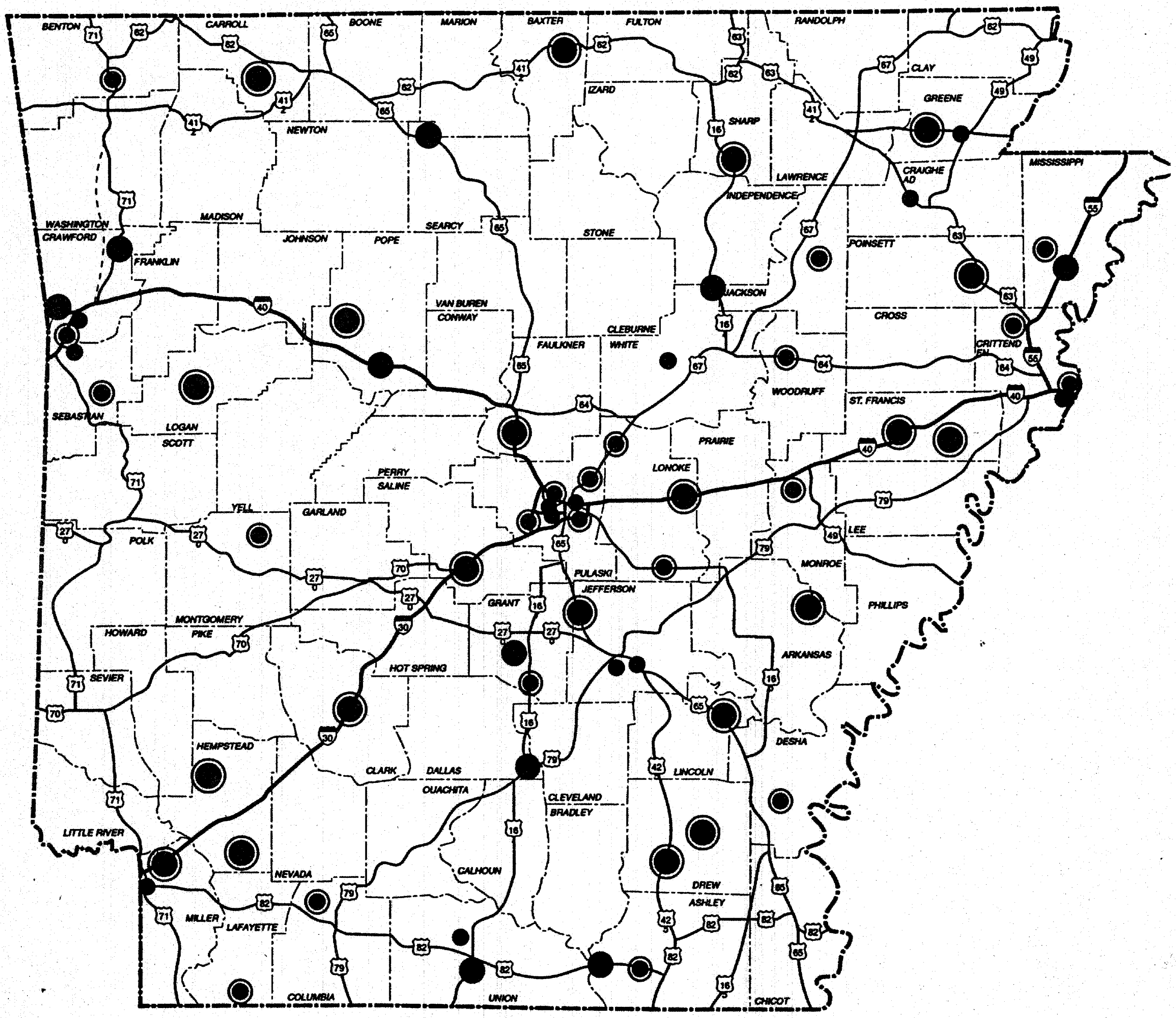


FIGURE 2
Arkansas Proposed Traffic Data Collection Plan



Future Highway Data Collection Program
Consolidated Multipurpose Sites

- ● Rural Collection Station
- • Urban Collection Station
- ◉ Co-located Speed Site

BRINGING PIEZOELECTRIC WEIGH-IN-MOTION ON-LINE AT LTPP SITES IN CONNECTICUT

Ms. Anne-Marie H. McDonnell
Connecticut DOT

Presented at
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Anne-Marie H. McDonnell, P.E.
Connecticut Department of Transportation

The National Traffic Data Acquisition Conference
September 21, 1994

ABSTRACT

In 1991 a research project was undertaken in Connecticut to determine the durability and accuracy of piezo-electric weigh-in-motion sensors. The project included the installation and continuous collection of data at four permanent sites at the SHRP-LTPP sites. This paper describes the procedures followed in the study and the findings over the first three years of investigation. This report is intended for other states that are planning to install or have already installed similar systems.

INTRODUCTION

In 1991 piezoelectric weigh-in-motion (WIM) systems were installed at the four Strategic Highway Research Program - Long Term Pavement Performance Experiment (SHRP-LTPP) sites in Connecticut. A SP&R study was initiated to monitor the systems. This paper describes the findings, including: a description of the test sites and instrumentation; calibrations that have been conducted at the four sites; and the tracking of the data as it has been gathered. It concludes with the concerns and issues for future data analysis and data collection.

SITE DESCRIPTIONS

There are four SHRP-LTPP sites in Connecticut, as shown in Figure 1. They were selected by SHRP staff from twenty-eight candidate areas for inclusion in the Long Term Pavement Performance Experiment. The sites are located in the towns of Manchester, Vernon, Glastonbury and Groton. The pavement structure differs at each site.

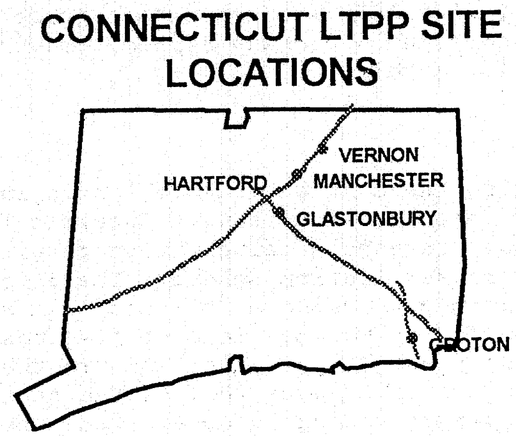

FIGURE 1: MAP OF SITE LOCATIONS

The Manchester site (SHRP I.D. 094008) is located on the westbound direction of Interstate-84. At this location, I-84 is a six-lane divided facility with long ramps that service adjacent commercial developments both north and south of the test area. The average daily traffic is approximately 37,400 vehicles per day and 10 percent trucks. All three lanes of the portland cement concrete pavement are instrumented with piezoelectric sensors.

Five exits east (6.53 mi) of the Manchester site on I-84 is the Vernon site (SHRP I.D. 095001). This 8-in. continuously reinforced concrete pavement section is a six-lane divided facility with an average daily traffic of approximately 33,400 vehicles per day and 10% trucks. This site is also in the westbound direction and carries much of the same through traffic as the Manchester site.

The Glastonbury site (SHRP I.D. 094020) is located on Route 2, westbound constructed in a 3-in. asphalt overlay on an 8-in. portland cement concrete pavement. The average daily traffic is approximately 17,200 vehicles per day with 6 percent trucks. Both westbound lanes of the four-lane divided highway are instrumented.

The fourth site is on the northbound direction of Route 117 in Groton (SHRP I.D. 091803). Connecticut Route 117 is a two-lane, two-way roadway with an average daily traffic of 5,000 vehicles per day and 4 percent trucks. The northbound lane of this site is also instrumented for the FHWA/LTPP seasonal monitoring experiment.

Each site is equipped with a controller cabinet to house the necessary hardware. The hardware includes: a customized 386 computer and monitor, a battery back-up, and 9600 baud modem. Each cabinet is furnished with electrical and telephone services. Continuous data is collected at all four sites. The systems are autopolled via modem and data are downloaded weekly at night to our central data acquisition office in Rocky Hill, CT.

The installation locations were fixed by proximity to the SHRP test sites. Essentially, the WIM placement complies with the ASTM criteria, with two notable exceptions: roughness and distance from structures. Specific site placement areas were selected to minimize pavement roughness. The contractor was not required to smooth or in any other way change the pavement surface. And of course, roughness changes as a function of time. Regarding proximity to structures, we were limited and could not comply with ASTM site selection guidelines due to the age and geometry of Connecticut's highway system, adjacent developments, and the need for access.

INITIAL SYSTEM SET-UP

During the system installation the contractor established initial values for factors required by the software algorithms. Specific factors were input for: weight calibration, threshold values, temperature compensation curve, and the classification scheme. The initial weight calibration factor was determined by using a "classic" class-9 vehicle. The process to determine the factor was to: conduct five passes with one five-axle semi-trailer of known weight per lane; compute the mean and adjust the system to measure within 5-10 percent of the static weight; and conduct five additional passes. Vehicle speeds were checked using a radar gun and found to be within 1 mph. The threshold values were input based on the contractor's experience. The temperature compensation curve was set at a constant value and left on its own to develop over time.

The classification scheme used by the Federal Highway Administration (Reference 3), describes vehicle types qualitatively. In order to use the FHWA Classification Scheme in a automated system, quantitative descriptors need to be assigned to each classification type. Because a national quantitative classification scheme does not exist, the assignment, or interpretation of the classification types is left up to the individual contractors. At the time of installation, the contractor input their qualitative interpretation of the vehicle types in the software.

CLASSIFICATION VERIFICATION

To establish and check the classification scheme, traffic was videotaped from within a vehicle parked alongside the road at each site. The traffic was videotaped for a two hour period. Manual counts and classifications were also gathered. The three counts collected(i.e. videotaped, manual from field, and WIM output) were compared. The counts were taken at peak and non-peak traffic hours. This led to several adjustments which improved, but did not correct, both the classification scheme and the linking of vehicles together.

WEIGHT CALIBRATION PROCESS

To validate the data collection at the test sites, the manufacturer's guidelines were chosen. This entailed the running of a fully loaded five-axle vehicle 5-10 passes and adjusting the calibration factor accordingly. For additional testing purposes, other test vehicles of known weight are run on the three divided highway sites. Specifically, an FHWA class-5, i.e., two-axle state dump truck, and an FHWA class-8, i.e., four-axle flatbed truck, loaded with jersey barriers are used (Classification Reference, 3). The vehicles are operated at the speed limit at all sites.

After the first calibration, an additional class-9 vehicle was hired to expedite the calibration process. In addition to enabling the calibration to be conducted in one day at each site, the extra truck provides data to determine vehicle-specific properties.

CALIBRATIONS APRIL 1992/ SEPTEMBER 1992

From the first two calibrations, it became apparent that vehicle weights were being measured to be approximately 16 percent higher each visit from the previous setting, as shown in Figure 2. This weight drifting led to the examination of the autocalibration (software data validation method) of the system. It was found that the systems were assuming front axle weight ranges. When compared to a small weight sample collected by the state police from an enforcement weigh station, the assumed weights were determined to be too high. The assumed values were reduced and consequently the amount of weight drifting was minimized.

These findings lead to the question, "Can software camouflage data by matching it to assumed weights?" To minimize the possibility of this happening, periodic updates need to be conducted to check the physical truck qualities of each particular traffic stream or regional traffic streams. An example of this is the newer class-9 trucks that have a longer or "spread" front axle in comparison to the "classic class-9" truck. During our most recent calibration (May 1994), the spread front axle truck measured lower at all sites than the classic configuration. Further investigation is required to determine if this is the result of the different axle configuration.

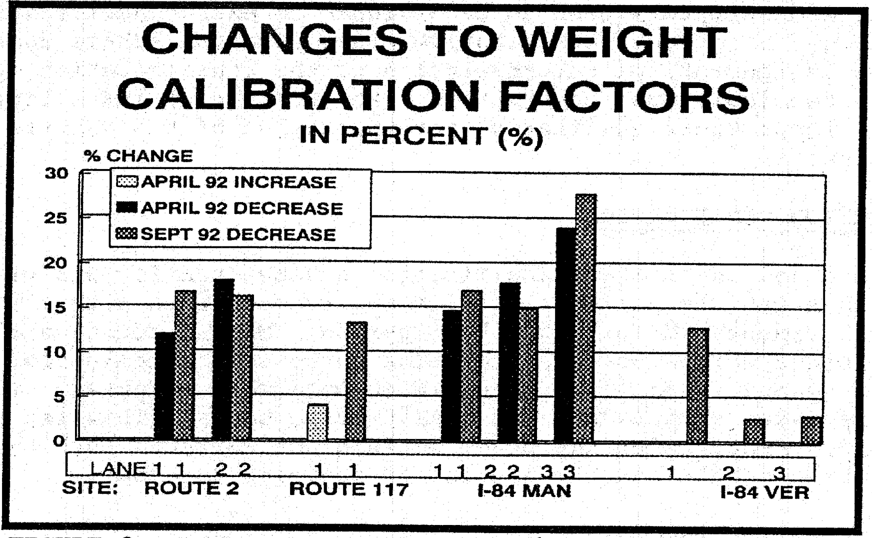

FIGURE 2: CALIBRATIONS APRIL 1992/SEPT 1992

SIGNAL OUTPUT

During the January 1993 calibration, vehicle weights were found to be two times expected values. "Ghost axles", or axles that appear in the records but are seen to not exist, were observed. In order to diagnose these problems, we inspected the signal outputs. It became apparent that during colder temperatures, the signal became stronger, exceeding the allowable range, causing extraneous noise. The effect observed was much like the effect of "maxing out" an amplifier on a stereo. Figure 3 demonstrates how the signal reflects from the boundary. By physically reducing the resistors, the signal size was reduced. It is important to check the signal output and not just the software output to determine the clarity and consistency of the signal being produced.

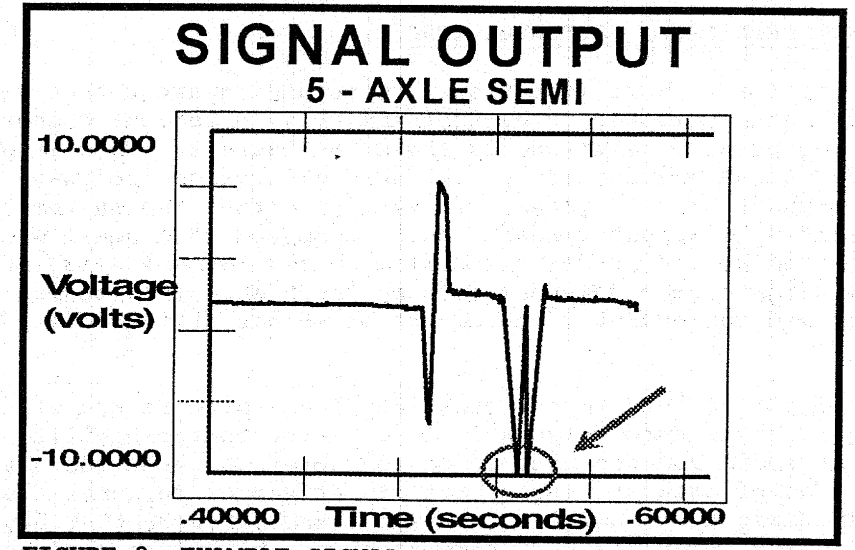

FIGURE 3: EXAMPLE SIGNAL OUTPUT

TEMPERATURE DEPENDENCE

Temperature dependence is an inherent quality of piezoelectric cable. During calibrations, it was found that as the day would progress, the weights would leap as a function of the temperature compensation curve. The result was that we would be chasing the vehicle weight outputs. At the Manchester site, the values remain more consistent. This may be because at that particular site, the sensors are sheltered by an overpass and therefore the temperature changes are more gradual.

To track the temperature dependence, the temperature curves are plotted. As shown in Figure 4, steep peaks are evident at the Vernon site curve when plotted. Small changes in temperature can translate into large changes in the autocalibration factor. These large changes in the factor directly influence the weights produced. Initially, we considered that the large peaks were caused by an insufficient sample collected for the particular temperature, however, Figure 4 represents data after three years of operation.

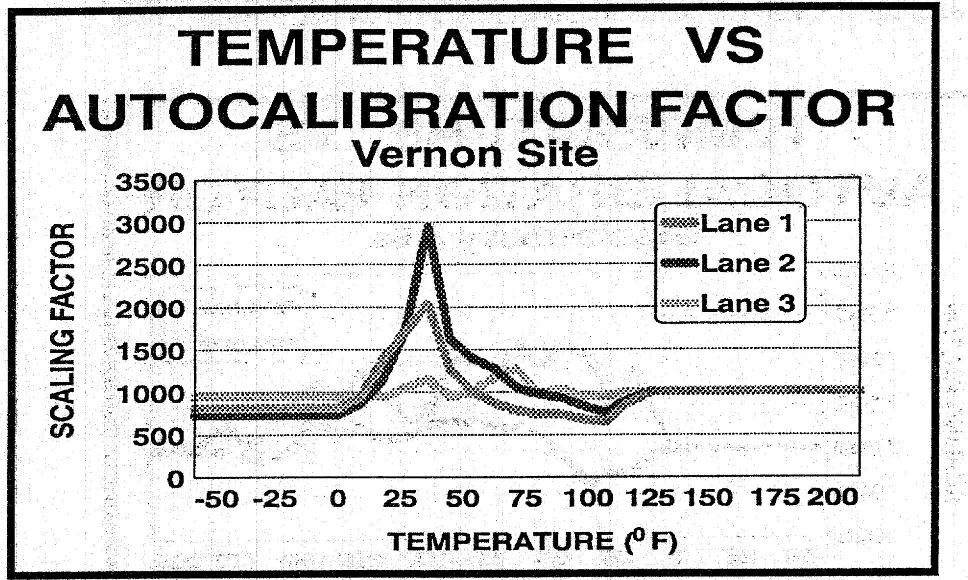

FIGURE 4: VERNON AUTOCALIBRATION FACTOR MAY 1994

Comparing Figure 4 and Figure 5, a difference is seen in the temperature curve at the Vernon site changes between September 1993 and May 1994. Looking at Figure 5, the high speed lane does not have a large enough sample because it is illegal for trucks to travel in this lane in Connecticut. The ability to designate a best-fit temperature curve has been discussed with the contractor. What the "best -fit" curve should be and how to designate it in the software need to be determined.

The temperature curve from the Glastonbury site is shown in Figure 6. Comparing Figure 6 with Figures 4 and 5 it can be seen that the temperature curve is both site and lane specific.

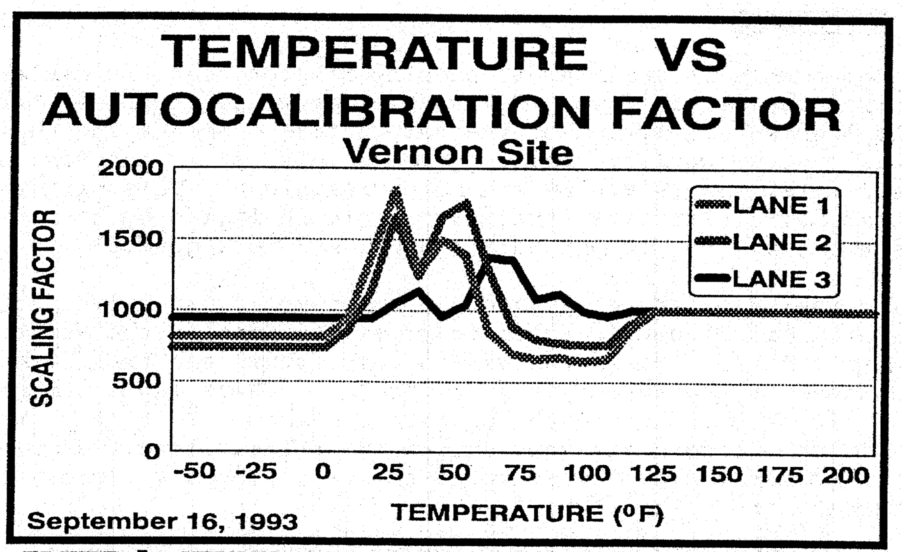

FIGURE 5: VERNON AUTOCALIBRATION FACTOR SEPTEMBER 1993

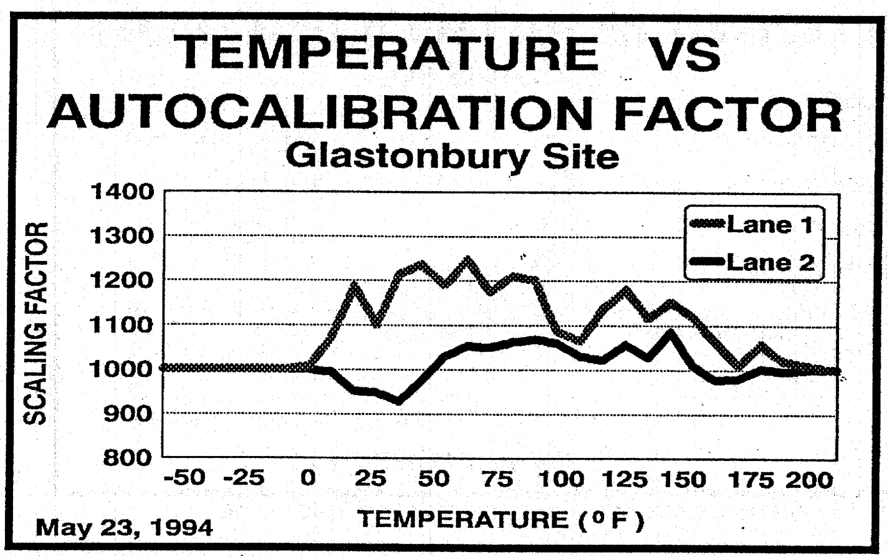

FIGURE 6: GLASTONBURY AUTOCALIBRATION FACTOR MAY 1994

DATA CHECKS

The incoming data is checked for : 1) vehicles classified as errors; 2) unclassified vehicles; 3) the distribution of gross vehicle weights (GVW) and; 4) the distribution of front axle weights. By checking these items, valuable observations have been made.

The number of vehicles classified as errors is not negligible. In fact, as many a 70 percent errors have been recorded in one lane. As shown in Figure 7, there is a seasonal relationship. This is found to be the case at all sites. We have attempted to justify these occurrences by correlating them to storm activity. Snow storms appear to be a plausible reason, as a result of vehicle tracking. It was found that some, however not all of the days correlate to this explanation. It was also found that there may be a relationship between a high number of errors and wind speed. In addition, an inverse relationship between the number of erroneous vehicles and the number of unclassified vehicles is observed.

Tracking of the GVW, as described by Mr. Curtis Dahlin and Mr. Mark Novak of Minnesota (Reference 2) is also conducted. Definite repeatability has been found at the Manchester site, as shown in Figure 8. The other sites do not display the same degree of correlation. The data from the Vernon site, just upstream from the Manchester site is similar but not as consistent as the Manchester site data, as shown in Figure 9. Note: A higher number of empty class-9 vehicles register at these sites. Class 9 vehicle distributions are found to be site dependent.

The Groton site data however does not lend itself to this sampling procedure. As shown in Figure 10, either three months of data is insufficient or a pattern does not exist. The volumes indicated in Figure 8, 9 and 10 refer to, in chronological order, the number of class-9 vehicles during the time periods indicated.

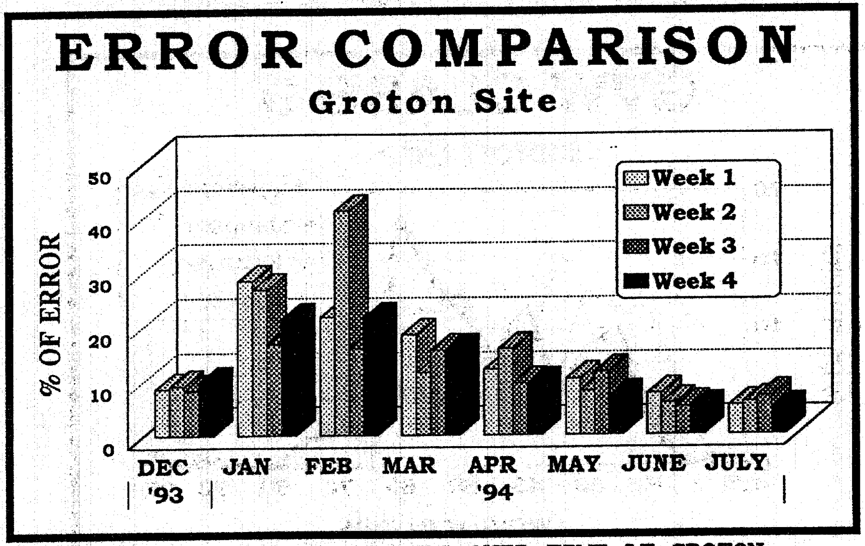

FIGURE 7: RECORDED ERRORS OVER TIME AT GROTON

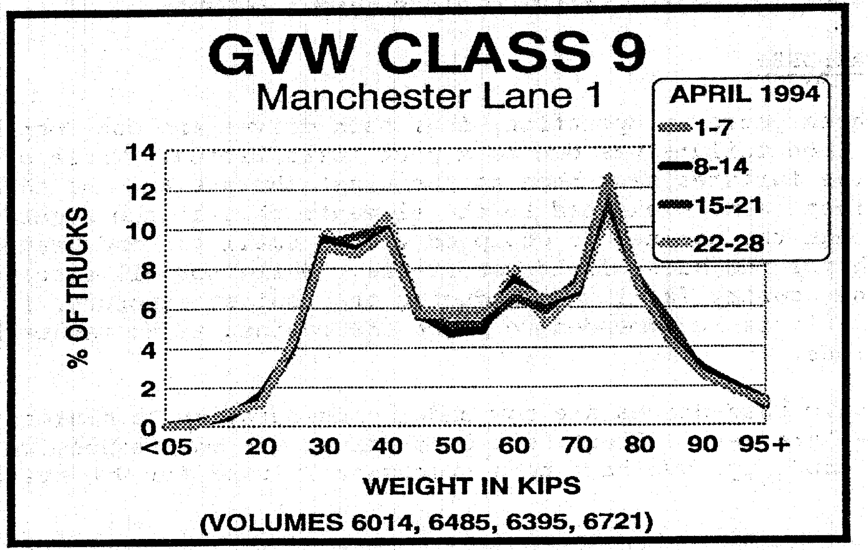

FIGURE 8: SAMPLE WEIGHT DISTRIBUTION - MANCHESTER

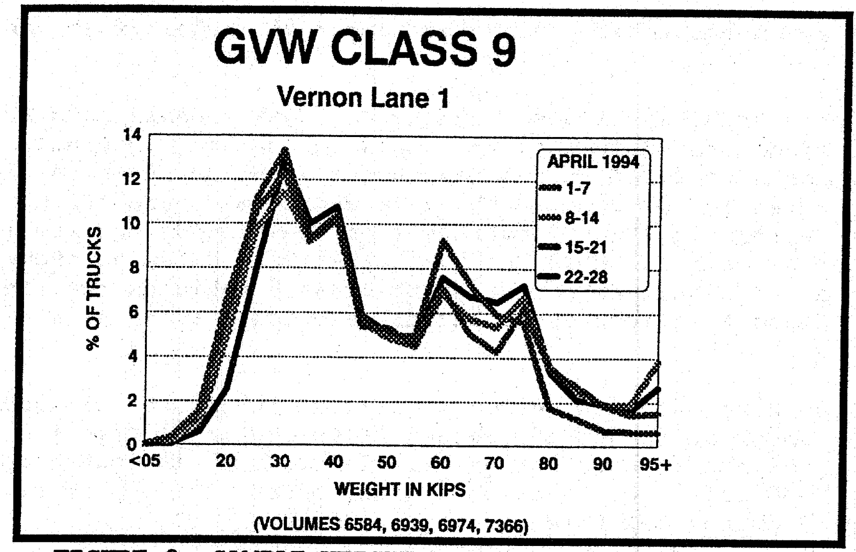

FIGURE 9: SAMPLE WEIGHT DISTRIBUTION - VERNON

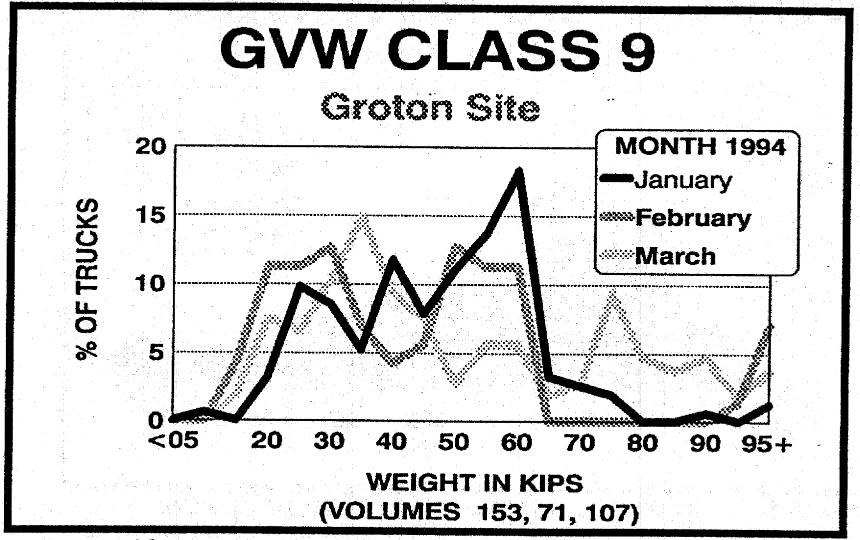

FIGURE 10: SAMPLE WEIGHT DISTRIBUTION - GROTON

MECHANICAL FAILURES

During the three years in operation, four hard-drives and one loop have failed. The loop failure was due to a poor installation. Three of the four hard-drive failures have been at the Glastonbury site. At this site the cabinet is more exposed to the elements than at the other sites. Although the cabinet is equipped with a small fan and heater, it is not enough for the harsh field conditions. While not all sites or regions of the country facilitate reducing the cabinet exposure, if the choice exists, it is recommended to place the cabinet as to reduce harsh field conditions.

Electronic hard-drives are now under consideration to minimize the hard-drive failure rate. Electronic hard-drives are more expensive and have limited capacity, but have been successfully used for WIM systems in France.

OPERATING COSTS

When considering the installation of piezoelectric versus other types of WIM systems, all costs need to be considered. A comprehensive list of items when determining costs should include: 1) training of personnel; 2) system calibration and maintenance; 3) estimated life of system; 4) data collection and analysis; and of course, 5) the quality of data. In anticipation of calibration and maintenance costs a contingency fund was created. We have had to use this fund every year. In addition to data collection and analysis, money should be allocated to cover the time required to properly analyze the data. Two key issues are involved in the cost of collecting quality data: first, the cost of collecting poor data to the Department and secondly, the direct cost required to collect better quality data.

CONCLUSIONS

In conclusion we have increased our understanding of these systems. Many issues have been raised that need to be addressed by the industry and users. Specifically, some of the issues include:

- The need to establish a National quantitative classification scheme for automated systems;
- Direct examination if the piezoelectric signal output;
- Checking traffic stream characteristics and comparing to software-based assumptions;
- Plotting and tracking of data as it is collected;
- Identification of erroneous vehicle volumes and causes;
- Reduction of mechanical hard-drive failures.

The accuracy of data collected by piezoelectric weigh-in-motion systems must be monitored. Fluctuations in accuracy can be site, lane, and seasonally dependent. Any agency installing systems needs to allocate appropriate funding and personnel time to track and maintain data quality. Data collectors need and must provide quality data to the broad spectrum of users. Governmental agencies and private industries need to work together to overcome the obstacles and to provide reliable data.

REFERENCED DOCUMENTS

1. ASTM Standards: E 1318 Standard Test Method for HIGHWAY WEIGH-IN-MOTION (WIM) SYSTEMS WITH USER REQUIREMENTS AND TEST METHOD.

2. Dahlin, Curtis and Novak, Mark. Comparison of Weight Data Collected at Weigh In Motion (WIM) Systems Located On The Same Route. Minnesota Department of Transportation for Transportation Research Board, January 1994.

3. FHWA Traffic Monitoring Guide. Publication No. FHWA -PL-92-017. Federal Highway Administration, Office of Highway Information Management. U.S. Department of Transportation, Washington, D.C., October 1992.

SUPPLEMENTARY NOTES

Prepared in cooperation with the U.S. Department, Federal Highway Administration.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Connecticut Department of Transportation or the United States Government. The report does not constitute a standard, specification or regulation.

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CALIBRATION AND AUTO-CALIBRATION OF WEIGH-IN-MOTION EQUIPMENT UNDER THEORETICAL AND ACTUAL FIELD CONDITIONS

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Alaska DOT & PF Highway Data Section

Presented at
National Traffic Data Acquisition Conference
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Calibration and Auto-Calibration
of Weigh in Motion Equipment
Under Theoretical and Actual Field Conditions

by
Douglas Terhune
Highway Data Supervisor

Weigh in motion (WIM) data is increasingly used by state and federal transportation officials. Ensuring that WIM equipment is operating properly and that the resulting WIM data is accurate is a source of ongoing concern to the highway officials responsible for collecting the data.

Types of WIM Equipment - [VIEWGRAPH] There are several major types of weigh in motion (WIM) equipment, including bending plate, piezoelectric, hydraulic load cell, capacitive strip, capacitive pad, and bridge WIM. Since 1986, the Alaska DOT Highway Data Section (HDS) has examined all of these WIM types in various configurations. The two types which I will address in detail are the Bending Plate WIM and the Piezoelectric WIM, however much of the material can also be applied to any type of WIM.

Operational Characteristics - [VIEWGRAPH] The operational characteristics of bending plates and piezoelectric sensors are dissimilar. Bending plates rely upon strain gauges mounted within the plates to weigh the axles of passing vehicles. An electrical signal is sent to the strain gauges from roadside electronics. Passage of a vehicle causes deflection of the plate; the action of the embedded strain gauges results in a change to the electrical signal which is then interpreted by the electronics.

By contrast, piezoelectric sensors actually produce electric current; kinetic force from the axles of passing vehicles results in a DC signal which is roughly proportional to the force of the axle on the sensor. In both types of WIM, analog signals from the WIM sensors are converted to digital pulses for interpretation by the electronics.

WIM Configuration - [VIEWGRAPH] In all cases, WIM equipment is triggered by an leading inductive loop, which remains activated as long as a vehicle is in the magnetic field. Two separate sensors are needed to determine the speed of the vehicle; either a second inductive loop, or a bending plate and another axle sensor, or dual piezoelectric sensors. The time between activations of the two sensors, together with the known distance between the sensors, is used to calculate the speed of the vehicle (distance divided by time equals speed). The calculated speed and the measured time between axle hits on the WIM sensors is used to back-calculate the spacing between axles (speed multiplied by time equals distance). As long as the leading loop is activated, all axles are assigned to an individual vehicle. The number of axles, the spacing between the axles, and the weight of each axle, are used to classify the vehicle.

Theory of Operation - [VIEWGRAPH] WIM equipment attempts to interpret signals from the sensors, reduce all the affects of dynamic forces to a few variables, and back-calculate to a close approximation of what the weight of an axle would be at rest on a static scale. The equipment attempts to ignore all the individual dynamic forces, such as the horsepower produced by combustion in the engine; friction affects, suspension systems, etc. The resultant force is assumed to be directed perpendicular to the pavement, opposite the force of gravity, and therefore can represent the weight of the vehicle. Considerable debate has been generated as to whether this is a reasonable or desirable goal.

Uses of WIM Information - [VIEWGRAPH] Except in a few research situations, WIM data is not collected without an intended use. Individual vehicle or axle weights are seldom needed; the serviceability of WIM systems and WIM data should be evaluated within the context of a larger program goal. The intended use of the information affects all aspects of the WIM program, including the quantity and quality of data needed, the type of equipment required, the number and location of data collection sites, the type of vehicles to be weighed, the measurement accuracy of the equipment, the statistical accuracy of the overall program, the amount of analysis to be performed, and the types of reports to be generated. All of these factors determine the amount of resources, including money and time of skilled staff, which can be justified to support the program.

[VIEWGRAPH] Information from processed raw WIM data is used for pavement design, bridge design, and in support of weight enforcement activities; the resulting information is also available for general research purposes such as in the Strategic Highway Research Program (SHRP). In Alaska, the primary use of the WIM information has been defined as pavement design. Development of Equivalent Single Axle Loads (ESALs) is used to define evaluation criteria for WIM systems. This clearly defined goal has been used to guide development of the program, and has helped to resolve many theoretical and operational issues.

Dual Process Data Collection Program - [VIEWGRAPH] The Highway Data Section has employed the paradigm of the traffic volume program in developing an integrated vehicle classification and weight program relying on Automated Vehicle Classification (AVC) and WIM equipment. The traffic volume program is designed to produce accurate

Annual Average Daily Traffic (AADT) figures over most of the road network. Individual daily, weekly or monthly average traffic volumes may vary widely at the same location throughout the year. Generation of AADT figures normalizes the data to enable meaningful comparisons of the same type of information from different locations, collected with different methods at different times.

The traffic volume paradigm relies on a dual process data collection program, consisting of a small number of continuous count stations and a much larger number of short-term counts. Data from the permanent traffic recorder (PTR) stations is processed to yield seasonal variation factors (SVF). Short-term counts are associated with PTR(s) with similar seasonal characteristics. The data from the short-term counts is expanded to AADTs using the SVFs from the associated PTRs.

The HDS AVC/WIM program is similar in that we employ both continuous and short-term data collection. However, the continuous data collection sites collect either vehicle classification data or class and weight data, but the short-term counts collect only vehicle classification data. After years of work, we have had no success in collecting accurate WIM data with portable equipment. Portable WIM is not an element in our data collection program. A significant factor which enables us to substitute low-cost class data for expensive weight data is the classification scheme used to sort vehicles into the 13 vehicles categories identified in FHWA Scheme F. This will be discussed in more detail later, but it is important to note here that the HDS application of this procedure is oriented toward identification of vehicle types with similar ESAL characteristics.

Factors that Affect Accuracy and Calibration - [VIEWGRAPH] In our experience, just about everything about the AVC/WIM program affects the accuracy of the data, either directly or indirectly. The cumulative result of all of these effects great and small, is most evident during the calibration process. In the larger context, the number and general characteristics of the site affect the overall program level, or network level accuracy, or potential accuracy, of the information. Specific site selection, installation, commissioning, on-going operation, data retrieval, and subsequent data processing also have direct impacts on the accuracy of the resulting information. A cascade affect is evident; decisions made early in the program will have increasing effects either as the program develops or as the data is processed. Although most errors can be compensated for later, subsequent compensation becomes increasingly more difficult.

The three elements discussed above; that is. how the equipment operates, what it is attempting to simulate, and how the processed information will be used; must be continuously referred to when examining site selection, operational characteristics, and autocalibration. Careful attention to elements of site selection, installation quality and general workmanship can minimize the number and type of extraneous operational factors which must be compensated for during operation and calibration.

Site Selection - [VIEWGRAPH] An important goal in initial site selection is to minimize affects that must be compensated for and offset later. There are elements here that reappear again under day-to-day operation of the equipment.

Significant factors to be considered in site selection are the approach roughness, the amount of pavement rutting, presence of horizontal or vertical curves, the constancy of the speed of the vehicles, and lane discipline. All elements should be analyzed from the standpoint of the affect on the dynamics of the vehicles. Other design factors include the type and thickness of pavement in which the sensors are installed, the composition, layering, porosity and compaction of the base and sub-grade, and the typical saturation levels at the site. All of these elements interact and affect the accuracy of the system, particularly the temperature sensitivity of piezoelectric WIM sensors.

Installation Methods - [VIEWGRAPH] The quality of the initial installation and commissioning has profound effects on subsequent calibration and day-to-day operations. The types of materials used, such as the type of piezoelectric sensor, and the type of epoxy used for installation, can mean the difference between consistent, error free data or continual maintenance problems.

Just a few examples of installation techniques which can improve operational reliability and data accuracy are :

> Proper foundations for the sensors are critical. We usually thicken the pavement section in the vicinity of the WIM sensors. Bending plates should be installed in concrete pavement sections. We've looked into vaults but are very skeptical because of problems with wheel rutting and differential settling.
>
> When constructing the cavity for the sensors, careful preparation is essential. We sawcut the cavities, then powerwash, and thoroughly dry with air and heat prior to embedment to avoid cracks and breakout.
>
> Bury the piezo sensor in epoxy below the pavement surface, especially if there is significant wheel ruts at the site.

The type of epoxy used for installation is very important. Don't assume that the vendor will provide the optimum for your situation.

If the pavement is too cool, we use a tent and space heaters. Always protect from rain during installation and curing.

Provide strain relief on coaxial cables at connections to piezoelectric sensors. We use plumbers putty to form an epoxy-free cavity at the end of the sensor, which is filled with flexible inductive loop sealant; all cables are run in underground conduit.

Avoid splices in wiring, but if splices are made, always solder all connections and completely encase in splice kits. Never run sensor wiring in same conduit with higher voltages (120/240/480). Provide weep holes at the low points of all conduit, with properly sized drain rock below, to avoid damage or failure from ice in conduits.

During commissioning and subsequent operation, systematically and periodically check the signal strength of all sensors; we have had to modify nearly all of our WIM units at the hardware level, by changing resistors or shunts, to ensure that input signals are within a range that the equipment can process. Examples of out-of-range signals include clipping, dropping below minimum thresholds, or low signal-to-noise ratio.

Most of this is obvious to those who are familiar with the equipment, but apparently is not to contractors and construction personnel.

Evaluation Criteria - As mentioned, evaluation of the adequacy of the equipment begins with a clear definition of the intended use of the resultant information from the entire program. We have performed a number of activities to develop evaluation criteria for the WIM program, ranging from literature review, attendance at conferences, extensive field evaluation of multiple systems, and operation of models and simulations based on theory and local field experience.

WIM Simulation Model - [VIEWGRAPH] One of the methods used to determine the required program accuracy was use of a WIM simulation model to generate several types of errors in the weight data, and subsequent use of this information in simulations of the pavement design process for a number of representative highway projects. This sensitivity analysis provided a real-world example of the relationship between the various pieces of equipment, the comprehensive data collection program, the affects on highway design projects, and some idea of the potential benefits and costs to the Department of various implementations. To briefly recap the process;

> [VIEWGRAPH] The computer model used a series of 1000 trucks of FHWA Scheme F classes 5, 6 and 9. These vehicle types comprise a large proportion of the design loads for Alaskan roads.
>
> As a worst-case scenario, and to simplify the calculations, we assumed that all of the vehicles were loaded to legal maximums on all axle groups. The model data represented the axle weight measurements of the 1000 trucks.
>
> We introduced two types of error into the WIM measurements. In all simulations, the WIM measurements were normally distributed about the mean. This represented what our experience confirmed in the field.
>
> We varied the standard deviation of the WIM measurements. A small standard deviation indicates that the equipment more frequently measures the axle weights with only a small error, that is, most of the WIM readings are very close to the corresponding weights measured at a static scale.
>
> We computed the equivalent single axle loads (ESALs) from the WIM measurements, and from the corresponding static scale weights and compared the two. Obviously, the ESALs computed from light WIM measurements were low when compared to the static weights, and the ESALs from the heavy WIM measurements were high.
>
> However, the relationship between axle weight and ESAL is non-linear. The equation used by the Department, which makes some simplifying assumptions, is exponential to the 4.6 power.
>
> [VIEWGRAPH] As a result, axle weights that are measured as heavy have an exaggerated error. In our model, the error in ESALs from 'light' vehicles and 'heavy' vehicles does not cancel out; the cumulative ESAL value is exaggerated by the axles which are measured as 'heavy'.
>
> This exaggerated error is greater when the distribution about the mean has a large standard deviation. If all the WIM axle measurements are close to the static weights, the error is minimized.

Up to this point, the mean of the WIM measurements and the mean of the corresponding static weights has been assumed to be the same. This situation would occur when the WIM equipment is properly calibrated. A high standard deviation in the WIM measurements would correspond to a poorly-designed WIM system that just doesn't measure trucks very consistently.

[VIEWGRAPH] We next introduced another type of error, where the mean of the WIM measurements was skewed higher or lower than the mean of the static weights. This would correspond to a situation where the WIM system was not properly calibrated.

In this case, the error in ESALs calculated from WIM measurements that were too high is even more exaggerated. Again, the exponential relationship between weights and ESALs operates to exaggerate the measurement errors.

[VIEWGRAPH] We simulated various combinations of the two types of measurement error. In some cases the errors can cancel out. For example, this can occur when a normally accurate WIM unit with small standard deviation is configured to measure axles somewhat light. The WIM measurement mean will be lighter than the static weight mean. In other cases the errors reinforce each other to produce even larger errors in ESAL calculations. This can occur when a poorly-designed WIM unit with a large standard deviation is configured to measure axles much too heavy. The mean of the WIM measurements will be heavier than the static weight mean.

Affects of WIM Measurement Errors on Local Pavement Design - [VIEWGRAPH] The ESALs computed from the WIM model were than used in a series of pavement designs for different highway projects in Alaska. We were interested in what amount of error in the WIM systems would result in significant under- or over-design of pavements. For example, what error or combination of errors in the WIM measurements would result in a pavement design that was 1" too thick?

[VIEWGRAPH] Briefly, the cumulative 10- or 20-year ESALs are estimated for the subject road section. Many highway projects in Alaska are required not because of structural failure, where the pavement has exceeded the design life and suffers from alligator cracks and potholes. Instead, the project is needed because of functional or operational failure, where the road suffers from serious wheel rutting or capacity constraints.

For rehabilitation projects on the same alignment, a pavement overlay is usually performed. In urban areas with curbs and gutters, the existing pavement is usually roto-milled to level the wheel ruts, while in rural areas a thin leveling course is applied to level the ruts prior to overlay. A falling weight deflectometer (FWD) is used to measure the remaining life in the existing pavement. The cumulative estimated ESALs are reduced by amount of load carrying capacity in the existing pavement, and the overlay is designed to carry the remainder of the cumulative estimated ESALs.

We found that it is standard practice to design no less than a minimum 2" overlay. In many cases, the low cumulative ESALs and remaining pavement life resulted in a required pavement overlay that was less than 2 inches thick. Under actual conditions, it required a large error in the WIM systems to force the pavement design over the 2" threshold. The possibility of errors this large occurs mostly in the urbanized areas.

As a consequence of this and other factors, we have concentrated our WIM installations in and around the areas with high potential for expensive pavement design errors. We are aware of the bias which this introduces into the random sampling methodology of the FHWA Traffic Monitoring Guide (TMG).

Classification Methodology - [VIEWGRAPH] Another very significant result of our analysis of the sensitivity of pavement design to the measurement accuracy of the WIM systems was recognition of the importance of the methodology used to classify vehicles. Under our program, the accuracy of the vehicle classification process has as large an impact on the usefulness of the data as the measurement accuracy of the WIM systems, in terms of the cost or benefit to the Department.

Accuracy Standards - [VIEWGRAPH] It has been our experience that equipment vendors, particularly of WIM systems, cannot define the accuracy of their equipment in exact terms. For example, we have heard accuracy claims of a certain percent or number of pounds of gross vehicle weight (GVW), such as "within five %" or "within 300 pounds", or a certain percent or number of pounds for each individual axle. Sometimes a specific vehicle speed range, ambient air temperature or pavement temperature range, or certain vehicle type or types are mentioned. Sometimes the accuracy figures are quoted as if to apply to each vehicle measured, or to a stated portion of a number of vehicles. Over the years, we have heard accuracy claims for any combination of all of the above from different vendors, or from different representatives of the same vendor, or even from the same representative at different times.

[VIEWGRAPH] HDS has developed an accuracy specification, grounded in statistics, and expressed in terms of precision and confidence interval. Acceptance testing and calibration requires the use of three types of vehicles, representing FHWA Scheme F classes 5, 6 and 9. The class 5 represents a heavy delivery vehicle or recreational vehicle, both of which comprise a large portion of the truck traffic in Alaska, particularly during the summer tourist season. The class 6 represents a 3-axle, 10-wheel dump truck. The class 9 is a standard 5-axle, 18-wheel tractor semi-trailer. On some Alaskan routes, research indicates that we should also include a class 13, double- or triple-trailer combination vehicle, but these units are very difficult and expensive to use as test vehicles. The types of vehicles were selected after analyzing weighstation data and numerous classification counts. We also performed a large-scale AVC/WIM equipment test where we installed and tested a dozen different types of AVC and WIM equipment at two locations in Alaska.

The ESALs for each vehicle type and the number of vehicles of each type combine to produce most of the pavement loads over most Alaskan roads. Based on the results of the equipment test, on the sensitivity analysis and on our assessment of the operational accuracy of the equipment when first calibrated and over time, we developed accuracy standards with a precision of 10% for GVW, 12% for axle groups, and 94% confidence intervals. I'll give more detail under the section on initial commissioning and calibration on how this accuracy standard is applied.

This accuracy standard is appropriate for Alaskan highways of highest interest to the Department, and probably is not the best for all installations under all circumstances. A similar analytical procedure could be used to develop similar standards for other areas.

Vehicle Classification - [VIEWGRAPH] The vehicle classification procedure is a critical element in the HDS program. The older, traditional definition of vehicle classification assumes a visual process, where profiles of representative examples is used to define vehicles in each class. This process dates back to when most classification studies were performed by individuals at the roadside, and is unsuitable for most classifications studies today which are performed by automated methods.

A new definition of vehicle classification must be focused on the goals of the data collection program to which it applies. In Alaska, the goal of the AVC/WIM program is based on the needs of pavement design. Under this program, vehicles are grouped by similar ESAL characteristics. As described above, the basic criteria available to classify vehicles under an automated system are the number and the spacing of axles of the vehicles. Analysis of the data available from WIM equipment also provides the normally expected weight of the axles of each vehicle. From WIM data, the normally expected minimum and maximum axle weights can be defined, although this may well conflict with auto-calibration process as discussed and explained later.

We continue to expend a great deal of time and resources on developing a set of classification criteria which adheres as closely as possible to the FHWA Scheme F, yet meets the State goals of grouping vehicles into categories based upon similar ESAL characteristics. HDS does not save the individual vehicle data for classes 1 through 3, encompassing automobiles and light trucks or pickups. However, all unclassifiable vehicles are saved for later study. The unclassified vehicles are periodically reviewed and analyzed, and the classification scheme is adjusted as possible.

Currently, HDS is employing four different types of AVC/WIM units on a regular basis, which classify vehicles. Under our program, it is necessary to classify all vehicles with similar ESAL characteristics into the categories useable for pavement design.

Calibration and Auto-calibration Overview - [VIEWGRAPH] Next, I will give a short description of the theory and assumptions underlying calibration and auto-calibration, the procedures developed by WIM vendors to apply the theory, and the local application and refinement of theory and procedures, based on field experience.

All the vendors of WIM equipment have similar suggested procedures for initial calibration of their respective systems. Basically, a vehicle of known weight is run over the sensors, and a manual calibration factor is entered into the system to adjust the WIM measurement until it approximates the weight from a static scale. These procedures make a number of simplifying assumptions, either implicitly or explicitly. The procedures assume that the correlation between inputs from the sensors and the actual weights is linear, i.e., the weights are directly proportional to the sensor outputs, and that the linear relationship holds not only for the range of weights being measured, but also for all speeds, temperatures, and all types of vehicles. These assumptions are evident from the fact that in earlier WIM equipment, no compensation factors were able to be introduced for other aspects of calibration. A single manual calibration number was entered for each lane. Some of the newer systems have begun to include changeable parameters for specific aspects of the process to convert a sensor signal to a WIM measurement.

Theoretical Auto-Calibration and Temperature Compensation Methods - [VIEWGRAPH] Most autocalibration theory in common usage relies on the detection and accurate measurement of class 9 tractor semi-trailer vehicles. The average front axle weights of class 9 vehicles remains fairly constant, over time and throughout the nation.

We have speculated about this phenomenon, and suspect that reasons for this include the facts that there are a limited number of heavy truck manufacturers; there are similar pavement designs and hence similar load restrictions nationwide; and there is a natural standardization of vehicle types employed by the trucking industry to control operating and maintenance costs. Therefore, the essential element of WIM calibration theory is that throughout the data being collected, one frequent data element remains fairly constant, and this constant can be used as an indicator of the accuracy for the remainder of the data. In other words, the mean front axle weight of class 9 vehicles is a relative constant in the data, and can be used as a signature to determine the operational accuracy of the equipment.

Application by WIM Manufacturers of the General Calibration Theory - Each manufacturer of WIM equipment have a different interpretation of the calibration theory, and have developed different suggested procedures for manual calibration and auto-calibration. What follows is a very quick survey of the procedures used by different manufacturers, based on our experience.

IRD Calibration and Autocalibration Procedures - [VIEWGRAPH]

For the initial commissioning, manual calibration numbers are user-input for each sensor in the usual way, along with dynamic compensation factors for each lane. The dynamic compensation factors allow the user to input a parameter which will cause the IRD software to increase the front axle weights by up to 10 percent. This is an attempt to deal with one of the most serious dynamic effects on the vehicles used for autocalibration.

To deal with the effects of temperature on piezoelectric sensors, the autocalibration software develops a temperature compensation (TC) factor for each 5 degree Centigrade interval, (9 degrees Fahrenheit). The signal input from the piezo WIM sensor is multiplied by both the manual calibration factor and the TC factor to yield the WIM measurement weight. The autocalibration software uses a learning process for developing a look-up table containing the TC factors. The software computes separate factors for each 5-degree C bin for each lane. Over time, the unit will compare the measured front axle means with the user-defined expected means, calculate the error between the two, and calculate new TC factors which will be used as a multiplier for subsequent measurements.

IRD normally uses the class 9 tractor semi-trailers in the traffic stream for autocalibration. The weights of the class 9 vehicles detected during the calibration interval are sorted into three GVW bins. The GVW bins are determined by two user-selectable upper and lower limits for the middle bin. In order to autocalibrate, the software requires that there be vehicles measured in at least two of the three GVW bins.

Each of the three GVW bins is assigned an expected mean front axle weight and an acceptable accuracy figure. The absolute error in the measured mean front axle must be greater than the acceptable accuracy for the unit to autocalibrate.

A temperature probe is mounted in the pavement, preferably adjacent to the piezo sensors. The temperature at which the WIM measurement is made is stored as a data element along with the axle weights and spacings.

To use the vendor-supplied default parameters to calibrate the system, simply turn on autocalibration and allow the system to develop site- and lane-specific TC factors. In our experience, this process can take more than a full year. Optionally, an initial set of TC factors may be keyed in. These factors correspond to a typical TC curve developed by the vendor based on information from several state highway agencies.

PAT Calibration and Autocalibration Procedures - [VIEWGRAPH]

Manual calibration numbers are developed in the usual way, based on multiple passes with a test vehicle. Manual calibration numbers are entered for each lane, for each of three speed bins. The inclusion of three speed bins as an attempt to account for dynamic effects of moving vehicles.

This review is based only on our experience with PAT DAW 200 and DAW 100 bending plate WIM units. We do not have any PAT piezoelectric WIM units, and are unfamiliar with any calibration procedures for these systems.

GK - Calibration and Autocalibration Procedures -

The GK system was the simplest of those tested in 1990-91. Manual calibration numbers are developed in the usual way, based on multiple passes with a test vehicle. For autocalibration, a number of class 9 vehicles, for example 100, is selected by the equipment from the traffic stream. The mean of the front axle weights is compared with a user-defined expected mean front axle weight and the manual calibration number is modified.

Local Application and Refinement of Theory and Procedures, Based on Field Experience - [VIEWGRAPH] Detailed procedures were developed and documented in the form of a checklist for calibration and on-site maintenance. Other written forms were also developed for use as worksheets and to record actions in the field. It became clear that the single most important aspect of achieving and maintaining accuracy from the WIM equipment was to develop written procedures and to document what was being done to the equipment. Even if, or especially if the actions being taken were not achieving the desired result, they should be clearly identified. Changes should be in written form, and some idea of the reasons for the changes, even if the improvements were speculative, should be developed and shared with all members of the team.

In our case, there were four people working with the equipment, both in the field and from the central office and the field operations shop via telemetry. Each person had a different understanding of how the equipment and autocalibration process worked in detail. Each seemed to get separate pieces of information from various equipment vendors (WIM, modems, software, hardware). Each of us seemed to have different experience with the equipment, which in turn shaped our understanding of how the systems operated. Even with perfect recall, there were so many things happening with the systems that it was difficult to keep up with new developments. Over a period of several years, as memories faded, opportunities for confusion increased. Our rate of progress increased, and our level of frustration decreased, after we began to systematically document our experiences and make the additional effort required to share all information between members of the team.

Field Conditions: Initial Calibration - Initial calibration appears very simple in theory, but quickly becomes much more complicated in practice. As I mentioned earlier, the vendors appear reluctant to give precise accuracy standards. Without knowing what the equipment is capable of measuring, it is difficult to determine if optimum accuracy has been achieved at any point during calibration. In our initial naivete, we attempted to follow all of the vendors' instructions to the letter, in those cases where instructions for calibration were provided. We discovered that the longer that data was collected, the more the information collected would be in conflict. I won't present in detail all of the procedures which we have tried over the past 8 years, but I will mention a few that seem to be most successful for us.

Comparison with Weighstation Data - [VIEWGRAPH] We have performed several studies to determine if the class 9 front axle weight phenomenon is present in Alaska and can be used to perform autocalibration under local conditions. Actual weighstation data was examined to determine if the front axle weights behaved as proposed. The review supported some of the theoretical expectations, within accuracy needed to meet local goals for pavement design. Analysis of weighstation data indicated that the mean steering axle weight of class 9 vehicles does remain fairly constant, with relatively small standard deviation. However, the average front axle weights varies by more than 1000 pounds, or more than 10 percent, between different locations. We have been cautious when using this data; weighstations normally do not weigh empty vehicles, and stations are often closed due to budget restrictions. We have not yet performed a detailed subsequent review, but experience gained with working systems indicates that local or site-specific modifications of the theory are required. I'll address some of these later in this discussion.

Local Autocalibration Parameters - [VIEWGRAPH] The vendors do not provide direction on how to determine the GVW bins, the expected mean front axle weights, or the acceptable maximum error. To develop initial figures for these parameters, we performed extensive review of weighstation data. With funding from the DOT&PF and technical assistance of the HDS, the Division of Measurement Standards (DMS), who operate the weighstations, have computerized many functions. As a result, HDS has access to all weighing performed by the DMS. We used this data to determine the initial GVW bins and expected mean front axle weights for class 9 vehicles.

A typical procedure is to summarize all class 9 vehicles for one year, for each direction at the individual weighstations, sorted into 2000 # bins by GVW. We have observed that the distribution of the summary data for weighstation is often bi-modal. We selected the mean GVW and one standard deviation (STD) either side of the mean for the middle GVW bin. We then computed the average front axle weight for each GVW bin. When the summary data is dis-aggregated by GVW bin, the standard normal distribution (bell curve) can be observed for both the GVW and the front axle weights.

By using one STD, the middle GVW bin should include about 2/3 of the trucks in the weighstation data. In actual practice, a larger proportion of trucks is often observed in either the low or high GVW bins. Recall that the weighstations do not usually weigh empty trucks, which in operation of an actual WIM system will increase the proportion in the low GVW bin. There are a greater number of heavy or overweight trucks which operate when the weighstations are closed, which will increase the number in the high GVW bin. The expected front axle means for each bin will need to be adjusted accordingly.

Manual Calibration - [VIEWGRAPH] According to the vendors' suggested procedures, the initial manual calibration is very simple. Since the signal from the WIM sensors is directly proportional to the weight, and the input signal is multiplied by a user-input manual calibration number, it should be a straight-forward procedure to make a few passes with a test vehicle, compare the WIM measurements to the static weights, compute the error, multiply the manual calibration number by the inverse of the error to compute a corrected manual calibration number, enter that number into the system, and calibration is complete.

Our field experience has been considerably more complicated. Close attention to detail and a systematic approach to deal with a number of elements, which I mentioned under the initial site selection, will greatly improve chances of a successful calibration. Some of the conditions at the site which affect manual calibration are:

> Pavement approach to the sensors - Cracks in the pavement near the sensors, especially at the inductive loops and near the piezo cables, will often affect the signals received by the WIM electronics unit. Full-depth cracks, spalling and sealant failure on contraction joints, and failure of load transfer devices that lead to slab jacking, will also produce signal noise. The impact of an axle on a pavement crack upstream from the WIM sensor can cause an impact force that will travel through the pavement to the piezo sensor ahead of the actual vehicle.
>
> Installation and condition of the sensors - Cracks along the sides of the sensors, pavement roughness, wear, snowplow damage, studded snowtire damage, and differential expansion and contraction leading to 'chevron' cracking at the tips of the sensors, will also affect the signal.
>
> Sensor signals - A variety of factors can directly affect the signals from the sensors. For inductive loops, we check the resistance, inductance and frequency. We use a megger, which places a high voltage on the loop wire, to check for shorts to ground and insulation damage. Problems with loops often appear intermittently or during the winter months when repairs often cannot be made. We check the inductance, which affects the loop sensitivity, and the frequency; loops with similar frequencies can cross-talk for erroneous signals. For bending plates and piezo sensors, we run UNKELSCOPE software on the WIM computer, or use a TEKTRONICS oscilloscope, to check the amplitude and duration of the signal. If the signal strength is too small, not all axles will be detected. If there is noise, multiple signals or echos the result is often that 'ghost axles' are detected. We also establish a baseline value for the Wheatstone bridges for bending plates, and otherwise balance between the individual sensors in multi-sensor configurations.

Other factors which affect the calibration of the WIM system include:

Speed of the test vehicles - The accuracy of the systems will degrade above and below certain speeds. The speeds at which the system response degrades are different for piezo and for bending plate systems, and varies between sites.

Lane discipline - Poor lane discipline is often a problem at WIM sites. Drivers will often hug the centerline or fog line, especially during periods of extreme weather such as heavy snow or rain. The severity of lane discipline problems varies from site to site and from time to time in a way not easily identified from observation of the data.

Dynamics of the test vehicles - This is affected by the condition of the suspension and the load being carried.

Pavement temperature - A change in temperature during the course of the calibration will cause a significant change in sensor output. Pavement temperatures near the freeze-thaw point will produce wildly unpredictable weight measurements.

Load Initial Parameters - After thoroughly checking the physical condition of the site and the WIM hardware, we review the software and install correct parameters to describe the physical system, such as axle sensor type and spacing, loop size and spacing, and our most current classification scheme. We operate three calibration vehicles, a class 5, class 6 and class 9. Per our accuracy specifications, each of the three test vehicles must qualify individually for the WIM system to be fully accepted. We make a number of passes in each lane to establish an error rate, and use the inverse of the error to factor the manual calibration number. We continue to run the test trucks and make adjustments to the manual calibration factors, sensor thresholds, and other parameters until the system meets the accuracy requirements for each vehicle. If the site geometrics require, we will enter dynamic compensation factors, individually developed for each lane.

For the initial calibration, the autocalibration portion of the software is disabled. Subsequent calibrations will be performed with the temperature compensation factors enabled. After the system meets accuracy standards and is passed, we install the autocalibration parameters, including the GVW bin ranges, the expected front axle means for each bin, the acceptable error to trigger autocalibration, .

Field Conditions: Autocalibration - [VIEWGRAPH] Autocalibration is only required for piezo cable WIM systems. In our experience, bending plates are far more stable, but are considerably more expensive. To date, the resources of the Alaska program have been directed to development of autocalibration procedures for the piezo systems, which have proven to have much more serious operational errors. We have not performed a detailed study of the performance of bending plate systems under changing temperatures. Our field experience, however, has been affected by frequent failures of the bending plate sensors.

The vendors proposal for autocalibration is to simply turn on the autocalibration routine, using the default parameters, and allow the software to develop TC factors. Our field experience has again been considerably more complicated. It has been very difficult to establish the TC factors for all lanes in Alaska. What is required are sufficient numbers of class 9 vehicles, measured in each 5 degree temperature bin, in each lane, to develop correction factors for the initial TC factors. Recall that there must be vehicles recorded in at least 2 of the 3 GVW bins, with front axle mean measurement errors greater than the acceptable maximum. The number of vehicles is used as a factor to determine the magnitude of the correction applied to the TC factor; the maximum correction is 50% of the error which is achievable only with a large number of vehicles.

There are often too few typical class 9 vehicles in the traffic stream at some sites. For example, on the long-haul route between Anchorage and Fairbanks, the class 13 (double trailer) vehicles are much more common. However, the software will not allow us to use these class 13 vehicles for autocalibration.

The low number of auto-classification vehicles is further reduced by operational characteristics of the WIM systems. Piezo sensor signal strength varies greatly between winter and summer. Initially, HDS used a classification scheme incorporating a minimum 5,000 pound front axle for class 9 vehicles, to remove half-axles from the autocalibration procedure. Unfortunately, when the signal strength is low, nearly all class 9 vehicles are interpreted to have front axle weights less than the minimum. The system may record a few significantly overweight vehicles on which to perform auto-calibration, but this is not sufficient to break the system out of the downward spiral of autocalibration.

Development of Local TC Factors - [VIEWGRAPH] The default TC factors in the IRD autocalibration software are 1. As mentioned above, a set of TC factors is available from the vendor which are based on field experience with the equipment in some midwestern states. However, these do not work very well in our applications. After our first winter with the equipment, we were very concerned about the amount of time and the number cycles required to develop accurate TC factors. We decided to develop our own local set of default TC factors to speed the autocalibration process.

To develop local TC factors, we enabled autocalibration at three of the piezo WIM sites. At another site with high truck volumes, we left autocalibration off and the default parameters at unity. All sites were operated normally for the winter of 1992-93. The hard disk drives on the WIM computers at two of the sites failed, and the TC factors were lost. At the time, there was no method of copying the TC factors via telemetry, and retrieval of these parameters required a site visit.

[VIEWGRAPH] The data from the site with autocalibration disabled was post-processed for each temp bin in each lane as follows:

> The average front axle weight was determined,
>
> The error between the mean front axle weights measured with the WIM equipment and those from weighstation data were calculated for each temperature bin,
>
> Pseudo TC factors were derived.
>
> At either end of the temperature spectrum, the higher and lower TC factors were estimated from projections using a linear regression on the data.

The shape of the curves produced from graphing the TC factors from the different sites appeared to be very similar. We thought we had achieved quite a breakthrough. Based on the results of this study, default TC factors were specified for IRD piezo WIM. The default factors were selected such that the minimum numbers, encountered at about 40 degrees fahrenheit, would be multiplied by manual calibration numbers of about 0.5, plus or minus 0.1, to achieve calibration. Our intent was to enter the defaults TC factors on all units, adjust the manual calibration numbers using test vehicles, and then turn on autocalibration. We expected that subsequent adjustments during autocalibration would be minor.

Comments on the TC Factors - Subsequent observations of WIM unit results were unexpected. The results were not consistent. It appears that a 5 degree C (9 F) range is satisfactory if the system remains relatively stable across temperature bins. However, the change in signal strength, and the resulting TC factors, should not be greater than the maximum acceptable error of the system. For the Alaska program, the acceptable error was intended to be 12%. Between some temperature bins, the observed change is as much as 100%, far greater than the acceptable error. After several site visits, we determined that some of the problem was 'clipping' of the signal. At different temperatures, the signal from the piezo sensors increases to the point that the signal is larger than the electronics and software is designed to process. The signal is 'clipped', resulting in multiple axle readings with erroneous weights.

Problems with Signal Strength - As part of our calibration procedures, we have been recording signal traces from the sensors when activated by test vehicles. Based on these observations, we have had to modify all of the piezo interface cards at the piezo WIM installations. Initially, depending on the site and the temperature, the signals were either too high or too low and the boards were modified accordingly. Unfortunately, in some cases we over-compensated and at the opposite end of the temperature swing, approximately six months later, the signals would be either too low or too high, causing the corresponding opposite problems with signal processing, weight measurement, vehicle classification, manual calibration and autocalibration. Near Fairbanks in interior Alaska, for example, we have observed asphalt pavement temperatures ranging from minus 60 degrees F up to 120 degrees F.

We are concerned that no single hardware setting can be used with the piezo interface cards. Two different cards may have to be used, one for the summer temperature range and one for the winter temperature range. This would also require that a separate set of TC factors be developed and loaded for use with each interface card.

Autocalibration Procedures - [VIEWGRAPH] After the initial manual calibration, we perform a number of activities to monitor and direct the autocalibration process. Currently, the IRD on-site WIM software at all installations can be accessed via telemetry, and the computers at the sites can be fully accessed using pcanywhere. Some of the on-going activities related to WIM operation and autocalibration include:

> Periodic Data Retrieval, Report Generation and Review: We particularly look at the number of vehicles in each class, and the distribution of GVWs and front axle weights, with special attention to the class 9 autocalibration vehicles.
>
> Backup of Key Parameters: We periodically shutdown to pcanywhere, and retrieve and review copies of the calibration log, power log, HDS-developed error log and other files. Because of past experience with failure of the computer hard drive, resulting in loss of all parameters and unretrieved data, we make an attempt to

copy all of the critical parameters on a regular basis. In particular, the TC factors require a long time to develop and to re-develop.

Manual Recalculation of TC Factors: If the calibration log and weight reports indicate large differences between the expected and measured mean front axle weights, and if the differences are consistent over time, we will manually calculate new TC factors and edit the TC lookup table.

Adjustment of Key Parameters: If the data indicates that there are too few class 9 vehicles, this may indicate that the signal strength is too high or low and the vehicles are not registering correctly. If the signal is too high, tandem axles often appear as tridems or quadrems, if the signal is too low, class 9s may appear as class 8s. We may change the manual calibration numbers and/or the thresholds to attempt to 'center' the signal strength within the range able to be processed by the WIM system.

Substitute Classification Scheme - Alternately, we have developed a 'Winter' classification scheme with all the minimum axle weights set to zero. In some cases, the number of axles detected and the spacing is adequate to identify enough class 9s to enable the WIM to autocalibrate.

On-site Calibration Procedures - [VIEWGRAPH] The following procedures are used in the Alaska program.

Prior to the site visit, we review operational history, past and current from logs.

Once on site, we establish existing conditions - physical, hardware, software;

We perform a through visual inspection, observe and record features which may affect the operation of the system. Some are obvious, such as damaged sensors, excessive pavement roughness, cracks, lane discipline determined from wheelpaths, new intersections, traffic signals etc. that affect constant speeds.

We perform backups of all critical parameters or software prior to making any changes.

We perform a series of tests on the hardware. We check the signals with test instruments, the insulation, inductance, and resistance. We are often able to detect bad splices, loose wiring, and insulation flaws.

We review the software parameters that describe the physical system; such as axle sensor type and spacing, loop size and spacing, etc.

We perform a series of diagnostics to determine if system is operating correctly. We check the loop and sensor triggering, the duration, and signal size. If the signal is too small, the system will not detect smaller vehicles. If the signal is too large, clipping may interpreted as ghost axles. Both conditions result in incorrect weights.

We review the autocalibration parameters; GVW bin ranges, expected front axle means, acceptable error to trigger autocalibration.

[VIEWGRAPH] During the calibration, we adjust threshold for sensors and balance multiple sensors within each lane.

Finally, we operate test vehicles, adjust manual calibration figure, and dynamic compensation factor for front axles. We repeat this step until the unit is calibrated.

[VIEWGRAPH] One common problem is that review of the calibration log and other reports indicates that the system is operating within close tolerance, yet the measured weights of the test vehicles contain large, consistent errors. In other words, the measured mean and the expected mean front axle weights of the traffic stream are close, but the measured front axle weight of the test trucks have large, reproducible errors.

[VIEWGRAPH] This may indicate that the expected user-defined mean front axle weight is not correct. This may be caused by the presence a large number of empty or overweight trucks on the traffic stream, which are not weighed at the weighstation. As a consequence, the expected mean front axle weights in the three GVW bins are incorrect. This assumes that all or most of the class 9 vehicles are being correctly classified.

However, a problem with signal strength, lane discipline, or classification scheme may input a large percentage of incorrectly identified or non-representative calibration vehicles. To repeat, if the signal is too high, tandem axles often appear as tridems or quadrems, while if the signal is too low, an axle may not register and class 9s may appear as class 8s. In this case, the hardware or software must be adjusted to provide a correctly identified and representative sample of class 9s to the autocalibration software.

If there is a problem with lane discipline, a high number of half axles may be measured, where only one side of the vehicle is contacting the sensor. This behavior may occur intermittently, during periods of heavy rain or snow, in no detectable pattern. We have developed a couple of different methods to attempt to deal with this problem. One solution is to train or force the vehicles to operate within the lane; this may be accomplished with curbs, raised center medians, or rumble strips in the shoulders along the edge of the travel lane. If the travel pattern is constant, the WIM sensors may be moved. We have considered installing longer sensors which may protrude into the shoulder. We have used an expected mean front axle weight for the low GVW bin of approximately 30% to 60% less than would be used if lane discipline was observed. We have relied on the minimum front axle weight in the classification scheme to exclude half-axle vehicles. And, we have analyzed the data during post-processing to identify logical minimum front axle weights, for each lane, for each 5-degree temperature interval, for each month. All of these techniques are imperfect. The best method would appear to be to select sites with good lane discipline and avoid the problem altogether. However, once the WIM is installed, you may observe that a significant number of truck drivers will deliberately alter their driving patterns in the vicinity of the WIM site.

Our Current Solution - [VIEWGRAPH] If the system appears to be in balance, yet the measured weights of test vehicles are greatly in error, at least two parameters in the signal processing routine must be adjusted. If only one parameter is adjusted, over time the unit will revert to the balance where the weights are incorrect. For example, if the system is balanced, and test vehicles are measured as 50% of their static weights, doubling the manual calibration number may result in correct measured weights. If all else remains the same, however, the mean front axle weights will now appear too high and the autocalibration software will proceed to decrease all of the TC factors to bring the system back into balance. If the TC factor for that temperature interval is doubled, the autocalibration software will again proceed to decrease that TC factor to bring the system back into balance.

Our current procedure is to adjust the manual calibration number, and then proportionally adjust the expected mean front axle weight reciprocally. To continue the same example, if the system is balanced, and test vehicles are measured as 50% of their static weights, we will double the manual calibration number and concurrently reduce the expected mean front axle weight by 50%.

During calibration and autocalibration, some elements will cascade, misleading, a problem will appear to be caused by one thing when it is actually caused by a preceding element.

e.g. temp sensitivity variation/erratic signal suspected of sensor/materials interaction, actually an artifact of the IRD software in that greater than 10 volts the signal is 'clipped', sometimes a single signal is interpreted as multiple axles, is then classified into another type (not class 9), system cannot auto-calibrate

Summary - [VIEWGRAPH] In summary, I'd like to make four points.

1) As consumers, we can affect the development of the equipment we purchase. Rather than just accepting what the vendors choose to provide, we have the opportunity to work cooperatively to improve the systems.

2) We all need to maintain our emphasis on ensuring the accuracy, reliability, repeatability and operational stability of the equipment. This not only increases our professional credibility, it greatly improves usefulness of the information.

3) We need to encourage the use of the information within SHAs. We must be as proactive as proactive as possible within the constraints of budgets and within an environment of political solutions.

4) We need to continue to develop communications between SHAs. Sharing information is the most effective method to improve the installation, operation, program management, analysis, reporting, and development of applications for these systems and the information they provide.

Thank You.

A MULTIPLE FACTOR METHOD FOR CALIBRATING PORTABLE WIM DATA

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A Multiple Factor Method for Calibrating Portable Weigh-In-Motion Data

Scott W. Fugit - Idaho Transportation Department

Introduction

Calibration of weigh-in-motion (WIM) data collected with portable capacitance mat systems has proven to be a difficult and persistent problem. Factors which influence vehicle axle weights measured by a WIM system designed for temporary, portable operation are numerous and dynamic. Many may be specific to a given survey location, such as slope, wind or pavement condition. Others are machine related such as the mat calibration number defined by the manufacturer for each individual weigh mat. The collection of portable WIM data introduces the greatest number of outside variables having a negative influence on data accuracy. Agencies concerned about the accuracy of their portable WIM systems are left with few guidelines or options. Doing nothing is one alternative, but at the Idaho Transportation Department (ITD), experience has proven the blind faith approach non-workable. A reputation for poor, inaccurate data is the typical result when portable WIM equipment is trusted to perform accurately using no calibration methodology at all.

Calibration procedures developed for permanent WIM installations offer a logical starting point. However, their site specific nature offers problems when using the same methods to calibrate non-permanent equipment. A portable WIM system is typically set at any particular location for only 48 to 96 hours -- making the time and expense of a site visit solely for calibration impractical. The typical portable WIM application also requires flexibility in scheduling. During each portable WIM season, new survey locations are added which may or may not be revisited. Other scheduled sites may be dropped due to bad weather or road maintenance work, which further complicates site specific calibration arrangements. Some calibration techniques rely on presumption about a site's expected vehicle weights -- often comparing the latest data to historical observations. This approach may mask shifting trends in traffic characteristics which often accompany seasonal, economic or regulatory changes.

Clearly, a technique specific to each site was extremely impractical, yet some type of calibration procedure which provides for both understanding and systematically improving portable WIM data was needed. The factory provided mat calibration number, input during portable system setup, often fails to result in convincing weight data. "To minimize weight errors", the operators manual suggests, "scale the factory supplied mat calibration number by the ratio of average actual weight to average measured weight". No further explanation is offered. Unfortunately, there is an immediate and obvious limitation to simply changing the mat calibration number supplied by the manufacturer. This linear approach towards WIM system calibration applies the same percentage of adjustment (and thereby assumes the same level of accuracy) throughout the broad range of observed vehicle grossweights. Experience refutes that assumption. At best, when the mat calibration number is correct, accuracy seems greatest at midrange and is poor in both the lightest and heaviest vehicle catagories. A more refined methodology was needed -- one which acknowledges that system accuracy varies at different weight levels and, accordingly, provides individual calibration factors for each vehicle grossweight range encountered during WIM data collection.

ITD's experience with portable WIM equipment has shown that when a system component is replaced, especially the capacitance weighmat, subsequent accuracy is unpredictable. Although a previous mat and it's factory supplied calibration number may have performed effectively, there is no guarantee that it's replacement will provide similar results.

The Idaho Transportation Department's approach to multiple factor portable WIM data calibration is discussed in this paper. In a twice yearly test, both Port Of Entry (POE) static scale and WIM weights are recorded for the same vehicle, then compared and analyzed for 500 commercial vehicles randomly selected at the POE. Individual calibration factors are developed for each 10,000 pound grossweight group observed by each portable WIM system. These factors are then available to be applied as part of standard WIM data processing.

Although there is certainly debate on the logic of comparing static weights to dynamic, that subject is beyond the scope of this paper. For our purposes, the term "calibration" will refer to the process of adjusting the calibration factors so that the calculated grossweight output of a portable WIM system matches the grossweight measurements of the static scale.

Idaho's WIM Program

The first portable WIM equipment used in Idaho was acquired in late 1987. Prior to that, there had been only scant experimentation with a few permanent WIM systems. Today, ITD operates four portable single lane capacitance mat weigh-in-motion systems during an average seven month season. Roadway snow and ice precludes portable WIM operations from November through March. Permanent WIM systems are currently being developed at all thirteen of Idaho's SHRP/GPS sites. To date, however, all SHRP/GPS data has been collected with portable capacitance mat systems.

ITD's WIM crew of two technicians is each supplied with their own van. Using four capacitance systems and ample spare mats and parts, the crew is able to survey about 80 sites per season. Careful preparation and teamwork allow each single lane system to be setup in less than 15 minutes, thereby minimizing the crew's exposure to dangerous traffic. Sets range in duration from 48 to 96 hours, including weekends. Automatic vehicle classification equipment utilizing road tube sensors are also set as part of the test. WIM system thresholds established at setup time screen the data to allow only vehicles the size of Scheme F type 3 and larger to be recorded. By collecting weight data on only heavier than passenger vehicles, disk storage space and technician time are more effectively utilized. With Idaho's size and geographic diversity, each member of the WIM crew typically logs 30,000 miles per season. In 1993 a total of 322,670 commercial vehicle WIM observations were collected. Considering the amount of effort and expense invested in the collection of portable WIM data, it is important that a credible, cost effective means of adjusting the data be developed.

Idaho's WIM Calibration Test

Along with the purchase of ITD's first portable WIM systems came many questions. Soon after the preliminary data collection effort, it was decided that a direct comparison test with a certified static scale was a must. This seemed the only practical way to gain a realistic idea of how the system performed. In the spring of 1988, ITD's first WIM calibration test was organized. With a few critical refinements, the exercise has remained essentially the same since then.

The objective of the test is to collect matched sets of static scale and portable WIM data for 500 commercial vehicle observations. The first step is to collect static data at a selected Port Of Entry. ITD uses the East Boise POE located on I-84 ten miles east of Boise, Idaho. This interstate location has 3400 commercial vehicles per day -- plenty of opportunities for data collection. There is also an unequaled diversity in axle configurations including doubles, triples and specialty vehicles. The first portable WIM site is set up approximately 1 mile downstream of the POE on a smooth level stretch of the eastbound interstate. The remaining systems are spaced about 1/4 mile apart. All equipment involved is set in the righthand travel lane of the two lane asphalt surface. Roadway shoulder areas are solid enough to allow vans with monitoring personnel to be well removed from the pavement edge, thereby reducing the number of lane changes by the vehicles weighed at the POE static scale. The traffic approaching the WIM site is visible for more than one-half mile which aids observers. ITD's August 1993 test included our four

WIM systems, one guest vendor's WIM system, and two different automatic vehicle classification (AVC) units for a total of seven machines being evaluated.

Port-Of-Entry Data Collection

Ideally, the data collection effort is to result in matched sets of WIM and POE static scale data for all 500 tagged trucks, on all participating WIM systems. For a wide variety of reasons, the end result is usually something less. Equipment breakdowns, missed tag numbers, and tagged trucks that change lanes and bypass the WIM systems all contribute to a loss of data. Still, procedural errors and other problems have decreased with experience and a consistent effort at making improvements. Typically, 500 tagged vehicles will result in between 400 and 470 usable matched data records per WIM system.

The test routine, which will be repeated 500 times, begins with the sorting of the normal commercial traffic flow entering the POE. The goal here is to keep the data collection crew consistently busy, yet cause minimal delay for the trucks. Commercial vehicles are randomly selected with no specific effort made to include certain types of vehicles and bypass others. The one exception to this rule are cattle trucks which the tape measure crew -- intimidated by a little "slosh and splatter" -- flatly refuses to get close to. As axle weights and measurements are completed on one vehicle, the next truck in line regardless of classification is accepted into the test que. All excess traffic is directed to bypass.

Once each selected vehicle stops at a marked location in front of the POE scale, the driver is quickly advised of the test and requested to stay in the right hand lane after leaving the port until they have passed the WIM equipment about a mile downstream. At the same time, a three man crew measures axle spacings and bumper to bumper length recording them manually in feet and tenths of feet. Although many steps in the process are automated, the POE data collection must still involve some manual recording of information. Still prior to being weighed, an 8 1/2" x 11" sequentially numbered placard is taped to the right front portion of the vehicle. Once axle and bumper to bumper measurements are finished, the truck is waved onto the POE scale where individual axle weights and the tag number are captured directly onto a laptop computer's disk storage. The truck is then released and subsequently observed and registered at the WIM sites waiting downstream (figure 1).

All POE data is recorded and labelled using the tag number (1 through 500) placed on each truck. An in-house software program is later used to enter the axle spacing data from written forms. Together the spacing and weight data make up the 128 byte POE data file (figure 2). Generally, every effort is made to organize data collection and handling so that the analysis which follows will be as straightforward as possible.

WIM Site Data Collection

At each participating WIM site, an observer outfitted with a laptop computer is comfortably stationed in an appropriately equipped vehicle. A powerverter or cigarette lighter attachment is needed to keep laptop computers powered for a daily test of at least 8 hours. As each placarded truck crosses the WIM systems, an observer records on a special form both it's affixed tag number plus the WIM record sequence number (figure 3). WIM records are viewed in near real time using a software package called Ability (v2.0), set up in the "capture" mode (figure 4). As the observer records the two key numbers manually, the captured WIM data is saved to disk. The goal is the same at each WIM system location -- to accurately note, tag, and record sequence numbers for each test vehicle and successfully save the data. At the end of each test day, WIM files are downloaded and observer forms are gathered. Everything is clearly labelled showing date, WIM system number and the range of tag numbers included. The data collection portion of a typical 500 observation WIM calibration test takes 2 to 3 days.

Binary WIM files are later converted to ITD's standard 171 byte ASCII WIM format (figure 5). Once all files are in workable formats and organized in chronological order, the process of matching POE to WIM data can begin. That accomplished, the outcome is a file with 306 byte records which contains the matched POE and WIM results (figure 7). The comparative analysis of these matched files is what provides the groundwork for development of calibration factors that are both effective and specific to each WIM system.

WIM Calibration Software

The Idaho Transportation Department has developed four programs in the statistical package SAS which are the primary tools in analysing the combined WIM/POE data records. Their functions are as follows:

MERGE -- This program matches POE and WIM records based on an index file (figure 6) that associates the tag number on the POE record with the matching WIM record sequence number. The matched data is combined into one 306 byte record and output to a file (figure 7). This step is repeated for each WIM system.

POEWIM -- This program produces reports showing various comparisons of the matched data records. Contrasting POE/WIM results are shown based on vehicle type, gross weights, front axle weights plus driver, and trailer tandems. The "Nonmatching Axle Count Observations" report shows matched records that have different POE and WIM axle totals. Similarly, records showing the broadest mean difference in grossweight are listed in the report titled "Worst 50 Observations by Absolute Relative Difference". Both reports identify observations that should be reviewed for data entry or other errors, and may be excluded from further analysis. Report samples are listed in figure 8a-b. Other analytical graphs produced are similar to figures 10 through 17.

FACTOR -- Based on the mean relative difference between WIM and POE data contained in the edited and matched records, this program calculates the adjustment factor for each 10,000 pound interval of grossweight. First the relative difference is calculated for each validated observation, and then the average relative difference for each weight group. A separate set of factors is calculated for each WIM system included in the calibration test (figure 9).

CALIBRATE -- This program is used to apply the newly established calibration factors to all WIM data collected later with that system. The calibrated axle weight is produced according to the following formula [calibrated weight = raw weight - (raw weight x factor)]. The correct calibration factors are selected based on WIM system number, vehicle grossweight category and WIM data collection date.

Application of WIM Calibration Factors

The performance history of any portable WIM system is not necessarily static. Machine error, damage to the mat, moisture or other electronic degradation can alter results over time. To document any potential changes to our WIM systems, tests are run twice yearly. The resulting calibration factor file includes a creation date to which any subsequently collected WIM data is compared. If the data collection date is not later than the factor file creation date, no axle weights are altered. This procedure helps insure that only the most recent set of WIM calibration factors will be used on current data.

The portable WIM systems used at ITD were manufactured by the Golden River Corporation of England. It appears evident, based on our own test results and accumulated experience, that these systems are designed to be most accurate on single trailer commercial vehicles of approximately 70-80k pounds. Not coincidentally it would seem, this typical "18-wheeler" is the most prominent vehicle type in commercial traffic -- both nationally and in Idaho. Other vehicles above or below the 70-80k benchmark appear to have their weight's estimated by these systems using a straight line linear formula. Vehicles weighing below that range are routinely estimated light, while those over are typically projected as too heavy. This general pattern is shown by the graphs of uncalibrated data in (figures 10-17).

When the manufacturer's supplied mat calibration number is inaccurate, so too is the resulting data. Any changes in the number simply shifts the results for all weight groups up or down. Although this may help in selected ranges, overall accuracy could suffer. By incorporating a strategy which uses multiple calibration factors -- one for each system's observed weight groups, accuracy is increased over a broader range of vehicle grossweights.

With luck and careful maintenance, the life of a weighmat used in ITD's WIM operation may extend to 3 or 4 years. When a mat is replaced the WIM system should always be retested. As shown in figure 19, system performance can change drastically with a new mat and it's factory supplied calibration number. Standard procedure is to always test replacement mats at the first opportunity. The resulting calibration factors can be used to correct any data collected with a new mat prior to testing. With WIM tests done twice yearly, this provides ample opportunities to track mat performance over time. Temperature related comparisons can also be done since the tests are conducted in early spring and the hottest part of summer.

Although providing accurate vehicle axle weights is the primary function of any WIM system, axle spacing data is also collected. Routinely collected during the portable WIM program, the spacing data is used to monitor changes in commercial traffic by converting it to ITD's Axle Configuration Code (ACC) -- a vehicle identification label that provides a unique code for any axle configuration. Because spacing data is important, verifying consistent system performance on axle measurements is a worthy goal of the twice yearly WIM calibration test. Manual spacings on tagged vehicles are contrasted with those recorded by the various vehicle classifiers involved in the test. But comparisons between manual tape measurements and machine generated axle spacings may be difficult to justify. Which is most accurate? Quickly measuring a 100 foot truck in the wind with a flexible tape introduces some level of error -- perhaps more (or less) than the machine being tested. We can report however, that the accuracy of machine generated axle spacings has remained reasonably consistent with the manually collected data since Idaho's calibrations tests have started. Changing a weighmat and the factory supplied calibration number does not result in wild fluctuations in axle spacings. However, before WIM system spacing accuracy can be truly evaluated, an improved method of collecting axle spacings at the POE is required. ITD has had some success in testing an electronic Theodolite survey transit to measure the distance between two points (axles), and download directly to a laptop computer. We are hoping to do further research in this area.

The effect that the newly developed calibration factors have on vehicle grossweights is illustrated in the final portion of the test analysis. New calibration factors are applied to the WIM data collected during the test, and the POE/WIM comparison reports are then rerun. The results can be seen in figures 10 through 17. Please note that the before and after calibration graphs show significant changes in the X-axis range showing the mean differences in the WIM -vs- POE data. Also, those weight groups with the fewest observations reflect the least amount of correction.

Conclusion

Recent research trends have seemed to favor studies which involve larger more expensive permanent WIM installations. The numerous complicating variables that effect accuracy (and complicate research) are more easily held constant in a stationary system design.

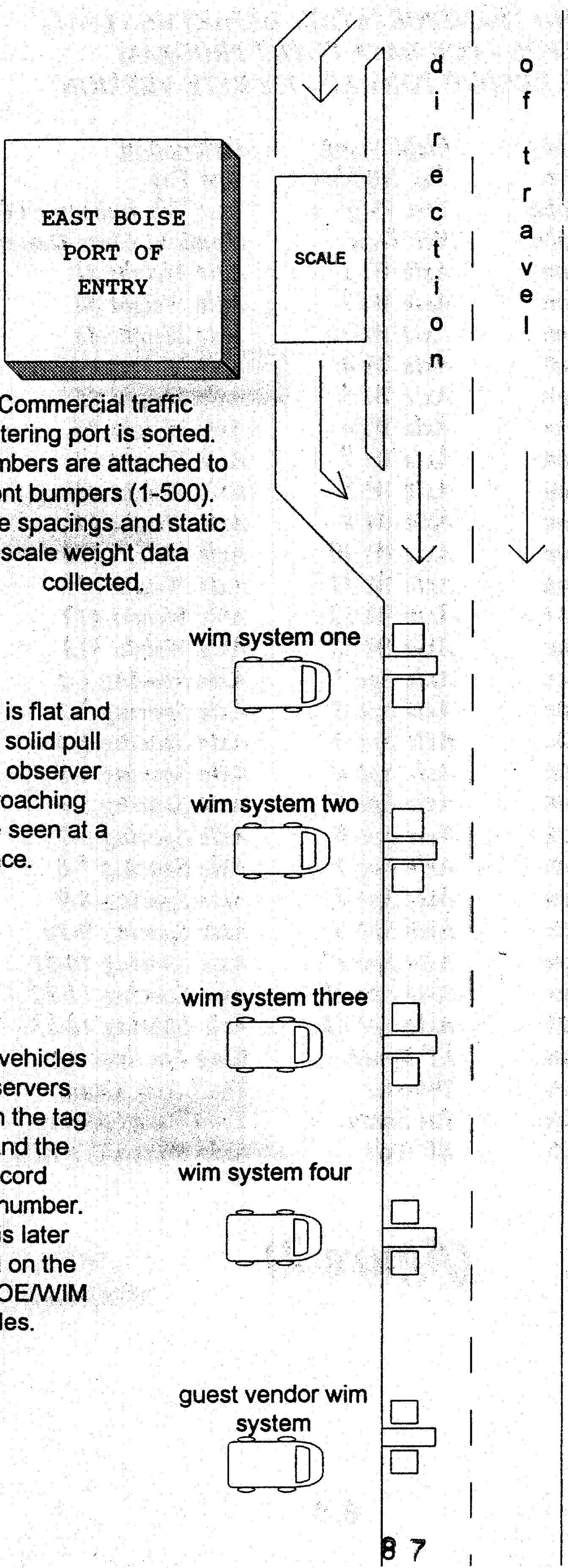
Yet the versatility and ease of use, plus the obvious cost advantages ensure that portable WIM systems will be around for years to come -- even if it's only those models currently available today. Since design improvements generally follow breakthroughs in research, portable WIM system development may have reached a plateau. Smaller profit margins associated with portable systems may also be influencing vendor research and development decisions. One trend seems clear -- if advances in portable WIM systems design are to continue, increased research on specifically related WIM applications must lead the way.

When presenting weigh-in-motion data to roadway planners designers and maintenance personnel we are invariably asked whether our WIM equipment is trustworthy. To most people the idea of weighing a loaded truck moving at highway speeds would seem dubious at best. End users of our WIM data are no different. It therefore becomes important to the credibility of those who collect, process and present the data, to genuinely understand their WIM system's characteristics and how calibration and adjustment procedures affect the resulting weight data. By performing twice yearly controlled comparisons with a static scale, WIM system performance can be evaluated in a variety of ways as well as tracked over time. In ITD's WIM calibration test, commercial vehicles throughout a broad range of grossweights are tagged and monitored during data collection at both the POE and WIM sites. Later analysis results in a calibration factor being determined for each 10,000 pound weight group, on each WIM system tested. These system specific sets of calibration factors allow for precise adjustments to all data collected thereafter by each WIM system. With a demonstrated method of calibrating portable WIM data, skeptics are more easily convinced of it's accuracy, and thus it's usefulness. The result is greater satisfaction among data users, more knowledge about our WIM equipment, and ultimately, a more complete understanding of the constantly changing trends in our state's commercial traffic flow.

Acknowledgements

The author greatfully acknowledges the contributions made to this report by student intern Kevin Harrington and the crew of the Idaho WIM calibration tests.

IDAHO TRANSPORTATION DEPARTMENT
WEIGH-IN-MOTION
CALIBRATION TESTS
EAST BOUND LANES OF I-84
NEAR BOISE, IDAHO



Commercial traffic entering port is sorted. Numbers are attached to front bumpers (1-500). Axle spacings and static scale weight data collected.

Test location is flat and smooth with solid pull off areas for observer vans. Approaching traffic can be seen at a distance.

As tagged vehicles pass, observers record both the tag number and the WIM record sequence number. Analysis is later performed on the matched POE/WIM data files.

First wim system approx 1 mile downstream of POE.

WIM systems approx 1/4 mile apart.

While at the POE, tagged vehicles are asked to stay in right hand lane until they pass WIM equipment.

(figure 1)

IDAHO TRANSPORTATION DEPARTMENT
IDAPOE - POE DATA ENTER PROGRAM
OUTPUT RECORD FORMAT - 128 BYTE VERSION

Pos No.	Size	Type	Field Name	Description
1	3	Num	Tag Number	Test Tag
4	1	Alpha	Test Flag	Test Veh Indicator (Y/N)
5	7	Alpha	Veh Desc	Standard Class Descriptor
12	5	Num	Axle Wt 1	Axle Weight #1
17	5	Num	Axle Wt 2	Axle Weight #2
22	5	Num	Axle Wt 3	Axle Weight #3
27	5	Num	Axle Wt 4	Axle Weight #4
32	5	Num	Axle Wt 5	Axle Weight #5
37	5	Num	Axle Wt 6	Axle Weight #6
42	5	Num	Axle Wt 7	Axle Weight #7
47	5	Num	Axle Wt 8	Axle Weight #8
52	5	Num	Axle Wt 9	Axle Weight #9
57	5	Num	Axle Wt 10	Axle Weight #10
62	5	Num	Axle Wt 11	Axle Weight #11
67	5	Num	Axle Wt 12	Axle Weight #12
72	5	Num	Axle Wt 13	Axle Weight #13
83	3	Num	Axle Spc 1	Axle Spacing 1-2
86	3	Num	Axle Spc 2	Axle Spacing 2-3
89	3	Num	Axle Spc 3	Axle Spacing 3-4
92	3	Num	Axle Spc 4	Axle Spacing 4-5
95	3	Num	Axle Spc 5	Axle Spacing 5-6
98	3	Num	Axle Spc 6	Axle Spacing 6-7
101	3	Num	Axle Spc 7	Axle Spacing 7-8
104	3	Num	Axle Spc 8	Axle Spacing 8-9
107	3	Num	Axle Spc 9	Axle Spacing 9-10
110	3	Num	Axle Spc 10	Axle Spacing 10-11
113	3	Num	Axle Spc 11	Axle Spacing 11-12
116	3	Num	Axle Spc 12	Axle Spacing 12-13
119	3	Num	KP Space	King Pin Spacing
122	2	Num	Totaxles	Total Axle Count
124	4	Num	Tot Space	Total Axle Spacing
128	1	Num	KP Axle	Axle Preceeding KP

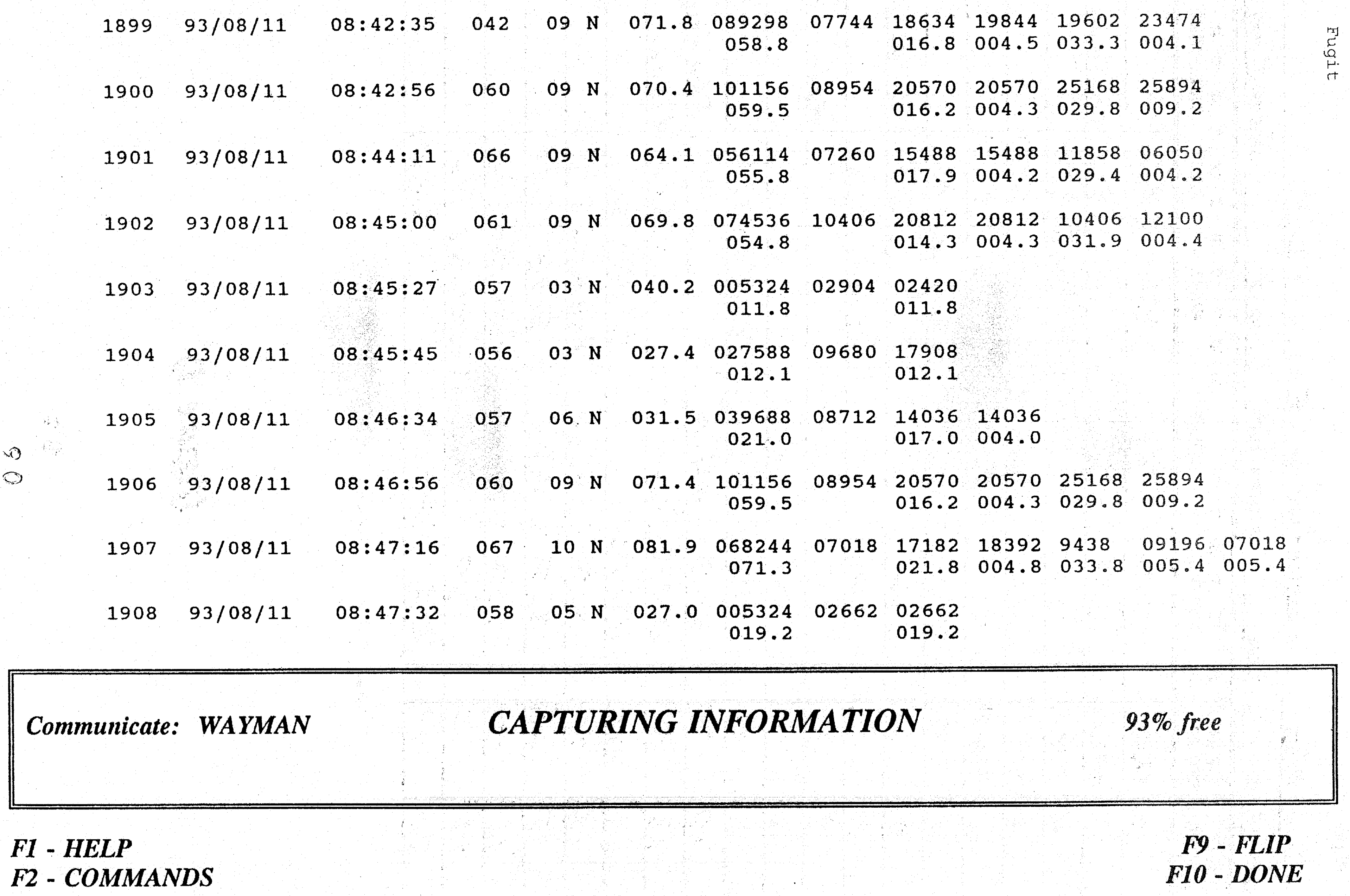
(figure 2)

DATE 8/10/93 LOCATION INFO E. Boise POE

PAGE 1 OF ___ LANE ___ SYSTEM INFO wim 1 OBSRVR GM

TRK TAG NO.	WIM SEQ NO.	m h	TRUCK DESCRIPTION				
			TYPE	COLOR	NAME	CAB	TRLR/LOAD
1	3960		352	Blue	Atlas	C/O	
2	3971		352	Blue		Std	Tanker
4	3982		2D	Red+BLK	Id. Power?	STD	
3	3987		352	Bronze	Giltner	STD	
5	4004		352	Black	Palmer	Std	
6	12		352	White	Archway Cks	std	
7	28		352		F	Std	Flatbed
8	39		352		Baldwin	Std	
9	49		3A	Orange			Equip Trk
10	55		3A	Red			
11	65		352	Blue	Clark	std	
12	78		352	white		std	Flatbed
13	91		352-3	white		Std	Flatbed, Emp
15	126		2S12-2		Cons. Frt	Std	
16	32		352	Blue	Freymiller	Std	
17	46		352	Red	G+G	Std	
18	53		352	White	Albertson	Std	
19	62		352	Red	Assoc. Food	Std	
20	79		2S1	White		Std	

(figure 3)



```
1899  93/08/11  08:42:35  042  09 N  071.8 089298  07744  18634  19844  19602  23474
                                           058.8           016.8  004.5  033.3  004.1

1900  93/08/11  08:42:56  060  09 N  070.4 101156  08954  20570  20570  25168  25894
                                           059.5           016.2  004.3  029.8  009.2

1901  93/08/11  08:44:11  066  09 N  064.1 056114  07260  15488  15488  11858  06050
                                           055.8           017.9  004.2  029.4  004.2

1902  93/08/11  08:45:00  061  09 N  069.8 074536  10406  20812  20812  10406  12100
                                           054.8           014.3  004.3  031.9  004.4

1903  93/08/11  08:45:27  057  03 N  040.2 005324  02904  02420
                                           011.8           011.8

1904  93/08/11  08:45:45  056  03 N  027.4 027588  09680  17908
                                           012.1           012.1

1905  93/08/11  08:46:34  057  06 N  031.5 039688  08712  14036  14036
                                           021.0           017.0  004.0

1906  93/08/11  08:46:56  060  09 N  071.4 101156  08954  20570  20570  25168  25894
                                           059.5           016.2  004.3  029.8  009.2

1907  93/08/11  08:47:16  067  10 N  081.9 068244  07018  17182  18392  9438   09196  07018
                                           071.3           021.8  004.8  033.8  005.4  005.4

1908  93/08/11  08:47:32  058  05 N  027.0 005324  02662  02662
                                           019.2           019.2
```

```
Communicate:  WAYMAN        CAPTURING INFORMATION        93% free

F1 - HELP                                                F9 - FLIP
F2 - COMMANDS                                            F10 - DONE
```

(figure 4)

IDAHO TRANSPORTATION DEPARTMENT

Weigh-In-Motion Data File Record Layout
171 Byte Format - SEPT 92

Pos No.	Field Size	Type	Name	Description
1	6	num	Segcd	Statewide indexing system.
7	6.3	num	MP	Indexing within Seg Code.
13	1	alpha	Dir	(A)scndng (D)escndng (B)oth
14	2	num	Lane	Lane number
16	6	alpha	DevType	Machine Serial Number
22	8	num	Date	Record Date (YYYYMMDD)
30	7	num	Time	Record Time (HHMMSSS)
37	6	alpha	Var	Road mode, #lanes, cnted
43	3	alpha	Edcode	Edit Status Code Doc
46	9	alpha	ACC	See ITD Axle Classfctn Doc
55	1	alpha	Accmod	See ITD Axle Class Doc
56	2	num	Totaxles	Total vehicle axle count
58	3	num	Speed	Vehicle speed in MPH
61	3.1	num	Axsp12	Axle Spacing 1-2
64	3.1	num	Axsp23	Axle Spacing 2-3
67	3.1	num	Axsp34	Axle Spacing 3-4
70	3.1	num	Axsp45	Axle Spacing 4-5
73	3.1	num	Axsp56	Axle Spacing 5-6
76	3.1	num	Axsp67	Axle Spacing 6-7
79	3.1	num	Axsp78	Axle Spacing 7-8
82	3.1	num	Axsp89	Axle Spacing 8-9
85	3.1	num	Axsp910	Axle Spacing 9-10
88	3.1	num	Axsp1011	Axle Spacing 10-11
91	3.1	num	Axsp1112	Axle Spacing 11-12
94	3.1	num	Axsp1213	Axle Spacing 12-13
97	4.1	num	Bmptobmp	Total magnetic length
101	5	num	Axwgt1	Weight of Axle 1
106	5	num	Axwgt2	Weight of Axle 2
111	5	num	Axwgt3	Weight of Axle 3
116	5	num	Axwgt4	Weight of Axle 4
121	5	num	Axwgt5	Weight of Axle 5
126	5	num	Axwgt6	Weight of Axle 6
131	5	num	Axwgt7	Weight of Axle 7
136	5	num	Axwgt8	Weight of Axle 8
141	5	num	Axwgt9	Weight of Axle 9
146	5	num	Axwgt10	Weight of Axle 10
151	5	num	Axwgt11	Weight of Axle 11
156	5	num	Axwgt12	Weight of Axle 12
161	5	num	Axwgt13	Weight of Axle 13
166	6	num	Grosswgt	Total Vehicle Weight

Notes: *1) All axle spacings are in feet and tenths of feet. (2) All axle weights are in pounds (3) All num variables are zero filled. (4) A size of X.Y indicates X total bytes with implied decimal point located Y digits from the right.*

(figure 5)

IDAHO TRANSPORTATION DEPARTMENT
WIM/POE Matching Record Index File
Used by "Merge" Program

Pos No.	*Field Size*	*Type*	*Name*	*Description*
1	*3*	*Num*	*Truck Tag Number*	*Placard number placed on test trucks at POE. Used for tracking data.*
5	*4*	*Num*	*WIM Record Number*	*WIM record sequence number noted by observers at WIM site.*

EXAMPLE OF INDEX FILE
WIM System One - Aug/93

Truck Tag Number	*WIM Record Number*
1	*3960*
2	*3971*
3	*3982*
4	*3987*
5	*4004*
6	*4012*
7	*4028*
8	*4039*
9	*4049*
10	*4055*

(figure 6)

IDAHO TRANSPORTATION DEPARTMENT

Idaho Weigh-In-Motion Calibration Tests
306 Byte Data Record Layout

Position Number	Size	Type	Field Name	Description
		WIM Data		
1	6	num	Segcd	Statewide Index System
7	6.3	num	MP	Indexing within Seg Cd
13	1	alpha	Dir	(A)scending (D)escndg
14	2	num	Lane	Lane number
16	6	alpha	DevType	Machine Serial Number
22	8	num	Date	Record Date (YYYYMMDD)
30	7	num	Time	Record Time (HHMMSSS)
37	6	alpha	Various	Rd mode, #lns, #cntd, stg
43	3	alpha	Edcode	See ITD Edit Code Doc
46	9	alpha	ACC	See ITD AxleClsCd Doc
55	1	alpha	Accmod	See ITD AxleClsCd Doc
56	2	num	Numaxles	WIM Total Veh Axles
58	3	num	Speed	WIM Vehicle Speed MPH
61	3.1	num	Wimsp1	WIM Axle spacing 1-2
64	3.1	num	Wimsp2	WIM Axle spacing 2-3
67	3.1	num	Wimsp3	WIM Axle spacing 3-4
70	3.1	num	Wimsp4	WIM Axle spacing 4-5
73	3.1	num	Wimsp5	WIM Axle spacing 5-6
76	3.1	num	Wimsp6	WIM Axle spacing 6-7
79	3.1	num	Wimsp7	WIM Axle spacing 7-8
82	3.1	num	Wimsp8	WIM Axle spacing 8-9
85	3.1	num	Wimsp9	WIM Axle spacing 9-10
88	3.1	num	Wimsp10	WIM Axle spacing 10-11
91	3.1	num	Wimsp11	WIM Axle spacing 11-12
94	3.1	num	Wimsp12	WIM Axle spacing 12-13
97	4.1	num	Bmptobmp	WIM Total mgnetic lngth
101	5	num	Wimwgt1	WIM Axle weight 1
106	5	num	Wimwgt2	WIM Axle weight 2
111	5	num	Wimwgt3	WIM Axle weight 3
116	5	num	Wimwgt4	WIM Axle weight 4
121	5	num	Wimwgt5	WIM Axle weight 5
126	5	num	Wimwgt6	WIM Axle weight 6
131	5	num	Wimwgt7	WIM Axle weight 7
136	5	num	Wimwgt8	WIM Axle weight 8
141	5	num	Wimwgt9	WIM Axle weight 9
146	5	num	Wimwgt10	WIM Axle weight 10
151	5	num	Wimwgt11	WIM Axle weight 11
156	5	num	Wimwgt12	WIM Axle weight 12
161	5	num	Wimwgt13	WIM Axle weight 13
166	6	num	Wimgrswt	WIM Gross Weight
172	5	num	Wimseq	WIM Sequence Number
177	2	num	Wimclas	WIM scheme F class

(figure 7)

Record layout - page 2

Position Number	*Size*	*Type*	*Field Name*	*Description*
		POE Data		
179	*3*	*Num*	*TagNo*	*Test Tag Number Used*
182	*1*	*Alpha*	*Testflag*	*Test Vehicle Flag (Y/N)*
183	*7*	*Alpha*	*Vehtype*	*Veh Descriptive Code*
190	*5*	*Num*	*Poewt1*	*POE Weight Axle 1*
195	*5*	*Num*	*Poewt2*	*POE Weight Axle 2*
200	*5*	*Num*	*Poewt3*	*POE Weight Axle 3*
205	*5*	*Num*	*Poewt4*	*POE Weight Axle 4*
210	*5*	*Num*	*Poewt5*	*POE Weight Axle 5*
215	*5*	*Num*	*Poewt6*	*POE Weight Axle 6*
220	*5*	*Num*	*Poewt7*	*POE Weight Axle 7*
225	*5*	*Num*	*Poewt8*	*POE Weight Axle 8*
230	*5*	*Num*	*Poewt9*	*POE Weight Axle 9*
235	*5*	*Num*	*Poewt10*	*POE Weight Axle 10*
240	*5*	*Num*	*Poewt11*	*POE Weight Axle 11*
245	*5*	*Num*	*Poewt12*	*POE Weight Axle 12*
250	*5*	*Num*	*Poewt13*	*POE Weight Axle 13*
255	*6*	*Num*	*Poegrswt*	*POE Gross Weight*
261	*3.1*	*Num*	*Poesp1*	*POE Axle Space 1-2*
264	*3.1*	*Num*	*Poesp2*	*POE Axle Space 2-3*
267	*3.1*	*Num*	*Poesp3*	*POE Axle Space 3-4*
270	*3.1*	*Num*	*Poesp4*	*POE Axle Space 4-5*
273	*3.1*	*Num*	*Poesp5*	*POE Axle Space 5-6*
276	*3.1*	*Num*	*Poesp6*	*POE Axle Space 6-7*
279	*3.1*	*Num*	*Poesp7*	*POE Axle Space 7-8*
282	*3.1*	*Num*	*Poesp8*	*POE Axle Space 8-9*
285	*3.1*	*Num*	*Poesp9*	*POE Axle Space 9-10*
288	*3.1*	*Num*	*Poesp10*	*POE Axle Space 10-11*
291	*3.1*	*Num*	*Poesp11*	*POE Axle Space 11-12*
294	*3.1*	*Num*	*Poesp12*	*POE Axle Space 12-13*
297	*3.1*	*Num*	*KPspace*	*POE King Pin Spacing*
300	*2*	*Num*	*Totaxles*	*POE Total Axle Count*
302	*4.1*	*Num*	*POEtotsp*	*POE Total axle spacing*
306	*1*	*Num*	*KP axle*	*POE Axle preceeding KP*

Notes:

1) *All axle spacings are in feet and tenths of feet.*
2) *All axle weights are in pounds.*
3) *A "Y" in TESTFLAG variable indicates special test vehicle.*
4) *All numeric and free space variables are zero filled.*
5) *A size of X.Y indicates X total bytes with implied decimal point located Y digit(s) from the right.*

(figure 7 cont)

```
                        WEIGH-IN-MOTION SYSTEM NO. 2
                      NONMATCHING AXLE COUNT OBSERVATIONS

            V
            E
          S H                                                      P P P                                           W W W
          E T                   P    P    P    P    P    P   P P P S S S    W    W    W    W    W    W    W    W W S S S
 O   T    R Y     A             S    S    S    S    S    S   S S S P P P    S    S    S    S    S    S    S    S S P P P
 B   A    N P     C             P    P    P    P    P    P   P P P 1 1 1    P    P    P    P    P    P    P    P P 1 1 1
 S   G    O E     C             1    2    3    4    5    6   7 8 9 0 1 2    1    2    3    4    5    6    7    8 9 0 1 2

 1   8  312 3S2-3 A2*2     14.4  4.7 14.7  4.3 15.5 19.2 3.9 . . . . . 15.2  4.3 14.7  4.1    .    .    .    . . . . .
 2  11  321 3S3   A1       15.5  5.3 29.7  5.0  5.4    .   . . . . . . 11.8    .    .    .    .    .    .    . . . . .
 3  71  614 2S2   A1*2     16.0 29.7  4.3    .    .    .   . . . . . . 16.6  4.4 26.2  4.2    .    .    .    . . . . .
 4  81  672 2S1-2 A1       15.9 21.6  9.3 22.3    .    .   . . . . . . 17.0    .    .    .    .    .    .    . . . . .
 5 101  777 2S1   A1       12.7 21.6    .    .    .    .   . . . . . . 13.1    .    .    .    .    .    .    . . . . .
 6 163 1285 3-4   A2*2     17.8  4.6 32.3  3.8 14.0  4.8   . . . . . . 13.8  4.5 35.6  4.2    .    .    .    . . . . .
 7 190 1510 3S2   A1*2     16.6  4.5 32.3  4.1    .    .   . . . . . . 11.2 16.4  2.8    .    .    .    .    . . . . .
 8 193 1520 3-2   A1*1     17.0  4.2 20.0  4.1    .    .   . . . . . .  3.9 23.1    .    .    .    .    .    . . . . .
 9 202 1556 2S2   A1*2     13.3 34.3  4.1    .    .    .   . . . . . . 12.0  4.4 29.8  3.9    .    .    .    . . . . .
10 235 3384 3S1   A2*1     18.2  4.8 34.0    .    .    .   . . . . . . 18.3  4.6 34.1  4.0    .    .    .    . . . . .
11 249 3439 3S2   A2*3     12.1  4.3 31.7  4.0    .    .   . . . . . . 11.7  4.5 31.6  4.2  4.1    .    .    . . . . .
12 273 3557 3S2-2 A2*2     12.1  4.4 23.0  3.8 17.4 16.0   . . . . . . 11.5  4.6 23.3  4.3    .    .    .    . . . . .
13 293 3705 2S1   A1*1     13.1 38.4    .    .    .    .   . . . . . . 13.8  4.4 34.9  4.0    .    .    .    . . . . .
14 302 3744 3-2   A1*1     18.4  3.9 16.0 22.7    .    .   . . . . . .  8.8 18.8    .    .    .    .    .    . . . . .
15 351 3992 3S2   A2*1A1   16.7  4.5 31.1  4.1    .    .   . . . . . . 16.8  4.3 19.2  9.1 22.0    .    .    . . . . .
16 420 4463 2D    A2*2     14.3    .    .    .    .    .   . . . . . . 14.8  4.7 32.8  3.9    .    .    .    . . . . .
17 476 4838 2S3   A2*3        .    .    .    .    .    .   . . . . . . 15.7  4.2 34.2  4.5  4.5    .    .    . . . . .
18 509 6980 3S2   A2B2*2   12.0  4.4 28.4  4.1    .    .   . . . . . . 13.8  4.2 13.4  3.8 13.8  4.2 13.4  4.2 . . . .
19 523 6486 3S1-2 A2*1     15.7  4.2 14.2 17.1 16.0    .   . . . . . . 15.6  4.3 14.5    .    .    .    .    . . . . .
20 571 6783 3S2   A1*2     17.4  4.0 32.0  4.3    .    .   . . . . . . 12.9 14.8  2.9    .    .    .    .    . . . . .
21 586 6861 2S2   A1*2     14.7 34.3  4.5    .    .    .   . . . . . . 14.3  4.4 30.3  4.3    .    .    .    . . . . .
22 589 6883 3S1   A2*1     17.2  5.4 38.4    .    .    .   . . . . . . 16.7  5.1 57.7  4.0    .    .    .    . . . . .
23 598 6955 3S3   A2*2     17.5  4.2 32.2  4.1  4.5    .   . . . . . . 17.3  4.5 31.3  3.8    .    .    .    . . . . .
```

(figure 8a)

```
                         WEIGH-IN-MOTION SYSTEM NO. 2
                 WORST 50 OBSERVATIONS BY ABSOLUTE RELATIVE DIFFERENCE

OBS  TAG  SERNO  VEHTYPE  ACC        ARELDIFF    RELDIFF  POETOTWT  WIMTOTWT   PWT1   PWT2   PWT3   PWT4   PWT5   PWT6   PWT7

  1  420   4463  2D       A2*2        1.67241    1.67241     16240     43400   5500  10740      .      .      .      .      .
  2  476   4838  2S3      A2*3        1.30132    1.30132     48320    111200  11480  36840      .      .      .      .      .
  3   10    317  3S2      A2*2        1.00224    1.00224     35760     71600  10340  16860   8560      .      .      .      .
  4   11    321  3S3      A1          0.92301   -0.92301     88320      6800  12700  33800  13420  28400      .      .      .
  5  302   3744  3-2      A1*1        0.89005   -0.89005     70940      7800  12720  29960  14960  13300      .      .      .
  6  571   6783  3S2      A1*2        0.83490   -0.83490     78740     13000  12360  33920  32460      .      .      .      .
  7   81    672  2S1-2    A1          0.83351   -0.83351     56460      9400   9560  14980  11860   9940  10120      .      .
  8  193   1520  3-2      A1*1        0.78912   -0.78912     29400      6200   8020  12780   8600      .      .      .      .
  9  190   1510  3S2      A1*2        0.74131   -0.74131     49480     12800  11240  24440  13800      .      .      .      .
 10  101    777  2S1      A1          0.64315   -0.64315     24100      8600   9820   8860   5420      .      .      .      .
 11    8    312  3S2-3    A2*2        0.53170   -0.53170    105060     49200  11360  24940  25360  16560  26840      .      .
 12  185   1389  3S2-2    A2*2A1      0.51153   -0.51153     65920     32200  10020  11280   7460   3780  33380      .      .
 13  299   3731  3S2      A2*2        0.50730   -0.50730     65760     32400  10320  28440  27000      .      .      .      .
 14   63    573  3S2      A2*2        0.47863   -0.47863     42580     22200  10760  20300  11520      .      .      .      .
 15  385   4286  4S3      A3*3        0.45183   -0.45183     96320     52800  12780   6360  35080  42100      .      .      .
 16  485   4877  2S1-2-2  A1*1A1A1    0.40073    0.40073     82100    115000  15980  15440  13920  13080  11940  11740      .
 17  381   4275  2S1-2-2  A1*1A1A1    0.38436    0.38436     73680    102000   9880  14600  10240  14600  11100  13260      .
 18  523   6486  3S1-2    A2*1        0.35839   -0.35839     30860     19800   8300  10140   4220   4220   3980      .      .
 19    4    287  3S2      A2*2        0.33641   -0.33641     47620     31600   3980   5060  10180  17300  11100      .      .
 20  401   4360  3S3      A2*3        0.33501   -0.33501     55640     37000   7660  23300  24680      .      .      .      .
 21  415   4424  3-2      A2A1        0.31804   -0.31804     31380     21400   7980  13260   4700   5440      .      .      .
 22  548   6615  2D       A1          0.30857   -0.30857     19380     13400   9000  10380      .      .      .      .      .
 23  632   7107  2D       A1          0.29239   -0.29239     14980     10600   5780   9200      .      .      .      .      .


OBS   PWT8   PWT9  PWT10  PWT11  PWT12   WWT1   WWT2   WWT3   WWT4   WWT5   WWT6   WWT7   WWT8   WWT9  WWT10  WWT11  WWT12

  1      .      .      .      .      .   6800   9800   7000  10000   9800      .      .      .      .      .      .      .
  2      .      .      .      .      .   7600  21000  18000  22000  20600  22000      .      .      .      .      .      .
  3      .      .      .      .      .   6800  17600  16800  16000  14400      .      .      .      .      .      .      .
  4      .      .      .      .      .   3600   3200      .      .      .      .      .      .      .      .      .      .
  5      .      .      .      .      .   2000   3200   2600      .      .      .      .      .      .      .      .      .
  6      .      .      .      .      .   4000   3400   2400   3200      .      .      .      .      .      .      .      .
  7      .      .      .      .      .   3400   6000      .      .      .      .      .      .      .      .      .      .
  8      .      .      .      .      .   2200   2800   1200      .      .      .      .      .      .      .      .      .
  9      .      .      .      .      .   3400   3000   3400   3000      .      .      .      .      .      .      .      .
 10      .      .      .      .      .   3600   5000      .      .      .      .      .      .      .      .      .      .
 11      .      .      .      .      .   6600  13600   8800   6600  13600      .      .      .      .      .      .      .
 12      .      .      .      .      .   6800   7200   3800   3000   3200   5000   3200      .      .      .      .      .
 13      .      .      .      .      .   7000   6800   6400   6800   5400      .      .      .      .      .      .      .
 14      .      .      .      .      .   6800   3800   3600   4200   3800      .      .      .      .      .      .      .
 15      .      .      .      .      .   7400   5000  10800  10800   7600   7600   3600      .      .      .      .      .
 16      .      .      .      .      .   8400  20400  20400  19200  16800  13000  16800      .      .      .      .      .
 17      .      .      .      .      .   7200  18400  17200  10400  18400  15000  15400      .      .      .      .      .
 18      .      .      .      .      .   5800   4800   5200   4000      .      .      .      .      .      .      .      .
 19      .      .      .      .      .   6800   8000   7200   5600   4000      .      .      .      .      .      .      .
 20      .      .      .      .      .   5000   9800   6200   5200   5200   5600      .      .      .      .      .      .
 21      .      .      .      .      .   6600   3400   4000   3000   4400      .      .      .      .      .      .      .
 22      .      .      .      .      .   5400   8000      .      .      .      .      .      .      .      .      .      .
 23      .      .      .      .      .   3400   7200      .      .      .      .      .      .      .      .      .      .
```

(figure 8b)

IDAHO TRANSPORTATION DEPARTMENT

Weigh-In-Motion Calibration Factor File

Output Record of "Factor" Program - 28 Byte format

Pos No.	Field Size	Type	Name	Description
1	6	Num	Weightcl	Startg Wt of Affected Wt Interval
8	6.3	Num	Mreldiff	Mean rel diff factor applied
15	6	Alpha	Device	System Identification Code
22	6	Alpha	Date	YYMMDD format

Notes:

1) Weightcl is the minimum GVW calibrated using this factor. The maximum is one pound less than the next Weightcl.

(2) Mreldiff is the mean relative difference factor for this weight class as determined in the POE/WIM calibration test. The factor is multiplied by the weight, and then the product is subtracted from each weight (calibrated weight = raw weight - (raw weight x factor)).

(3) Only WIM records with a matching system identification code are calibrated using this factor file.

(4) Only WIM records collected later than the factor file date are calibrated using this factor file.

FACTOR FILE SAMPLE

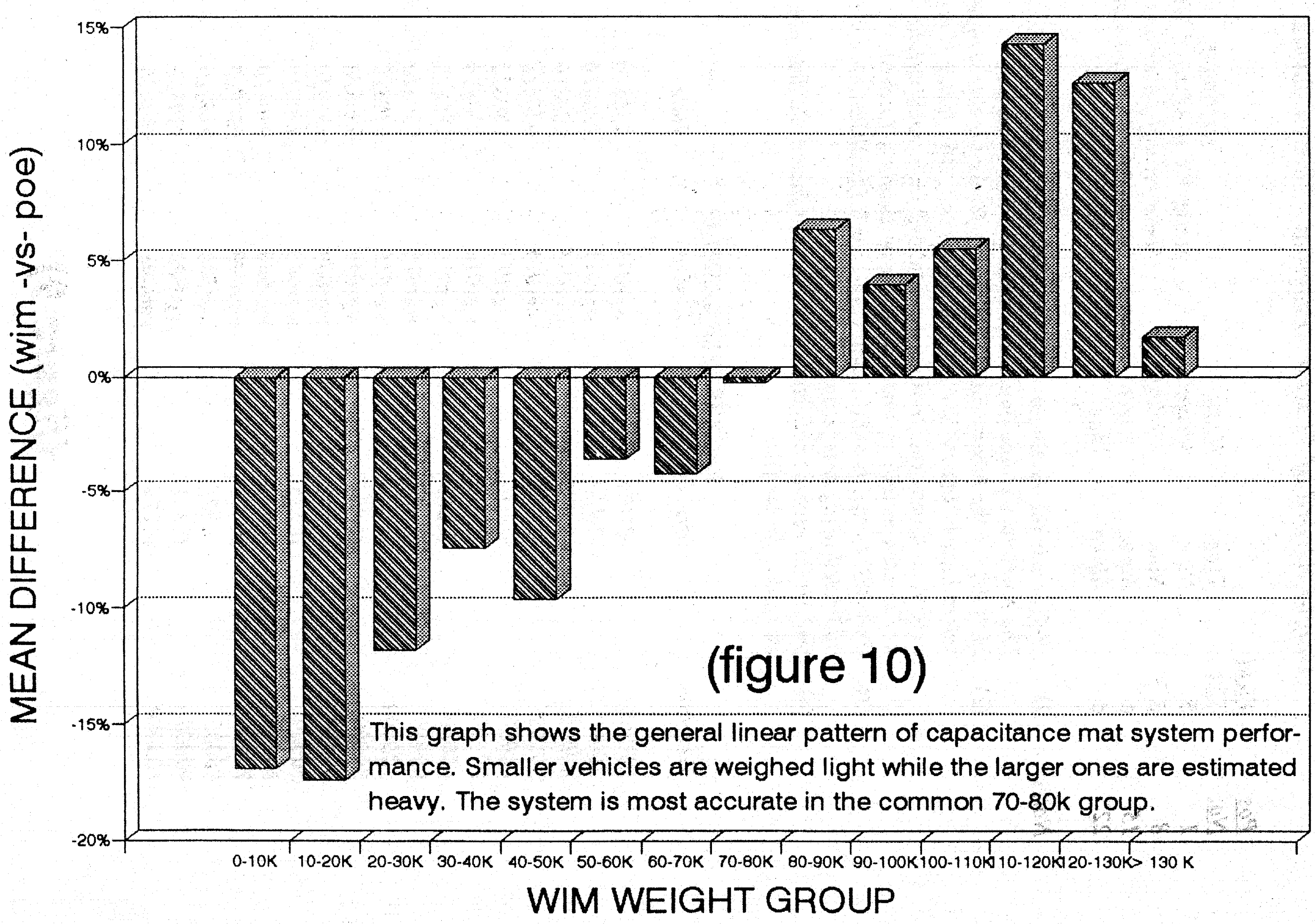
Weightcl	Mreldiff	Device	Date
20000	-0.174	wgr015	930810
30000	-0.118	wgr015	930810
40000	-0.075	wgr015	930810
50000	-0.097	wgr015	930810
60000	-0.036	wgr015	930810
70000	-0.042	wgr015	930810
80000	-0.002	wgr015	930810
90000	0.063	wgr015	930810
100000	0.040	wgr015	930810
30000	-0.002	wgr040	930810
40000	0.035	wgr040	930810
50000	0.125	wgr040	930810
60000	0.093	wgr040	930810
70000	0.133	wgr040	930810
80000	0.076	wgr040	930810
90000	0.131	wgr040	930810
100000	0.174	wgr040	930810

(figure 9)

AUG 93 WIM TESTS - WIM SYSTEM NO. 1

COMPARISON OF DYNAMIC - VS - STATIC GROSSWEIGHT DATA

WIM data is UNCALIBRATED



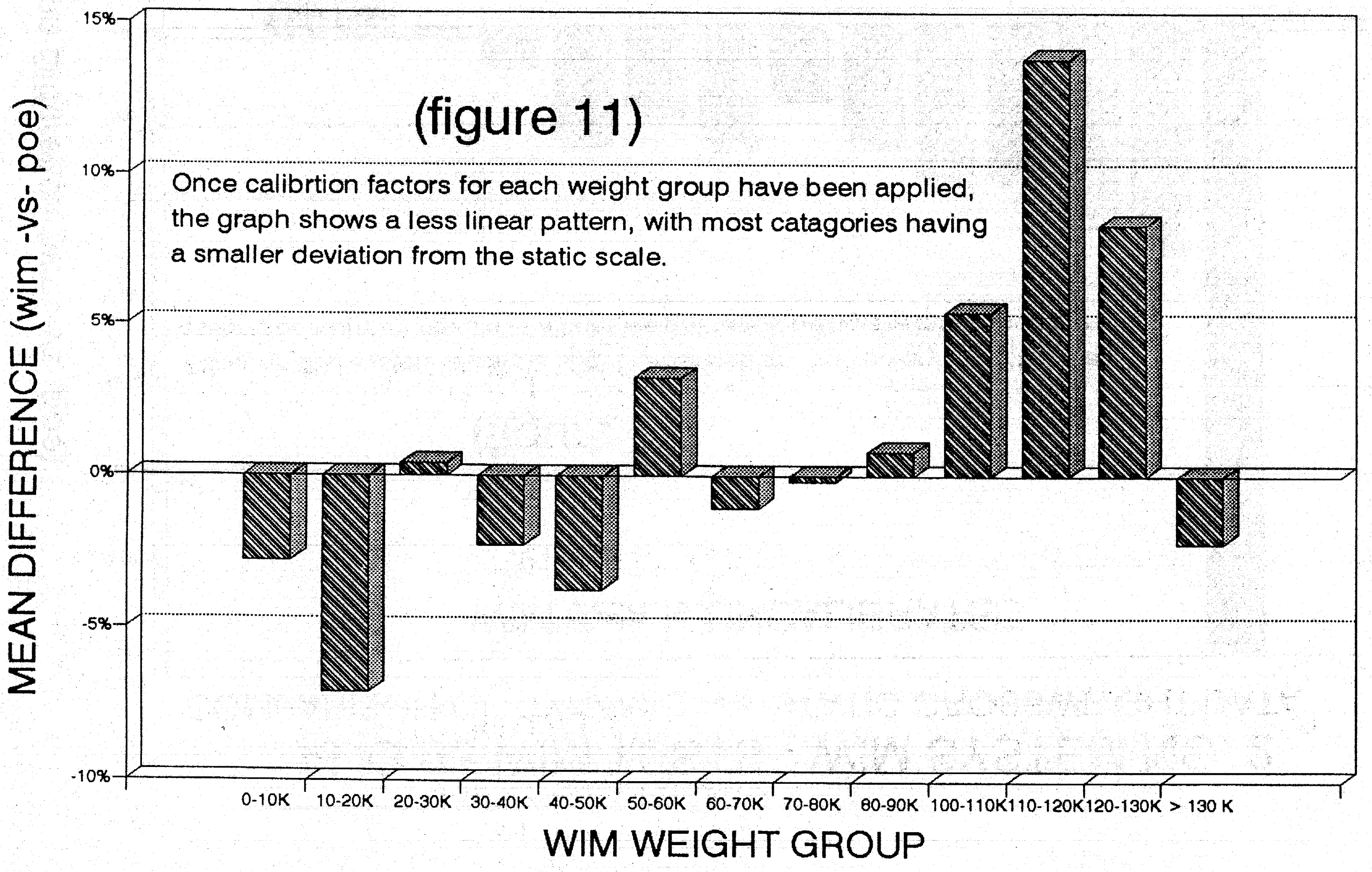
(figure 10)

This graph shows the general linear pattern of capacitance mat system performance. Smaller vehicles are weighed light while the larger ones are estimated heavy. The system is most accurate in the common 70-80k group.

AUG 93 WIM TESTS - WIM SYSTEM NO. 1

COMPARISON OF DYNAMIC - VS - STATIC GROSSWEIGHT DATA

WIM data is CALIBRATED

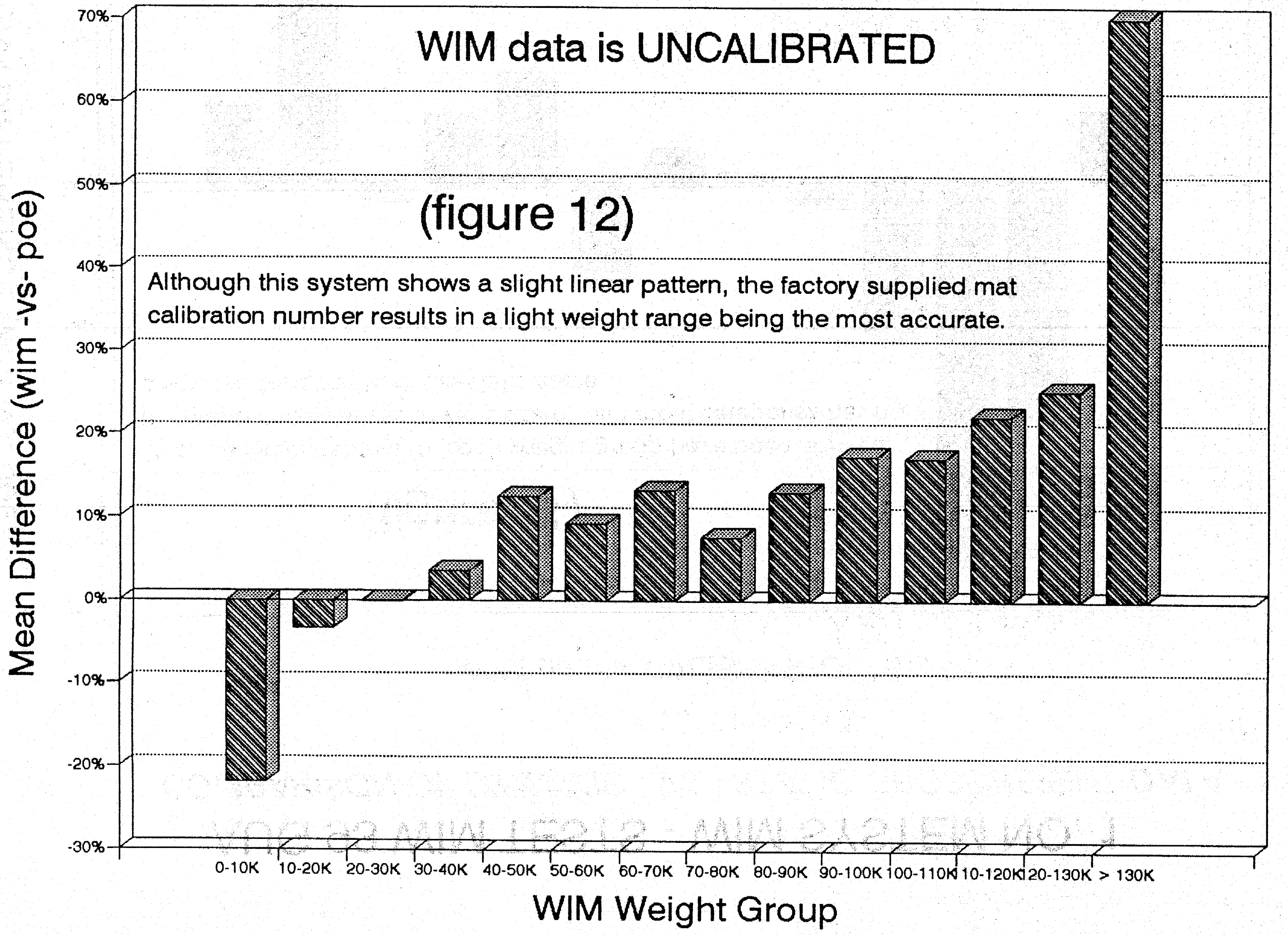


(figure 11)

Once calibrtion factors for each weight group have been applied, the graph shows a less linear pattern, with most catagories having a smaller deviation from the static scale.

AUG 93 WIM TESTS - WIM SYSTEM NO. 2

COMPARISON OF DYNAMIC -vs- STATIC GROSSWEIGHT DATA



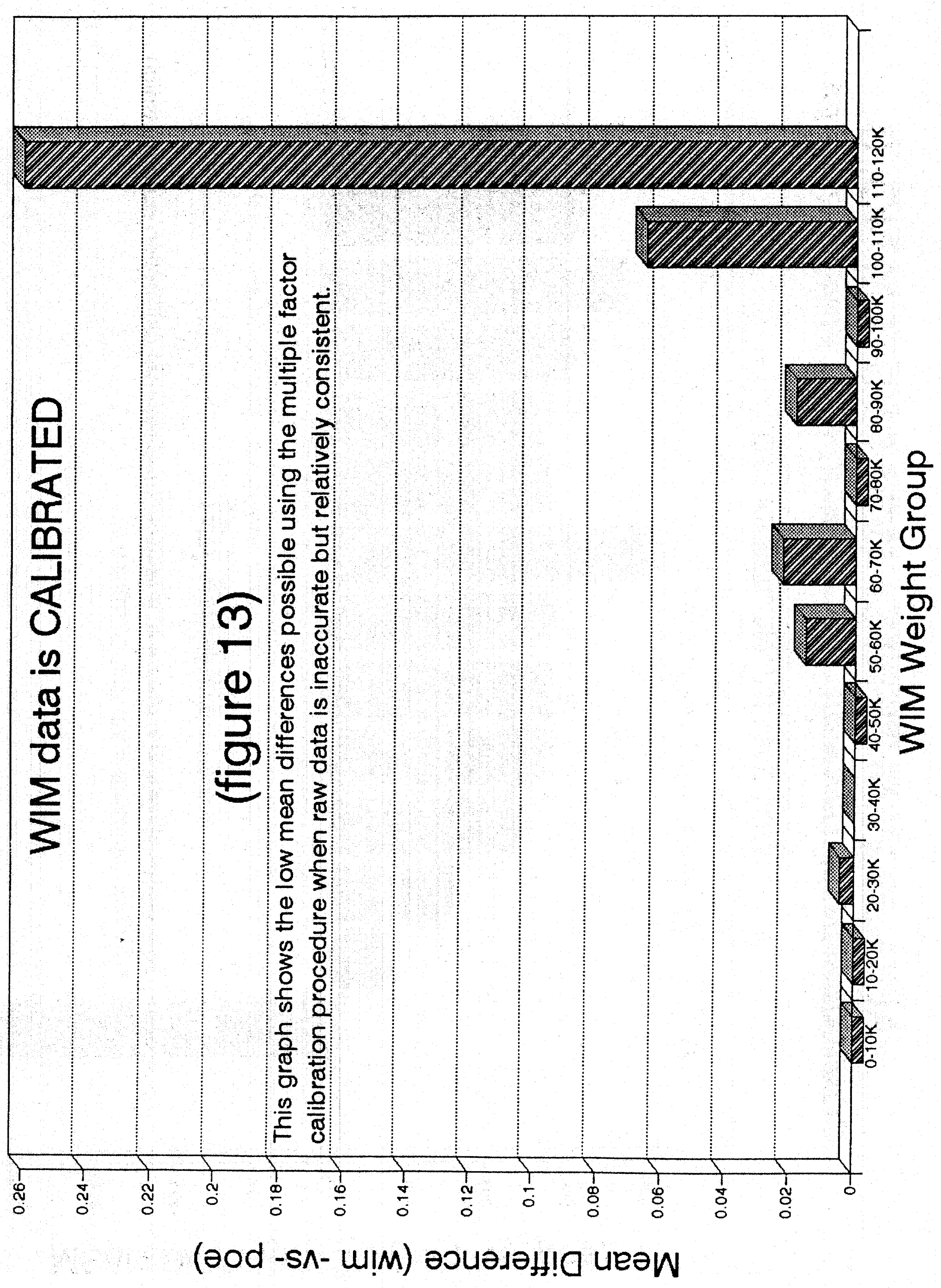
WIM data is UNCALIBRATED

(figure 12)

Although this system shows a slight linear pattern, the factory supplied mat calibration number results in a light weight range being the most accurate.

AUG 93 WIM TESTS - WIM SYSTEM NO. 2

COMPARISON OF DYNAMIC -vs- STATIC GROSSWEIGHT DATA



WIM data is CALIBRATED

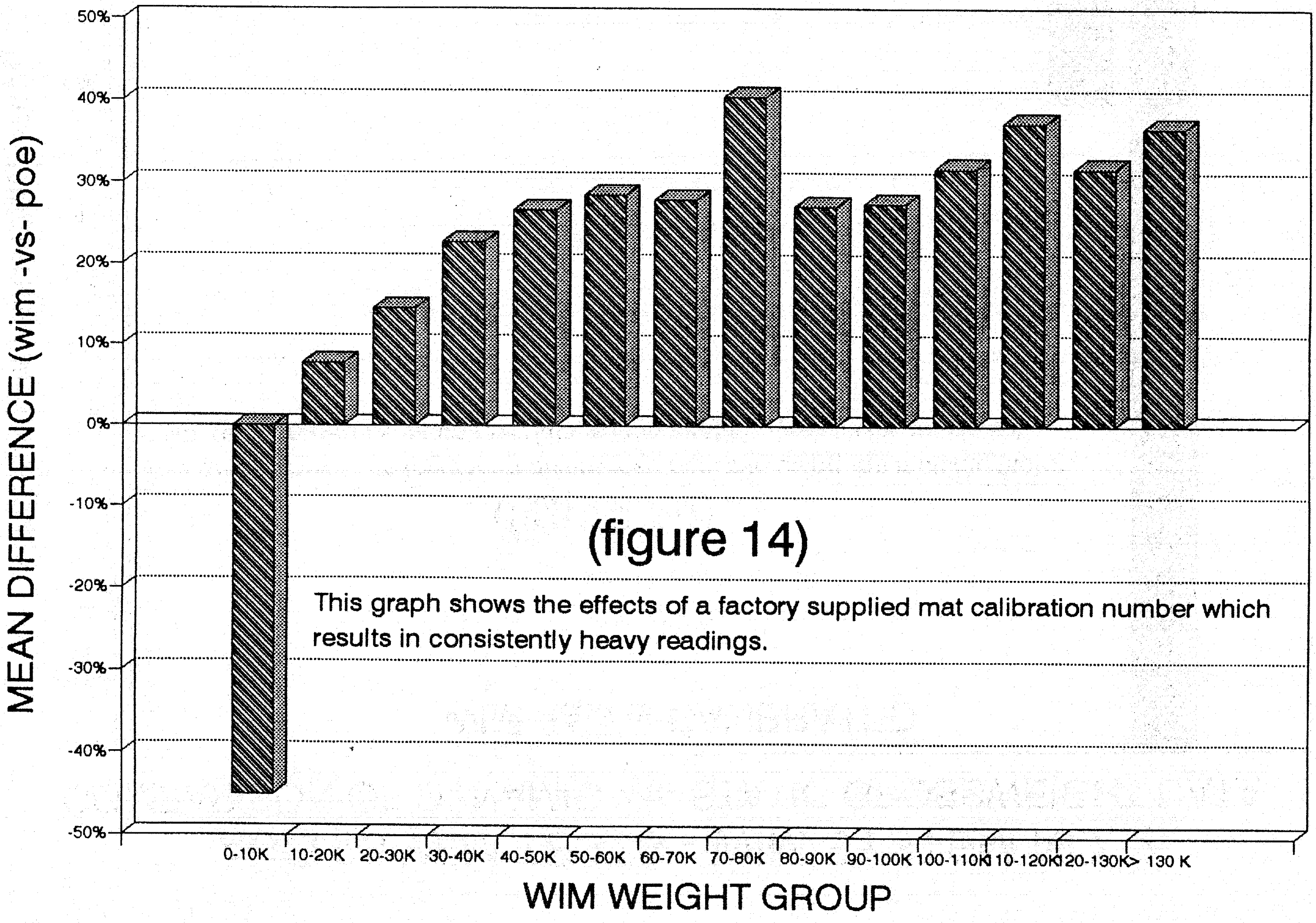
(figure 13)

This graph shows the low mean differences possible using the multiple factor calibration procedure when raw data is inaccurate but relatively consistent.

AUG 93 WIM TESTS - WIM SYSTEM NO. 3

COMPARISON OF DYNAMIC - VS - STATIC GROSSWEIGHT DATA

WIM data is UNCALIBRATED



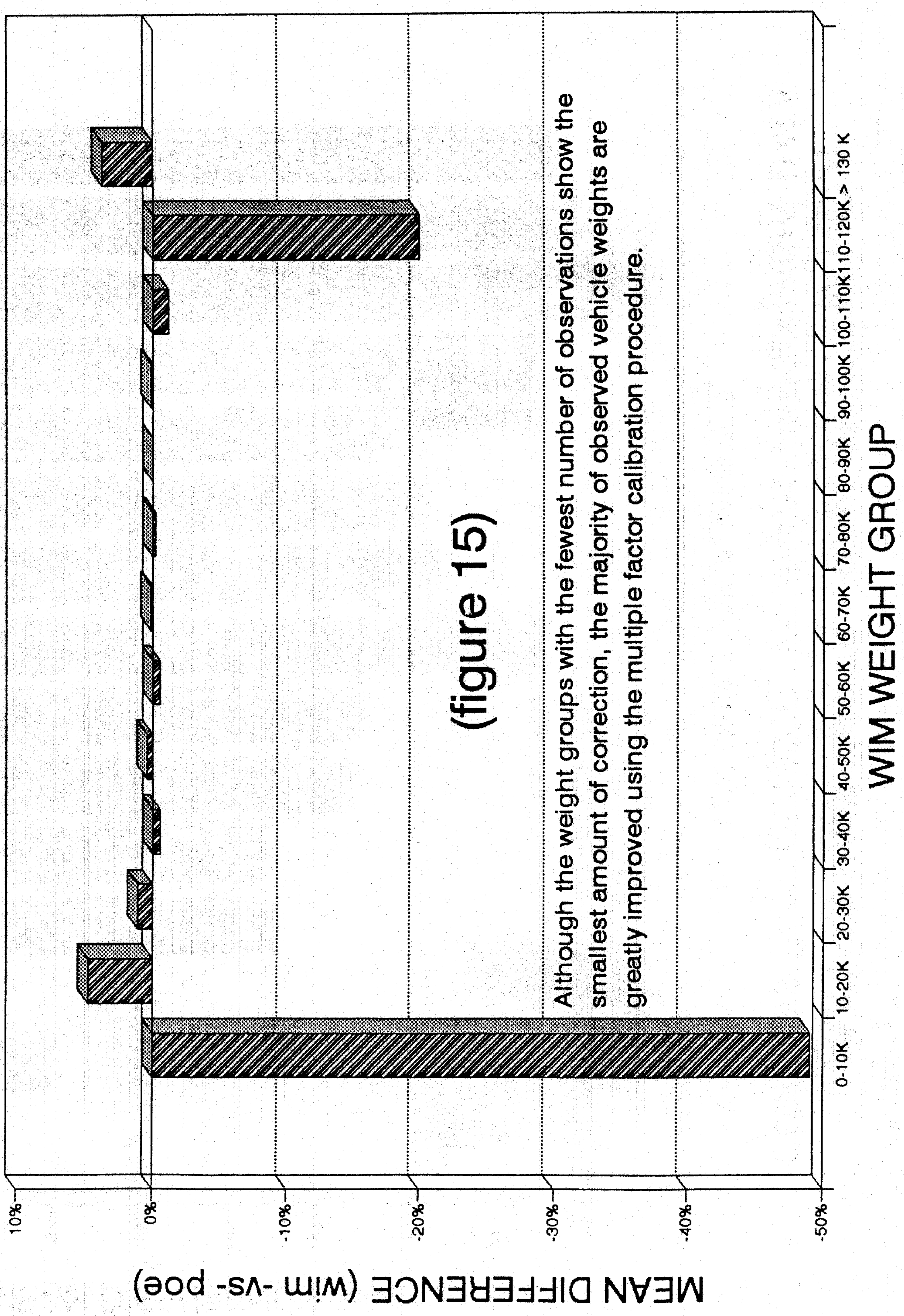
(figure 14)

This graph shows the effects of a factory supplied mat calibration number which results in consistently heavy readings.

AUG 93 WIM TESTS - WIM SYSTEM NO. 3

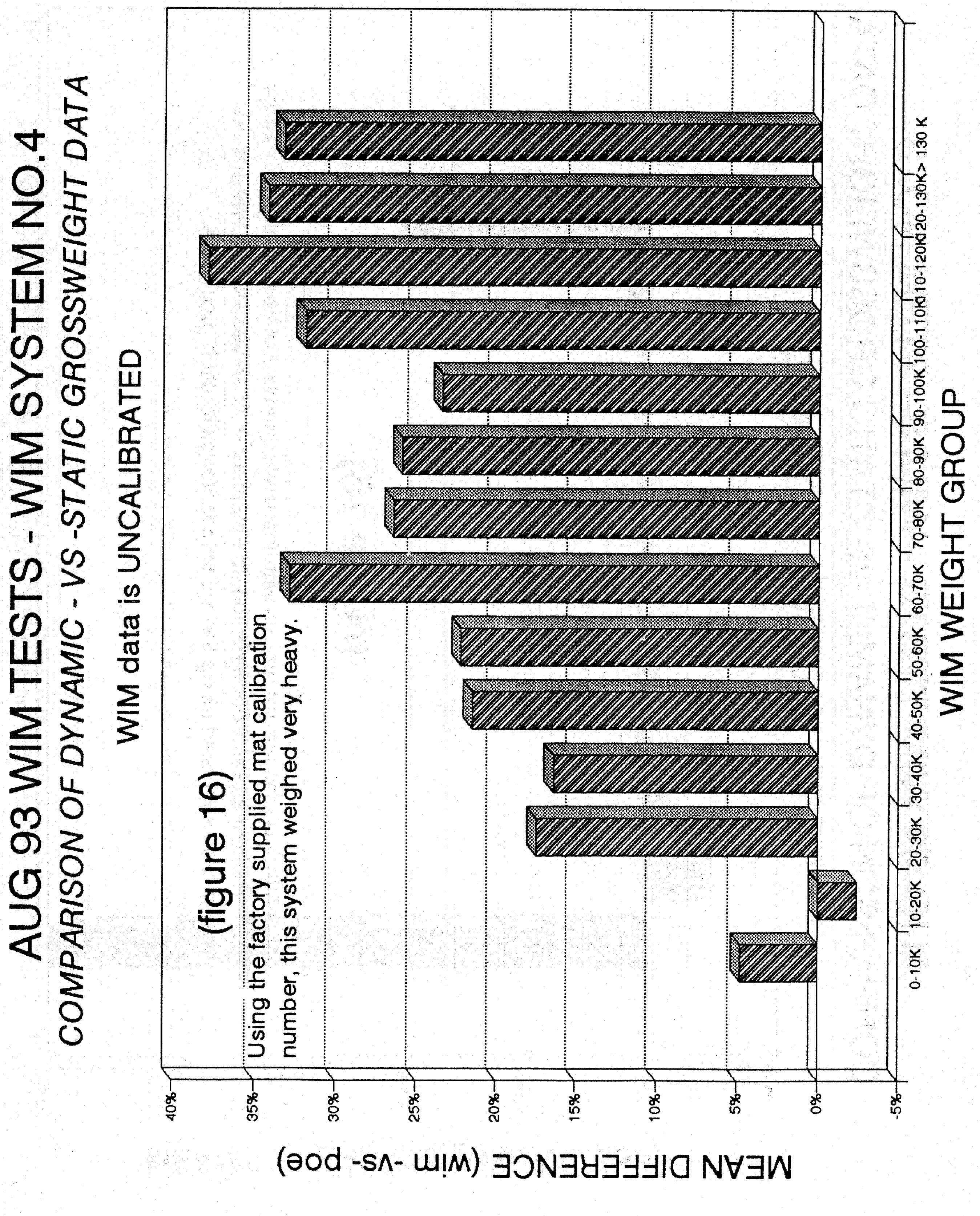
COMPARISON OF DYNAMIC -vs- STATIC GROSSWEIGHT DATA

WIM data is CALIBRATED



(figure 15)

Although the weight groups with the fewest number of observations show the smallest amount of correction, the majority of observed vehicle weights are greatly improved using the multiple factor calibration procedure.



AUG 93 WIM TESTS - WIM SYSTEM NO.4

COMPARISON OF DYNAMIC - VS -STATIC GROSSWEIGHT DATA

WIM data is UNCALIBRATED

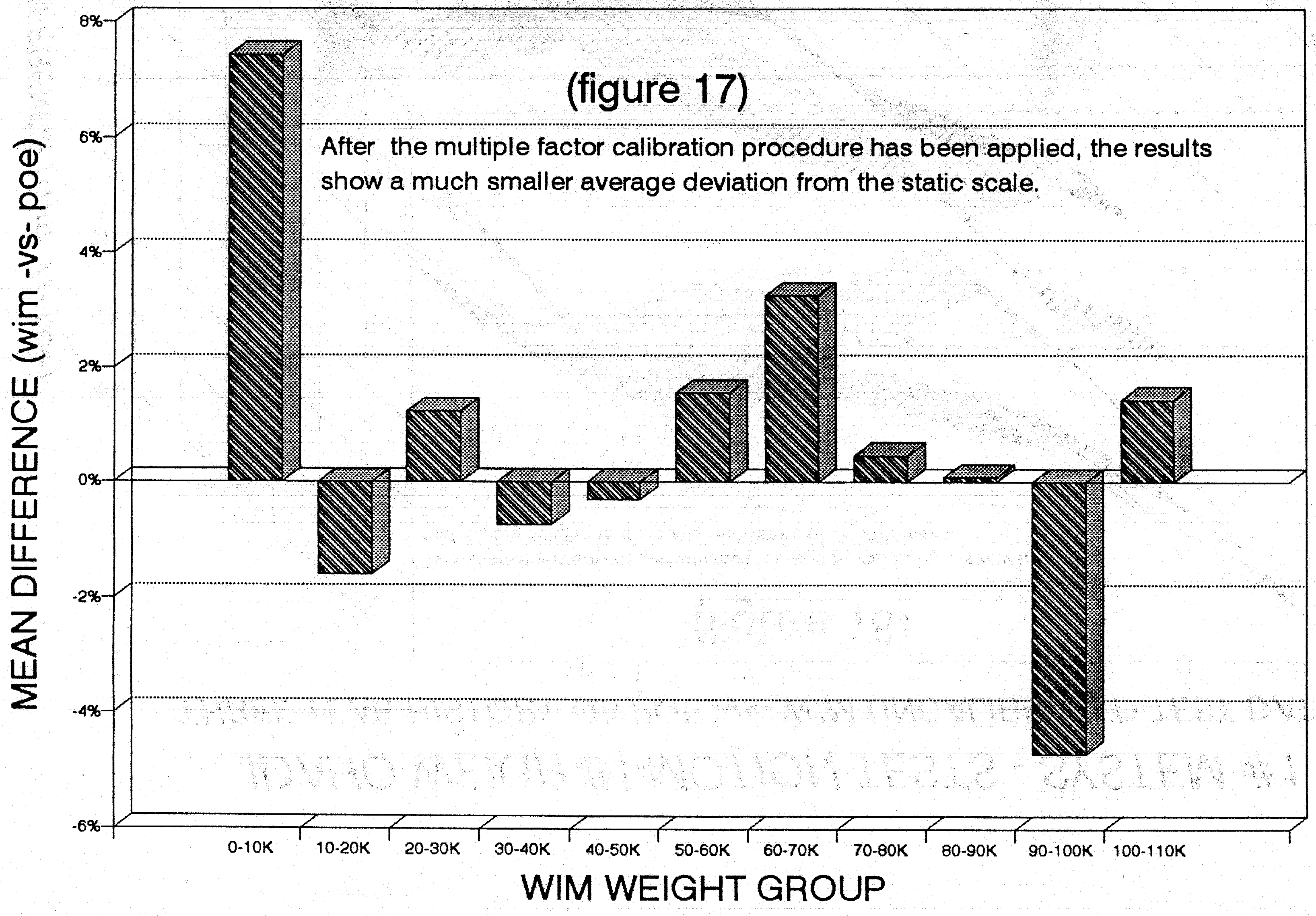
(figure 16)

Using the factory supplied mat calibration number, this system weighed very heavy.

AUG 93 WIM TESTS - WIM SYSTEM NO. 4

COMPARISON OF DYNAMIC - VS - STATIC GROSSWEIGHT DATA

WIM data is CALIBRATED

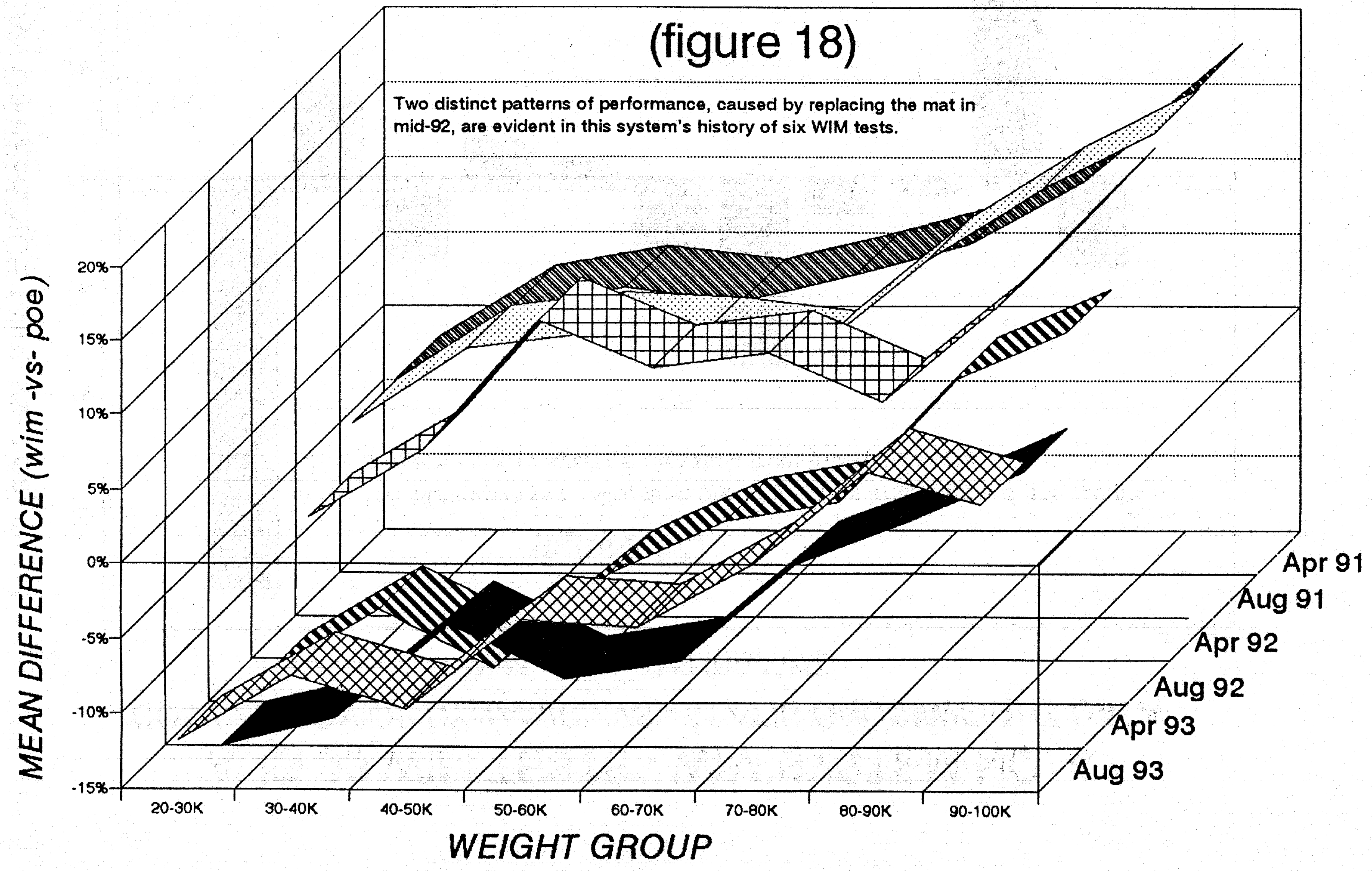


(figure 17)

After the multiple factor calibration procedure has been applied, the results show a much smaller average deviation from the static scale.

IDAHO WEIGH-IN-MOTION TESTS - SYSTEM #1

THREE YEAR HISTORY OF POE -vs- WIM UNCALIBRATED TEST DATA

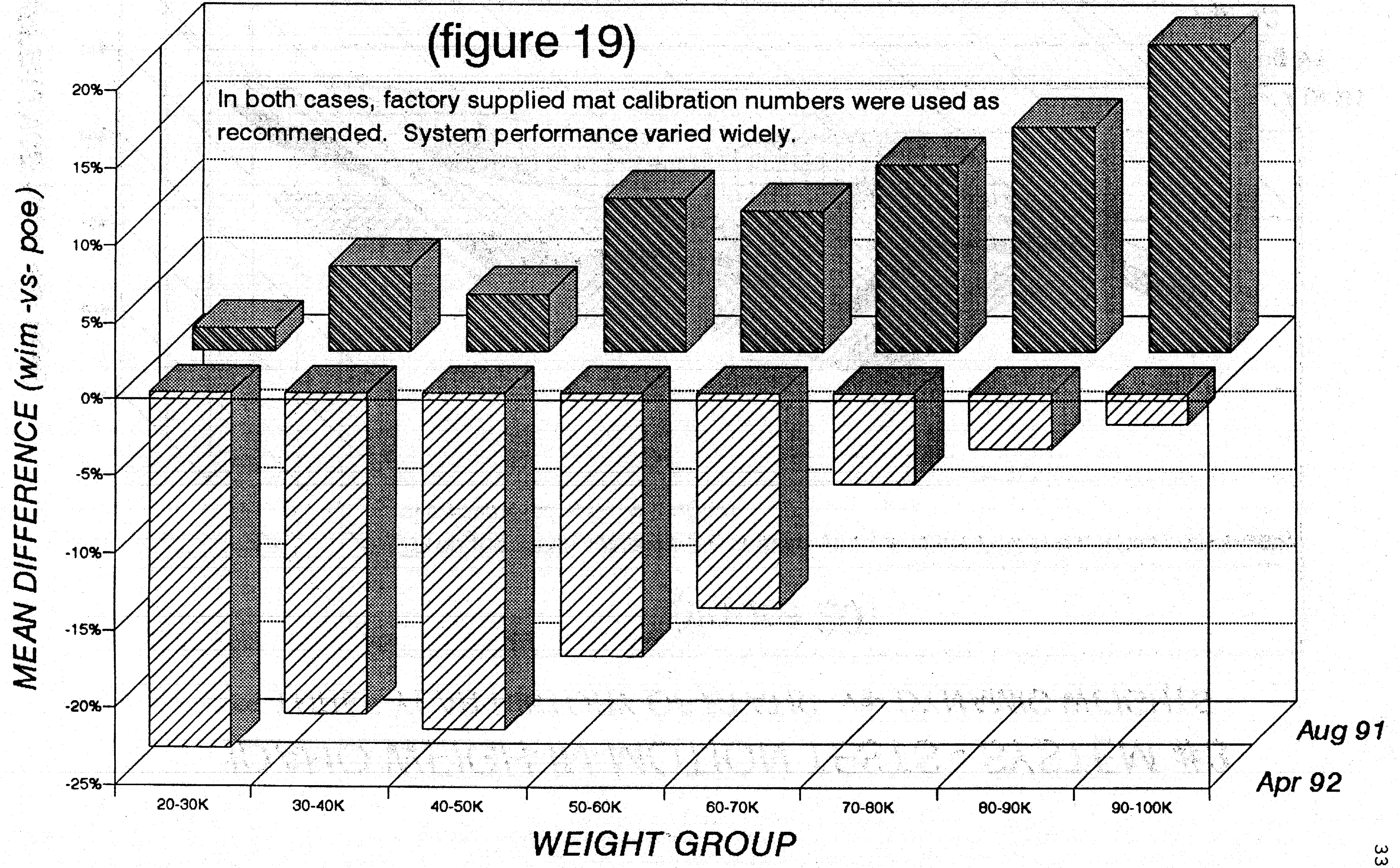


(figure 18)

Two distinct patterns of performance, caused by replacing the mat in mid-92, are evident in this system's history of six WIM tests.

IDAHO WEIGH-IN-MOTION TESTS - SYSTEM #2

SYSTEM PERFORMANCE BEFORE AND AFTER MAT REPLACEMENT

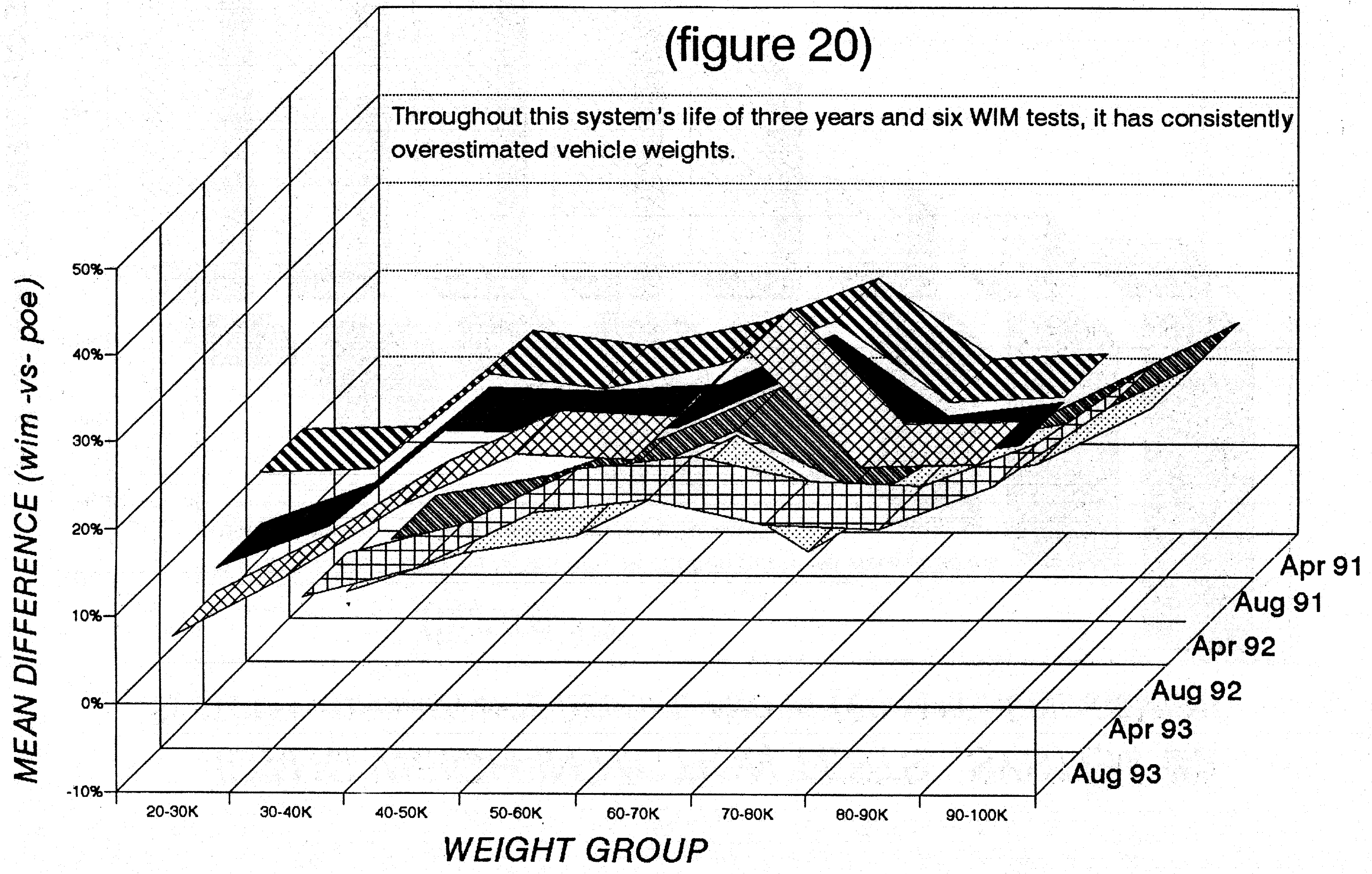


(figure 19)

In both cases, factory supplied mat calibration numbers were used as recommended. System performance varied widely.

IDAHO WEIGH-IN-MOTION TESTS - SYSTEM #3

THREE YEAR HISTORY OF STATIC -vs- DYNAMIC WEIGHTS

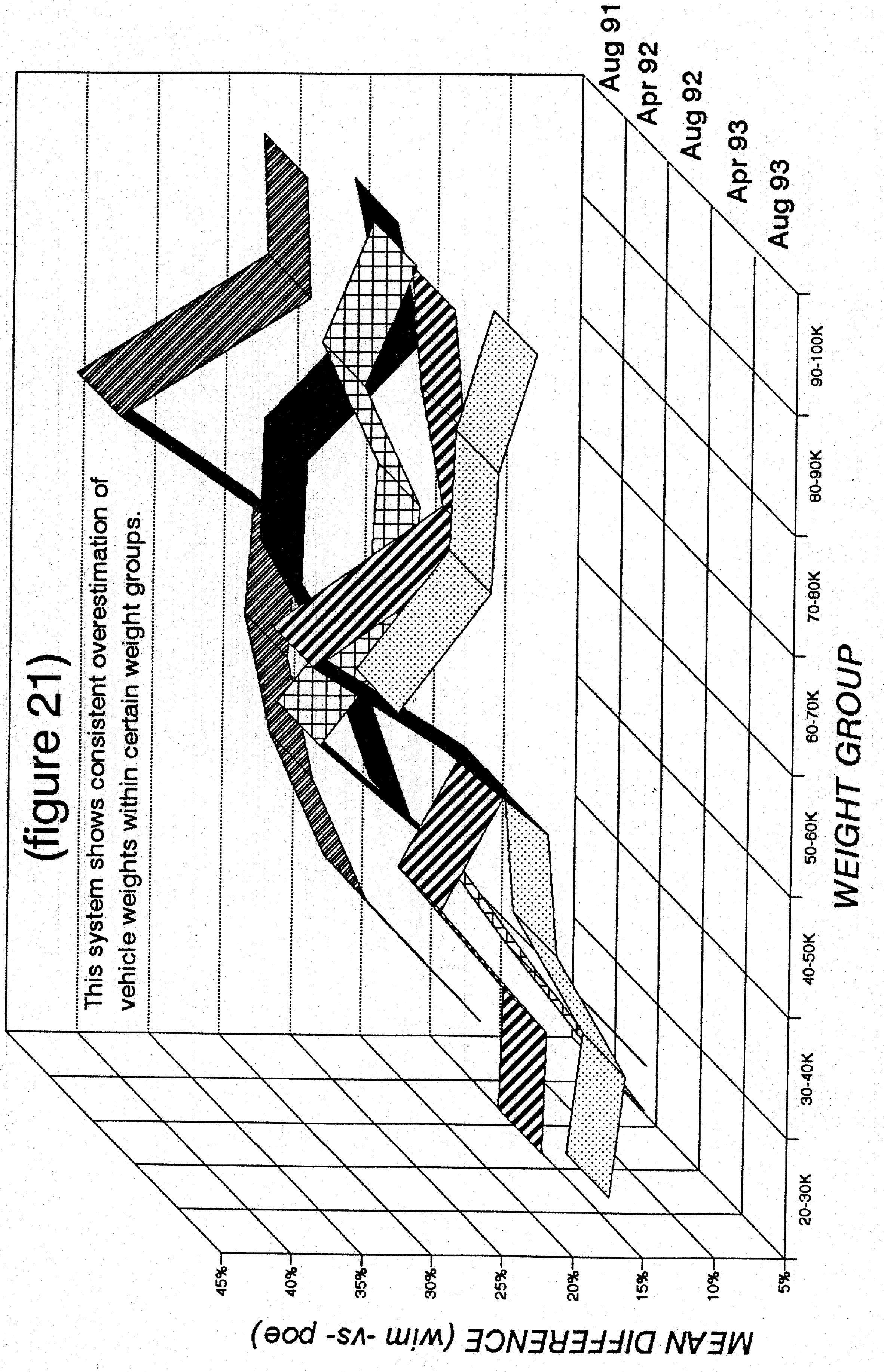


(figure 20)

Throughout this system's life of three years and six WIM tests, it has consistently overestimated vehicle weights.

IDAHO WEIGH-IN-MOTION TESTS - SYSTEM #4

THREE YEAR HISTORY OF STATIC -vs- DYNAMIC WEIGHTS



(figure 21)

This system shows consistent overestimation of vehicle weights within certain weight groups.

ACCURACY OF TRAFFIC MONITORING EQUIPMENT

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Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

Accuracy of Traffic Monitoring Equipment

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ABSTRACT

This paper describes the tests being performed by the Georgia Tech Research Institute (GTRI) and the Georgia Department of Transportation (GaDOT). Funding for this project was provided by the Federal Highway Administration (FHWA) Office of Highway Information Management. The objectives of these tests were to determine the accuracy of vehicle counting devices, the adequacy of equipment to correctly sort vehicles into the 13 FHWA vehicle classes, the accuracy of automatic measurement of overall vehicle length, the effects of vehicle and axle sensor technology on the accuracy of the vehicle classification, and the effects of vehicle repetitions and weather on pneumatic tube (and other) axle sensors.

The tests were conducted on a high-volume interstate in the metro Atlanta area where there was a good mix of vehicles for all FHWA vehicle classes except triple trailors which are illegal in Georgia. All the devices were installed in a single lane and testing was conducted simultaneously on the same traffic stream to ensure a fair comparison of the devices. Each vehicle was manually identified using video tapes from a camera mounted above and to the side of the traffic lane. Markings on the roadway were used to derive vehicle length and axle spacing on each of the vehicles. The tests included two 48-hour tests for detailed vehicle-by-vehicle analysis and a 7-day test to determine long term effects on the vehicle classification devices.

The setup, performance, analysis methods and general results of the tests as well as the problems encountered are presented in this paper.

BACKGROUND & PURPOSE OF TESTS

Traffic monitoring equipment and especially automatic vehicle classification (AVC) equipment are a very important part of an overall traffic management system. Many new devices are currently being marketed which are designed to not only monitor traffic density and speed, but also to classify vehicle into the 13 FHWA vehicle classes. The accuracy of the classification function of these devices should be independently verified under normal operating conditions. The tests described in this paper were used to test nine (9) vendor's equipments including 14 sensor sets of these AVC devices in a side-by-side test under normal traffic conditions.

There have been significant changes in the sophistication and technological approaches to the gathering of classification and volume count data since the completion of the testing of vehicle classification devices by the State of Maine in 1984 for the FHWA. (*1*) This has included the use of new types of sensors, such as piezoelectric axle sensors, and the development of programmable classifiers that allow the user to specify the dimensional thresholds for various vehicle types. Also, many of the new vehicle classifiers have the ability to retain individual vehicle information rather than simply binning or summing the vehicles into specified time intervals.

The devices being tested in this project were commercially available devices representing the current state-of-the-application classification devices as of September 1992, when the project began. The tests were conducted using off-the-shelf components and not prototype or developmental devices. Vendors of vehicle classification devices were requested to participate in the tests by providing classification data recording equipment (on loan) and to participate in the installation, check-out and calibration of their equipment at the test site. The sensors used for the tests were specified by the vendor and purchased by the project.

The objectives of the test were to:

- Determine the accuracy of vehicle counting devices.
- Determine the accuracy of various types of equipment to correctly sort vehicles into the 13 FHWA vehicle classes (as identified by the FHWA Traffic Monitoring Guide).
- Determine the accuracy of automatic measurement of axle spacings, wheel base length, and overall vehicle length.
- Determine how vehicle and axle sensor technology affects the accuracy of the vehicle classification.
- Determine the effects of vehicle repetitions, heavy axle loadings, and weather on pneumatic tube axle sensors.

TEST SET-UP & INSTALLATION

The tests were conducted on the shoulder lane of Interstate 20 near Covington Georgia, 30 miles east of the metro Atlanta area. This particular location was chosen for several practical reasons including available shoulder space for installing an equipment trailer, available power, and a conveniently located overpass. This section of the roadway met the conditions for the test including radius of curvature greater than 1740 meters (5700 feet), a longitudinal gradient of less than 2 percent, and a cross-slope of less then 2 percent with 46 meters (150 feet) available for sensor locations. The width of the roadway lanes were between 3 and 3.7 meters (10 and 12 feet), the pavement surface is relatively smooth, and the normal traffic flow is in the range of 19 and 40 kilometers per hour (30 to 65 miles per hour). The test site also had a good mix of vehicles for all FHWA vehicle classes except triple trailers (FHWA Class 13) which are illegal in the state of Georgia. Average daily traffic for the test lane was approximately 10,000 vehicles.

The sensors required by each of the classification device vendors were installed mostly under the supervision of vendor representatives or with provided instructions. The vendors participating in the test used only piezoelectric axle sensors, or some combination of piezoelectric axle sensors and loop sensors. Table 1 contains a list of the vendors participating in the tests and the sensor configuration used. The sensor configuration is depicted using "P" to indicate a piezoelectric axle sensor (voltage output), an "L" to depict a magnetic loop and "PR" to denote a piezoelectric resistive device. Therefore, a "P-L-P" configuration uses two piezoelectric sensors with a loop in between.

Installation of the vendor's classification equipment began in December 1992 and was completed by April 1993. Winter weather was one factor which delayed the installation, but perhaps the single most significant factor which delayed the installation was sensor and system failures. A total of six of the piezoelectric sensors had to be replaced due to failures. Also, tape was applied to the piezoelectric sensors surface to provide greater impact to the sensor in order to produce a stronger output signal. It turned out that 5 of the vendors required multiple visits to get their equipment operating to their satisfaction. GTRI also made considerable efforts to debug

Table 1. Equipment Vendors and Configurations

VENDOR	MODELS	CONFIGURATION
Peek Traffic, Inc.	TrafiCOMP III GK-6000	P-L-P P-L-P L-P-L
Mikros Systems	TEL-2CM	L-P-L
PAT Equipment Corporation, Inc.	AVC-100 AVC-100	P-L-P L-P-L
Diamond Traffic Products	TT-2001	P-L-P P-L-P
International Road Dynamics, Inc.	TC/C 530-4D/4P/4L	PR-L-PR P-L-P
Mitron Systems Corp.	MSC-3000 DCP	P-P
Golden River Traffic, Ltd.	Marksman 660	P-L-P
Electronic Control Measure	HESTIA	P-L-P
TimeMark, Inc.	Delta II	P-P

the equipment from four of the vendors. In spite of these efforts, one vendor (not included in Table 1) withdrew from the test after installing sensors, and one vendor was not able to get its classifier working in time for the first test. These failures and problems resulted in weeks of delays in executing the first test originally scheduled for January 1993, but not conducted until May.

To monitor the traffic at the test site, two cameras were installed. The first camera was installed on an overpass at the end of the test site to monitor vehicles changing lanes within the test area. The second was mounted on a utility pole off the side of the road pointing down at the test lane at a 30° angle. Two specially mounted street lights were used to illuminate the test lane at night. The pole camera was used to record the individual vehicles in the traffic stream as they passed through the test site. The video tapes of the traffic stream were used during the data reduction to form the ground truth (or reference) data which listed vehicle class, axle spacings and overall vehicle length for each vehicle which passed through the test site.

Figure 1 depicts the test set-up used for this project. A mobile trailer was used to house computer equipment, the video recording equipment for the pole camera, and the test personnel. The pole camera was mounted on a pole approximately 13.4 meters (44 feet) above the surface of the road and 21 meters (69 feet) from the side of the road. The classification equipment was installed along the right-hand lane of the highway with spacing sufficient to insure no interference between vendor equipment (60 feet between loop sensors of different vendor systems). Some of the vendor's equipment had to be modified (primarily software modifications) to provide individual vehicle records. In some cases, portable computers were required to provide the storage capacity needed to store individual vehicle records.

A camera was mounted on an overpass near the end of the test site to provide a record of vehicle changing lanes within the test site. This data was used to eliminate vehicles from the test which enter or leave the right lane within the test site. The resulting ground truth data was a file listing the vehicles which passed over all of the classification sensors and can be classified by the video from the pole camera.

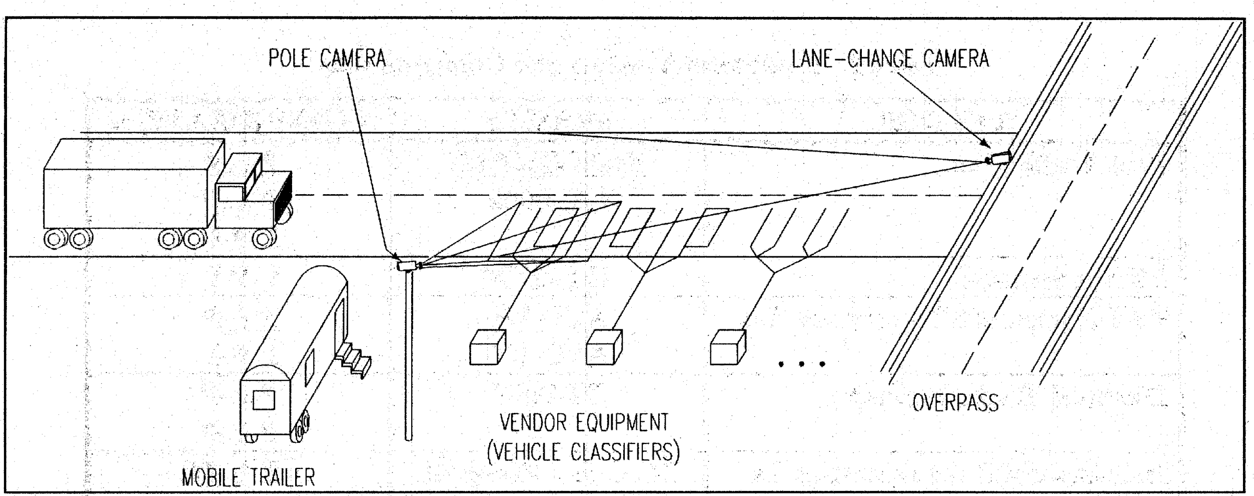

Figure 1. Vehicle Classification Test Site

THE TESTS

The required tests for the project included two 48-hour tests for detailed vehicle-by-vehicle analysis and a 7-day test to obtain longer term accuracy statistics. The classifier data collected during the 48-hour tests were compared on a vehicle-by-vehicle basis with the ground truth data set derived from the pole camera and the lane-change camera. During the 7-day tests, the classifiers were programmed to collect vehicle counts for each vehicle class over 15 minute intervals. This binned data was then compared to similarly binned ground truth data to obtain longer term statistics for each of the classification systems.

The first test was a 48-hour test conducted on May 5 - 7, 1993. The video cameras and computing equipment used to conduct the test worked flawlessly throughout the test. At the time of the test, one vendor's classifier was not operational. Another vendor's classifier apparently had a software crash about half way through the test. A third vendor's equipment had repetitive failures that had to be corrected by resetting the unit. Another unit failed to recognize the existence of an external memory card and did not have enough memory to store the vehicle classification data for the entire 48 hours. Most of the equipment did however work as intended for the entire 48-hour test.

Along with video recording of traffic, air and road surface temperature measurements were made every 15 minutes. The weather for the test was clear and warm with air temperatures ranging from 13 to 30°C (55 to 86°F). The pavement temperatures ranged from 17 to 48°C (63 to 118° F). No precipitation was noted and the pavement remained essentially dry for the entire test. Therefore, the first 48-hour test provided data to determine operation of the classification and test equipment under nearly ideal conditions.

The second 48-hour test was conducted on September 9-11, 1993. All of the vendors listed in Table I participated in the second test with the exception of one which pulled out of the tests due to piezoelectric axle sensor failures. One classifier received a software upgrade between the first and second test, but the upgrade apparently had a bug which was not detected until the data reduction. This bug resulted in errors in the data recorded which prevented meaningful data reduction. The weather conditions for the second 48-hour test were air temperatures ranging from 17 to 29°C (62 to 84°F), pavement temperatures ranging from 16 to 43°C (61 to 110° F), and no precipitation.

The augmented pneumatic tube test was conducted in parallel with the second 48-hour test. Two pairs of pneumatic tubes were used to monitor the traffic in both westbound lanes through the test site. One pair was used to monitor the outside (slow) lane, and one pair was placed across both lanes. The tubes were connected to a single classifier and configured as two separate lanes. The purpose of the test was to determine if the traffic in multiple individual lanes could be accurately monitored using the pneumatic tubes. Unfortunately, the classifier was accidentally configured to store only the sum of the two lanes, resulting in little of the desired information being collected. Currently, a repeat of this test is planned in conjunction with future tests.

The 7-day test was conducted in conjunction with the second 48-hour test. At the end of the second 48-hour test, the recording modes of the classification equipment were changed to record sums of the vehicles in each class every 15 minutes. This binned data was recorded for five more days. The data from each vendor's equipment for the first 48-hours of the test were converted to binned data and combined with the binned data from the last 5 days of the test to give a full seven days of binned data. This data was then used to compile long term statistics on the performance of each classifier.

Originally, a third 48-hour winter test was scheduled for this project. Unfortunately, construction to widen the interstate prevented the winter test from being conducted. The road construction resulted in the test site being paved over. A test is currently under way to determine if and how accurately the classifiers can monitor the traffic stream after the paving is completed.

DATA REDUCTION

The data reduction required for this project consisted of two phases for each test. The first phase, and perhaps the most time consuming, is the reduction of the video data to a baseline set of vehicles with classifications, length and axle spacings. The baseline set of data is referred to as the ground truth data for the test The second phase involves comparing the ground truth data to the data collected by each of the vendor's classification equipment.

Video data reduction from the pole camera is being accomplished using the Computer Vehicle Classification/Reduction System (CVCRS) developed by GTRI for this project. The CVCRS consists of a PC/486 computer with a video capture and processing card installed, a second VGA monitor, and a video cassette recorder (VCR). Custom software was written to allow a user to measure overall vehicle length, measure axle spacings, and classify each vehicle in an efficient manner.

Calibration marks in the test lane allowed the user to calibrate the CVCRS measurements and to correct for the viewing angle of the camera. The pole camera video tape of the traffic stream included a time stamp which was read by the CVCRS and stored with each vehicle record.. An initial classification of the vehicle is performed by the software based on the axle spacing. The user has the option of accepting or modifying the classification based on the written FHWA classification guidelines.

The accuracy of the measurements made by the CVCRS was tested using a specially marked and manually measured test vehicle provided by the GaDOT. The test vehicle was driven through the test site several times at varying speeds during the first 48-hour test. The tests revealed that the mean error of the CVCRS measurements was 6.1 cm (2.4 inches) and the standard deviation was 3.3 cm (1.3 inches).

Video data reduction from the lane change camera consisted of identifying vehicles which entered or exited the test lane within the length of the test site. The vehicles which did change lanes were removed from the ground truth data record for the 48-hour tests. The resulting data set included only vehicles which passed completely through the test site without changing lanes.

The second phase of the analysis began with the conversion of data from the specific formats of the individual members to a single, standard format for analysis. The results of the individual classifiers were then compared against the ground truth data and a statistical analysis performed. The object of the analysis was to answer the following questions: 1) How accurately do the various type of vehicle classifiers sort the traffic stream into each of the FHWA 13 vehicle types?; 2) For those vehicles that may be incorrectly classified by a device, into what class did the device place the vehicle?; 3) For those devices with the ability to measure axle spacing, how accurately monitored was the axle and distance information?; 4) For those vehicle classification devices that allow the operator to set the dimensional thresholds between various vehicle classes, how accurate were these devices as defined by points 1 through 3? [Note: FHWA scheme uses axle count and units to define vehicle classes, and not axle spacings.]; 5) How is equipment accuracy affected by vehicle speed?; 6) How is equipment accuracy affected by the percentages of vehicles with more than two axles in the traffic stream being measured?; 7) What is the impact of pavement and/or air temperature on the equipment accuracy?; 8) What is the impact of precipitation on the equipment accuracy (including wet pavement)?; 9) How accurately can devices monitor overall vehicle length as a function of vehicle speed, traffic volume, temperature, or vehicle mix?; 10) How is the device accuracy affected by the sensing device used?; and 11) Does accuracy change over time?

The binned data from the 7-day test was used to determine the long term accuracy of the classifiers tested. The total vehicles counted in each class and the number of axles counted were compared against the ground truth data for the 7-day test. Total count volumes and percent differences were compared to determine the counting accuracy of the classifiers. Also, statistics on the accuracy of the classifiers during the first day of the test were compared against the accuracy's during the last day of the test to determine if the accuracy was affected by the time in operation of the classifiers.

GENERAL RESULTS

In this paper, only the general results of the test will be discussed. The performance of individual classifiers cannot be released at this time. The results for each classifier will be included in a final report for the project due to be published in October 1994. This report will be widely circulated within the FHWA offices and the state DOTs.

Experiences from the installation and check-out of the sensors and classifiers resulted in several conclusions of interest. First, while the inductive loops caused no problems, roughly 1/3 of piezoelectric axle sensors installed failed and had to be replaced. Also, the in-pavement piezoelectric sensors were very sensitive to installation depth and the rigid sensors were difficult to install with even very slight rutting in the lane. These problems are not entirely unexpected and have been addressed in an earlier report (*2*). Often the classifier sensitivities had to be adjusted to obtain proper response for all type and sizes of vehicles.

Most of the classifiers tested worked without any or with very minor problems when they were first installed. Most, however, required some calibration or adjustment in order to optimize their performance. In some case, this adjustment required the devices to be opened to access internal adjustments while in other cases, the adjustments were made using software. This did show that many of the devices are not simply turnkey devices, but instead would require adjustments after installation. This would only be a minor problem if the devices were permanently installed or used for long periods of time, but multiple adjustments may be required.

The vehicle classifiers tested used axle spacing as their primary information for classification. As a result, it was very difficult for most classifiers to distinguish between long passenger cars (Class 2) and small pick-up trucks or minivans (Class 3). The analysis showed that errors between these two classes accounted for a majority of the classification errors.

Another problem that was anticipated was the misclassification of pole trucks, which are in Class 9 (tractor trailers), carrying utility poles or logs. The trailers on these units consist of a long metal beam between the trailer axles and the front of the trailer. It was anticipated that the classifiers would sometimes mistake the beam or pole for a gap between vehicles and classified the truck-trailer combination as two separate vehicles. Where a Class 9 vehicle (tractor trailer) was expected, the devices might sometimes classified it as a Class 6 (3-axle truck) and a Class 2 (car) vehicle. This problem turned out to occur only infrequently and did not significantly impact the results of the tests.

The classification accuracy of the devices ranged from 63% to 79% for these tests. If errors between Classes 2 and 3 are removed (classes combined), then the classification accuracy increases to between 82% and 97%. The primary factor affecting the classification performance of the devices tested was the reliability of the piezoelectric sensors to accurately count the number of axles on the vehicle. For this test, a sensor error was defined as an erroneous axle count on a vehicle. Figure 2 shows a plot of the classification accuracy of the devices as a function of the percentage of sensor errors. Also plotted is the same information with vehicle Classes 2 and 3 combined. Sensor error do not affect the classification accuracy between Classes 2 and 3 since both classes of vehicles have 2 axles.

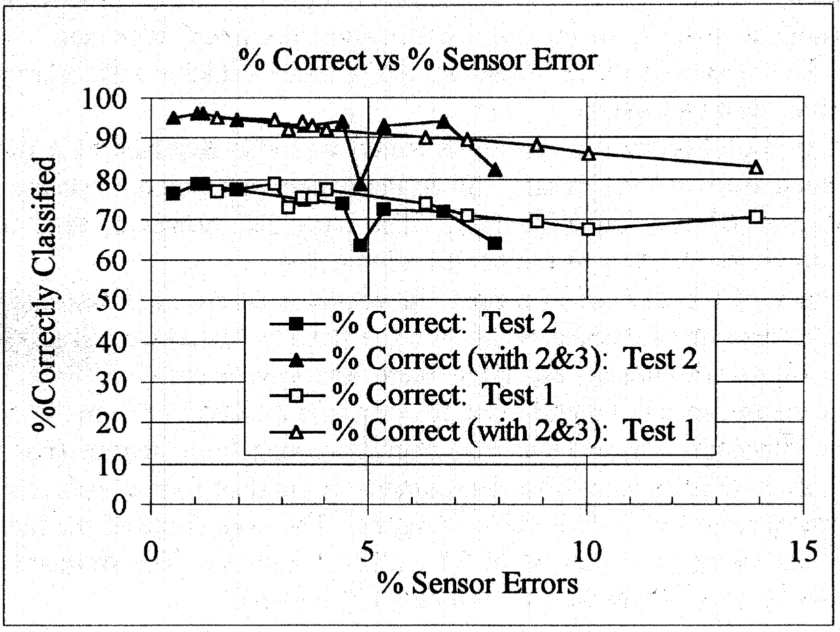

Figure 2. Classification Accuracy vs. Sensor Errors

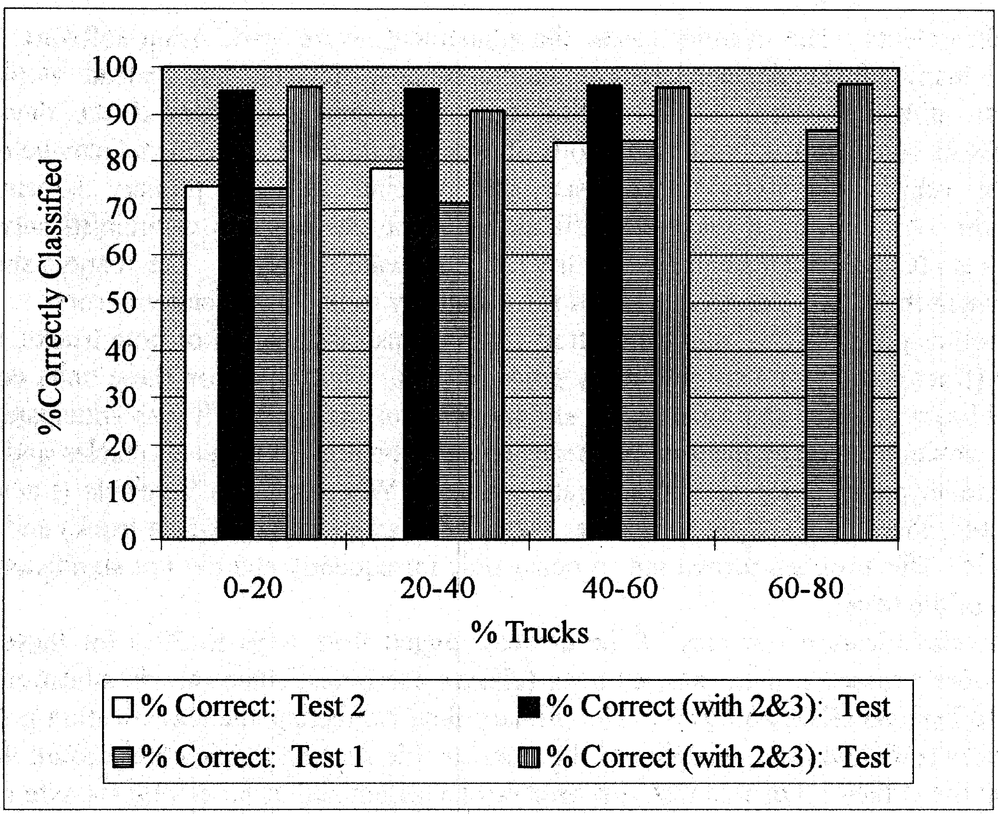

Figure 3. Classification Accuracy vs. % Vehicles With Greatger Than 2 Axles

The classifiers as a rule tended to most accurately classify standard tractor trailer vehicles (Class 9). Figure 3 demonstrates the classification accuracy of the devices tested as a function of the percentage of the vehicles in the traffic stream with greater than two axles (trucks). As the percentage of trucks increased, so did the classification accuracy, with and without combining Classes 2 and 3. This trend is a result of the fact that Class 9 vehicles were a large majority of the vehicles with greater than two axles.

The classification accuracy of the units tested was also assessed as a function of the air and pavement temperature at the test site. Since the winter test was not conducted, the range of temperatures experienced was rather limited. The data did, however, tend to show a slight reduction in classification accuracy as temperature increased.

The accuracy of the devices in measuring vehicle axle spacings was also assessed. The magnitudes of the mean measurement errors for the devices tested ranged from less than 1 cm (1/2 inch) to 13.4 cm (5.3 inches), but most were less than 6 cm (2.5 inches). The standard deviation the axle measurements ranged from 10.2 cm (4.0 inches) to 85 cm (33.5 inches).

For those classifiers which measured overall vehicle body length (not wheelbase), the accuracy of the measurements were also determined. A total of four classifier models recording data from 6 locations recorded overall vehicle lengths. The magnitude of the mean error of these devices ranged from 18 cm (7.2 inches) to 87 cm (34.2 inches). The standard deviation of the errors ranged from 66 cm (25.9 inches) to 348 cm (137 inches).

CONCLUSIONS

This study quantified the ranges of expected accuracies for the state-of-the-application vehicle classification devices (as of September 1992). It also provided information on axle spacing and overall length measurement accuracies for the classifiers. The installation and operation of the devices also provided valuable results. The overall results and conclusions for this project include:

- Piezoelectric axle sensor failures were a significant problem during and immediately after installation. A greater percentage of the flexible piezoelectric sensors failed than did rigid sensors.
- Piezoelectric axle sensors performance was the key factor in the overall classification accuracy of the devices tested. Even slight rutting in the lane caused significant problems in installation and operation of most axle sensors.
- All of the Classifiers required some adjustments after installation; some even required disassembly of the cases to adjust internal elements. None were turnkey devices.
- Classification errors were most common between Classes 2 (passenger cars) and 3 (pickups and minivans).
- The most accurately classified vehicle was the tractor trailers (Class 9), probably due to heavy axle loadings and unique axle configuration.
- The measurement of axle spacings was very accurate for most devices.
- Overall vehicle length measurement accuracies were less accurate due to the use of inductive loops to make the measurements.
- The augmented pneumatic tube test should be repeated due to a setup error.

For more information on the performance of individual classifiers tested, refer to the project final report due to be published in October 1994.

EARLY RESULTS FROM THE OVERLAY TEST

As of the writing of this report, the overlay test is in the early stages. At present, only the leveling course of pavement has been applied to the test site. The thickness of the leveling course ranges from about 1.3 cm (0.5 inches) to 2.8 cm (1.1 inches). Two more courses of pavement are planned for the test site: a 3.8 cm (1.5 inch) layer, and a 1.9 cm (0.75 inches) surface layer.

After the leveling course was applied, the sensor outputs were examined and the outputs of the classifiers were briefly assessed (no sensitivity adjustments made). The results of this early assessment included:

- The inductive loops were unaffected.
- The piezoelectric axle sensor outputs were reduced, but were still of reasonable level. The output signals tended to be more spread in time than before the overlay.
- Some of the piezoelectric sensors performed better after the leveling course had been applied. This is probably due to the improved contact with the sensor surface eliminating or reducing the affects of rutting.
- Several of the classifiers were still operational. The performance of the devices was significantly degraded for small vehicles.
- Some of the classifiers have sensitivity adjustments which may improve their performance.

The results of the initial tests after the leveling course was applied have been sent to the vendors. The vendors have been requested to send suggestions for improvement of the performance of their classifiers.

The remaining pavement layers are expected to be completed some time in the fall of 1994. After the pavement is complete, the plans are to perform a 4-hour test similar to the 48-hour tests performed for the project previously. The analysis will focus on the usability and accuracy of the devices after a sensor site has been paved over. The results are expected to be useful in the planning and maintenance of highway monitoring sites.

ACKNOWLEDGMENTS

This project is funded and directed by the Federal Highway Administration Office of Highway Information Management under the title "Accuracy of Traffic Monitoring Equipment." The FHWA funded the State of Georgia Department of Transportation to perform the study. The Georgia DOT contracted the Georgia Tech Research Institute to conduct the tests and analyze the results.

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(*1*) Wyman, J. H., Braley, G. A., and Stevens, R. I.. *Field Evaluation of FHWA Vehicle Classification Categories*. Technical Paper 84-5. Maine Department of Transportation, Final Report, December, 1984.

(*2*) Majdi, S. and Middleton, D., *Installation of Sites for Automatic Vehicle Classification*. Research Report 1901-1F. Texas Transportation Institute, November 1992.

USE OF DATA FROM CONTINUOUS MONITORING SITES

Mr. Herbert Weinblatt
Cambridge Systematic, Inc.

Presented at
National Traffic Data Acquisition Conference
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Use of Data from Continuous Monitoring Sites

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Abstract

Data from continuous monitoring sites in four states were used to simulate short-duration volume counts and to evaluate the effectiveness of various procedures for factoring these counts to estimate annual average daily traffic (AADT). Some of the findings are:

- Well-designed factoring procedures can reduce errors in AADT estimates by about 40 percent;
- Factor groups that reflect geographic variations in day-to-day usage patterns tend to work better than those that are based primarily on functional systems;
- The conventional distinction between an "Urban Interstate" factor group and an "Other Urban" factor group is of little value;
- Weekday 48-hour volume counts produce estimates that are only slightly better than those produced by weekday 24-hour counts; and
- Factors derived from data collected during the same year as the counts are taken work appreciably better than factors derived from data collected in earlier years.

Estimates also were made of the significant overestimates produced by existing procedures for deriving truck AADT from 48-hour weekday classification counts. It is recommended that these overestimates be controlled by using separate factors for truck classes or by collecting classification counts on both weekends and weekdays.

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Most of the material to be presented in this paper comes from a recently completed study of the *Use of Data from Continuous Monitoring Sites* performed for the Federal Highway Administration (FHWA) (*1*). Some additional material was produced in the course of developing a new traffic monitoring system for the Virginia Department of Transportation (VDOT) (2). All results are presented in more detail in Volume II of the FHWA study.

The primary focus of the paper is on the effectiveness of procedures for estimating annual average daily traffic (AADT) from short-duration traffic counts. In addition, the paper touches more briefly on the imputation of missing data for continuous automatic traffic recorder (ATR) stations, and the estimation of AADT by vehicle class.

AADT ESTIMATION

AADT estimation procedures were evaluated using actual and imputed traffic data for 1992 from 183 continuous ATR stations in four states: Colorado, Illinois, Nebraska and Washington. For each ATR station, each factoring procedure was tested by:

1. developing factors using data from all *other* ATR stations in the factor group;
2. applying the appropriate factors to each of the simulated coverage counts for the station in question; and
3. comparing the resulting AADT estimates to the station's "actual" AADT as indicated by the available actual and imputed daily counts for the station.

The evaluation procedure was applied to approximately 15,000 simulated weekday counts covering 48-hour periods starting at noon on Mondays, Tuesdays and Wednesdays.

Effects of Alternative Factoring Procedures

Seven different factoring procedures, listed in Exhibit 1, were tested and evaluated, as was the use of unfactored 48-hour counts as estimates of AADT. Procedure 4, Combined Month and Day-of-Week Factoring, is the procedure recommended by the American Association of State Highway and Transportation Officials (AASHTO) and used by most states. Procedure 5, Combined Week and Average Weekday Factoring, uses a separate "average weekday" factor for each of the 52 weeks in the year. Procedure 6, Specific-Day Factoring, uses 365 separate factors, one for each day of the year.

As Exhibit 1 shows, **all seven factoring procedures produce substantially better estimates of AADT than the use of unfactored 48-hour counts;** and **differences in the quality of the estimates produced by the different procedures are relatively small.** The percentage mean absolute error (MAE) for the unfactored AADT estimates is 12.4 percent, but it drops to 7.0 to 7.6 percent when a factoring procedure is used. Over 18 percent of all the unfactored estimates have errors over 20 percent, but only about 5 to 6 percent of the factored estimates have such large errors. The error estimates shown in Exhibit 1, and in the rest of this paper, are biased slightly upwards (probably by about 0.2 to 0.3 percentage points) as a result of the evaluation procedure used.

Effects of Factoring by Type of Factor Group

Exhibit 2 shows the effects of factoring by type of factor group. The top part of the exhibit indicates that, as would be expected, the best estimates of AADT are obtained for urban factor groups and the poorest for the recreational groups. **Of the 25 factor groups used by these four states, only two groups (both of which are urban) produce AADT estimates that meet the *Traffic Monitoring Guide* (3) goal of 10 percent precision with 95 percent confidence.** The exhibit also shows (in the column labeled "Average Error") that **use of unfactored weekday counts tends to result in overestimating AADT on urban sections and underestimating AADT on rural and recreational sections** -- though these biases are largely eliminated when factoring is used.

The bottom part of Exhibit 2 shows the effects of changing the factor groups that are used. Three of the four states use either separate recreational groups or groups that incorporate some geographical distinctions. The last line of the exhibit shows the effects of eliminating the recreational groups and all geographic distinctions while increasing the number of functional systems distinguished (generally from four to six or seven). The change produces some deterioration in the quality of the AADT estimates, especially for Colorado, indicating that **recreational and geographically defined groups are more effective than functional-system groups.**

Exhibit 1. Effects of Alternative Factoring Procedures on AADT Estimates

	Mean Absolute Error	Average Error	P (E > 20%)	Number of Factors Required for	
				Weekday Counts	Weekday and Weekend Counts
Unfactored	12.4 %	-0.6 %	18.2 %		
1. Separate Month and Day-of-Week	7.5	-0.5	6.2	17	19
2. Combined Month and Average Weekday	7.6	+0.4	5.9	12	24
3. Separate Week and Day-of-Week	7.5	-0.9	6.0	57	59
4. Combined Month and Day-of-Week	7.4	-0.2	5.8	60	84
5. Combined Week and Average Weekday	7.3	+0.5	5.1	52	104
6. Specific Day	7.1	+0.2	5.1	261	365
7. Specific Day with Noon-to-Noon Factors	7.0	+0.3	4.8	261	365

Exhibit 2. Effects of Factoring on AADT Estimates by Factor Group

	Mean Absolute Error	Average Error	P (Error >10%)	P (Error >20%)
Urban Groups				
Unfactored	7 - 9%	+0.8 - +6.5%	24 - 44%	1 - 4%
Factored	4 - 7	+0.2 - +0.9	3 - 24	0.1 - 2
Rural Groups				
Unfactored	8 - 19	-13 - +1.4	32 - 71	6 - 39
Factored	5 - 10	-1.5 - +2.1	6 - 43	0.7 - 12
Recreational Groups				
Unfactored	13 - 36	-15 - -5	53 - 90	20 - 77
Factored	9 - 20	-3.0 - -0.5	38 - 69	7 - 38
Overall Average				
Unfactored	12.4	- 0.6	48	18.2
Factored Using Current Groups	7.6	+ 0.5	24	5.9
Factored Using Functional Systems	8.4	+ 0.5	29	8.3

All factoring performed with the current-year "Combined Week and Average Weekday" procedure and, except as noted, the factor groups currently in use in the four states.

Exhibit 3. Effects of Alternative Urban Factor Groups on AADT Estimates

	Separate Groups	Combined Group
Urban Interstate		
Percent MAE	4.8%	4.7%
P (Error > 20%)	0.9	0.9
Urban Other		
Percent MAE	4.9	4.8
P (Error > 20%)	10	1.0

All factoring performed with the current-year "Combined Week and Average Weekday" procedure.

Urban Groups

Exhibit 3 compares the quality of AADT estimates produced when separate "Urban Interstate (IS)" and "Other Urban" factor groups are used with those produced when the IS/other distinction is dropped. As can be seen, there is virtually no difference in the quality of the estimates, suggesting that **the use of separate "Urban IS" and "Other Urban" groups is an inefficient use of resources.** We suggest that states wishing to use more than one urban factor group consider using three: "normal"; "low weekend" (covering industrial areas and portions of the Central Business District with relatively low weekend traffic); and "high weekend" (covering roads that provide access to suburban retail complexes).

Counting Periods

Exhibit 4 compares the results of using simulated 48-hour counts with those produced with simulated 24-hour counts. The shorter counts produce only a slight increase in the MAE (from 7.4 percent to 7.6 percent), but a somewhat larger increase in the percentage of errors that exceed 20 percent (from 5.8 percent to 7.2 percent). Most of the deterioration actually occurs on roads with low to moderate traffic volumes, with the difference between 24 and 48-hour counting being fairly insignificant for high-volume roads. We conclude that **the longer counting period has only a minor effect on the accuracy of estimates of total AADT,** though 48-hour counting periods make it possible to check the consistency of the results for the separate 24-hour periods and to use hourly data from one 24-hour period to replace missing hourly data from the other period.

Exhibit 4. Effects of Alternative Counting Periods on AADT Estimates

	Mean Absolute Error	Average Error	P(Error > 20%)
48 Hours	7.4%	-0.2%	5.8%
24 Hours	7.6	-0.3	7.2

All factoring performed with the current-year "Combined Week and Average Weekday" procedure.

"Historic" Factors

All results reported in Exhibits 1 through 4 were developed using "current-year" factors; i.e., they were developed for the year in question (1992) using factors derived from actual and imputed data for that year and applied to short counts collected in that year. AADT estimates for a given year using current-year factors cannot be developed until after the year is over. A few states develop such estimates early in the following year and also develop preliminary estimates of AADT using factors derived from continuous counts collected in the preceding year. However, most states only use factors derived from data collected during earlier years, frequently using three to five years of data.

Exhibit 5 compares the effectiveness of applying current-year factors to simulated 48-hour counts for 1992 with that of using two-year-old "historic" factors. The results are presented for Illinois and Nebraska, the only two states for which we had 1990 data.

Exhibit 5 indicates that historic factors do not work as well as current-year factors -- current-year factors reduce the MAE from 10.1 percent (without factoring) to 6.8 percent, but the historic factors reduce MAE only to 8.2 percent. Also, although current-year factors produce an insignificant average error of -0.2 percent, the 1990 factors produce an average error of +3.5 percent -- indicating a relatively strong upward bias in the AADT estimates. This result indicates that, between 1990 and 1992, weekday traffic grew appreciably faster than weekend traffic, probably in part due to a recession-induced drop in weekday traffic in 1990. The uneven growth rates between weekday and weekend traffic were probably also the principal reason why the historic factors were less successful than the current-year factors in improving the other error statistics.

The results presented in Exhibit 5 suggest that final AADT estimates probably should always be derived using current-year factors. If preliminary estimates are required for planning or design purposes, these estimates may be obtained using historic factors, preferably for the preceding year only. Alternatively, preliminary estimates may be

Exhibit 5. Effect of "Historic" and "Current-Year" Factors on AADT Estimates for Two States

	Mean Absolute Error	Average Error	P (Error > 20%)
Unfactored	10.1 %	+0.5 %	11.4%
Current-Year Factors	6.8	-0.2	4.1
Historic Factors	8.2	+3.5	5.8

Based on application of "Combined Month and Day-of-Week" procedure to 48-hour counts from Illinois and Nebraska.

derived using data for any 12-month period that incudes the dates on which the count to be factored was taken (e.g., September 1994 counts could be factored using data for the period October 1993 through September 1994). This last alternative should produce values that are good estimates of AADT for the 12-month period represented by the data used for developing the factors.

IMPUTATION

The AASHTO procedures for estimating AADT and for deriving monthly average day-of-week factors (4) require the averaging of daily traffic volumes for each day of the week in each month. For a given day of the week, say Tuesday, and a given month, this procedure can be used even if data is available for only one Tuesday in the month. When data is missing for any Tuesday, the procedure effectively assumes that the average traffic volume on the missing Tuesdays is the same as the average for the Tuesdays that are not missing. Thus, the AASHTO procedure *implicitly imputes* traffic volumes for the missing days.

Exhibit 6 presents the results of an evaluation of the accuracy of the AASHTO implicit imputation procedure. In this evaluation, actual counts for non-holiday weekdays were compared to the values that would be implicitly imputed by the AASHTO procedure if the counts were not available. All imputed counts for any day, say a Tuesday, were obtained using data from three or four other non-holiday Tuesdays in the same month. Approximately 20,000 counts for non-holiday weekdays were imputed and evaluated, using 1992 data from Illinois and Washington State.

Exhibit 5. Effect of "Historic" and "Current-Year" Factors on AADT Estimates for Two States

	Mean Absolute Error	Average Error	P (Error > 20%)
Unfactored	10.1 %	+0.5 %	11.4%
Current-Year Factors	6.8	-0.2	4.1
Historic Factors	8.2	+3.5	5.8

Based on application of "Combined Month and Day-of-Week" procedure to 48-hour counts from Illinois and Nebraska.

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Exhibit 6. Precision of Imputed Values for Non-holiday Weekday Counts

50% Confidence Interval	±3.5%
80% Confidence Interval	±8.0%
90% Confidence Interval	±12.5%

Exhibit 6 indicates that approximately half the implicitly imputed counts differed from the actual counts by no more than 3.5 percent, and about 80 percent of these counts differed from the actual counts by no more than 8 percent. When interpreting these results, it should be borne in mind that, if only one Tuesday count is missing for a month with four Tuesdays, a 4 percent error in the value used for the missing count produces only a 1 percent error in the resulting Tuesday factor for that month. We attempted unsuccessfully to design a reasonably simple explicit imputation procedure that would work better than the AASHTO implicit procedure.

Although the AASHTO implicit imputation procedure appears to be the best procedure for handling data for missing *days*, when data is unreliable or missing for only a *few hours*, use of the AASHTO procedure introduces more error than necessary. **When only a few hours of data are unreliable or missing, it is preferable to impute data for those hours explicitly.**

ESTIMATING AADT BY VEHICLE CLASS

Finally, we turn to the estimation of AADT by vehicle class. Exhibit 7 summarizes information about the quality of AADT estimates by vehicle class derived from 30 sets of simulated 48-hour weekday classification counts obtained at two moderately dissimilar Strategic Highway Research Program sites on I-64 in Virginia.

The first column of Exhibit 7 shows the average error obtained when unfactored 48-hour counts are used as estimates of AADT by vehicle class. Use of unfactored weekday counts results in a consistent tendency to overestimate AADT for buses and for the four groups of truck classes distinguished, with overestimates averaging 27 to 29 percent for the three heaviest sets of truck classes. The overestimates occur because operation of vehicles in all these classes generally is much higher on weekdays (when the counts are being collected) than on weekends. On the other hand, the unfactored weekday counts produce a tendency to underestimate total AADT and AADT of four-tire vehicles -- indicating that, at these two sites, both total traffic volume and the volume of four-tire vehicles increase on weekends.

Exhibit 7. Quality of AADT Estimates by Vehicle Class

Vehicle Classes	Unfactored	Distributed	Factored	
	Average Error	Average Error	Average Error	MAE
2-3. 4-tire vehicles	-11%	-4%	+0.1%	19%
4. Buses	+13	+26	+0.5	23
5. 2-axle, single-unit trucks	+5	+16	-0.9	31
6-7. 3+ axle, single-unit trucks	+29	+38	+28.9	52
8-10. Single trailer trucks	+28	+40	+1.0	5
11-13. Multiple trailer trucks	+27	+37	+0.4	9
All vehicles	-8%	0%	+0.4%	19%

An alternative to the use of unfactored classification counts as estimates of AADT by class is to use unfactored counts as the basis for distributing factored estimates of total AADT across vehicle classes. This procedure frequently is used to estimate AADT by vehicle class. The second column of Exhibit 7 shows that, for the two Virginia sites, this procedure produces a somewhat greater tendency to overestimate truck and bus AADT. In general, such an increase will occur at sites at which unfactored weekday counts tend to underestimate total AADT, and the reverse will occur at sites at which unfactored weekday counts tend to overestimate AADT.

The above discussion indicates that **the procedures currently being used in many states tend to produce consistent overestimates of truck AADT and, accordingly, produce similar overestimates of truck vehicle-miles of travel (VMT).** This finding explains why FHWA estimates of truck VMT have been found to be higher than estimates derived from the sources (*5*).

Finally, the last two columns of Exhibit 7 show the results of developing separate sets of month and day-of-week factors for each of the six sets of vehicle classes, and applying these factors to the corresponding 48-hour weekday classification counts. These columns indicate that **factoring has little or no effect on the quality of AADT estimates for single-unit trucks with three or more axles.** However, *for all other vehicle classes*, the factored counts produce AADT estimates with *average* errors of no more than 1.0 percent, though their mean absolute errors are fairly significant (ranging from 5 percent for single-trailer combinations to 31 percent for six-tire trucks). This result indicates that, **for these vehicle classes, factored weekday counts can produce relatively unbiased estimates of AADT by class, though the individual estimates may reflect a moderate to significant amount of error.**

The relative lack of bias in the estimates of AADT by class suggests that the individual errors will tend to cancel when a large number of AADT estimates are used. Accordingly, **for these vehicle classes, VMT estimates derived from factored AADT estimates are likely to be reasonably good and they will be free of the upward bias that results when unfactored weekday counts are used.** Other alternatives for producing unbiased estimates of VMT by vehicle class are to derive these estimates from an appropriate mix of weekday and weekend classification counts or to perform all short-duration classification counting over a period of seven days.

ACKNOWLEDGEMENT

A number of people contributed to the work reported here. The analyses were performed by Richard Margiotta of Science Applications International Corporation, Carolyn Frank of Information Systems and Services, Inc., and Daniel Haling of Cambridge Systematics. Mark Hallenback, of the Washington State Transportation Center, provided a substantial amount of insight into practical considerations in the collection, interpretation and factoring of traffic data; and additional guidance and insight were provided by our project monitors: Tony Esteve of FHWA and James B. Robinson and Eugene Martin of VDOT.

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CONCURRENT SESSION, TRAFFIC DATA QUALITY

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SUMMATION: CONCURRENT SESSION, TRAFFIC DATA QUALITY

Mr. Frederick P. Orloski
FHWA Region 1, Albany

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Frederick P. Orloski, FHWA Region 1, Albany

I moderated Session 1B which was on traffic data quality. We had two presentations and a panel discussion. Each of the panelists also gave presentations. We had some time for discussion during that session.

The first presentation by [Richard] Reel, [from Florida DOT], talked about his efforts to develop a procedure for the polling and editing of their data. They developed a procedure because of the increased amount of data they were getting recently. They are up to some 200 stations with their polling every night. This, I think, was for volume data. He mentioned the process they were using previously. Before it took several people one month to process the data, edit it, and verify it. What they developed is an automated procedure that takes one person one week to edit the data; so, it gets edited quicker with less time. It also applies to their classification data and truck weight data. He gave some statistics on the truck weight data; for example, approximately 10 percent to 30 percent of the data they receive fails their edit test.

The State of Colorado has developed [an] expert system for editing their data. [Gregory] Fulton, [from Colorado DOT], and George Hovey, [from In Motion, Inc.], talked about the development and implementation of that system. [It] is an expert system based on knowledge of some engineering principles. [The work] consisted of documenting their existing procedures and developing some rules of thumb and procedures for engineering analysis [that] they would apply to every station and all the data that came in. Their procedure basically consisted of developing a spreadsheet where the end result of the spreadsheet would automatically highlight either an hour, a lane or a group of data that was suspect. It was easy for the data reviewer to pick [up] that item or element of the data and do further analysis. What they developed that was unique was a graphic presentation of historic data showing the ranges in means for each hour or each vehicle class; however they wanted to display the data. They would show historic data on top of the current station data that they are editing to see how it would fit into historic trends. It was really easy to get a quick picture of whether the data was reasonable or not, based on historic trends.

The next item was a panel discussion by three states and by the SHRP contractor on developing editing procedures for SHRP data. The three states that presented their procedures [were Virginia, Minnesota and California]. Gene Martin, from Virginia [DOT], talked about his common sense approach to editing their approximately 12 to 15 SHRP locations. His common sense approach is based on the understanding of static versus dynamic weights and the relationship between the two. One thing he emphasized was for static weights the standards allow for 0.2% variability, which on an 80,000 ton vehicle is 160 pounds, whereas the standards for WIM data allowed for a 10 percent to 20 percent variability, which could be 8,000 to 16,000 pounds variability. So there is quite a difference in standards between static and dynamic.

Minnesota procedures were discussed by Mark Flinner, [from Minnesota DOT], which focused on knowledge of five-axle semis or class 9 vehicles. They focused on this class because it was the most important vehicle. They looked at weights of unloaded and loaded vehicles.

California procedures were discussed by Rich Quinley, [from California DOT]. He talked about validating data depending on such things as roughness, the calibration of equipment and the operation of the equipment. They were focusing on speed data during their validation processing. They looked at speed versus the weights that were being collected, and they found that at approximately the 50-55 mph speed limit data was produced that had the least variability. In that range, the variability was roughly 5 percent to 10 percent. He went on to further describe the two-level review process. The first level looks at identifying loop problems and things out in the field that could go wrong. The second level review was concerned about weight calibration, the axle spacing and the length data that was being collected.

The final presentation on the panel was by Mark Hallenbeck, [from Washington State Transportation Center], who talked about his efforts with SHRP to develop an editing process for SHRP data. He started by saying, that when SHRP got started seven or eight years ago, we all assumed that the states would buy weigh-in-motion equipment. It would be available, reliable and low-cost. That was the goal of SHRP seven or eight years ago. Well, we all know that we are far from that today in many states. So we need to look at the data. Basically, SHRP does not want states to be adjusting the data based on professional judgment. They wanted some documented procedure that all the states could use. The goal of SHRP was to develop this procedure to save costs in the quality assurance testing of the data and also to assure that the data submitted would be accurate. The quality assurance testing procedures that they are developing look at the calibration of the data and the vehicle volume by class. The basic concept was to identify unexpected values by sight and by weighing and then to provide information needed to determine if the unexpected values are valid or not. The expected values must be lane-specific based on class 9 vehicle weight distributions. SHRP is only going to provide a tool, one of the many tools that can be used by states to edit the data. It [will not] say that, once you go through SHRP procedures, your data is accurate. It is just a tool, and [the goal is] to get this information out by the spring of 1994.

This session [concluded with] some discussion on what data should states actually be sending SHRP. First, SHRP said that they did not want states to edit data at all. I think most states took it at face value and just sent whatever data they collected into SHRP. SHRP now is saying that if you know the data is bad, in other words, if there are zeros in the data because the equipment was not working, you should not be sending that data into SHRP. We do not really want data that does not have any vehicles associated with it. It is really not useful. I think that is a little change for some states because they were just routinely sending it in.

AUTOMATED EDITING OF TRAFFIC DATA IN FLORIDA

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AUTOMATED EDITING OF TRAFFIC DATA IN FLORIDA

Richard L. Reel, Jr., P.E.
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SUMMARY

Florida has implemented a system of programs that automatically poll each of the continuous traffic monitoring stations every night and automatically process the data collected. The polling routine automatically begins at 1:15 AM each night. It distributes the approximately 200 phone calls required to query each field counter among seven telephone lines. A CHECKSUM error protocol is used to ensure that the computer captures the exact same data that the counter sends. After receiving a station's data, the processing program examines the data to ensure that the station and date are valid, 24 hours of data are available for all lanes, and that none of the lane volumes exceed a specified maximum. If the data fails any of these checks, the computer will re-poll this site. If a site's data cannot be captured within 3 attempts, the site is written to an error report. All sites that failed to successfully poll can be manually re-polled by a system manager the next morning, if desired. Usually all polling is completed by 6:30 AM.

Successfully captured data is summarized by station, date and direction, and written to a database. An editing program examines the database and determines whether the data is good or bad. Count records are edited for consecutive hours of zeroes or the same volume, maximum hourly volumes based upon the number of lanes, and whether the new counts (daily and hourly) fall within reasonable ranges of previously accepted counts for the same station. Class records are edited for an excessive amount of unclassified vehicles and whether the volume of vehicles in each classification group are about the same as previously accepted values. Edits to WIM data are performed against the individual vehicle records. The WIM records are edited for proper classification, offscale, vehicle length, gross weight, axle weights, axle spacings, wheelbase, and vehicle speed. Only those records passing all edits are passed to the program that calculates the 18 Kip Equivalent Single Axle Loads and places them into the database.

AUTOMATED EDITING OF TRAFFIC DATA IN FLORIDA

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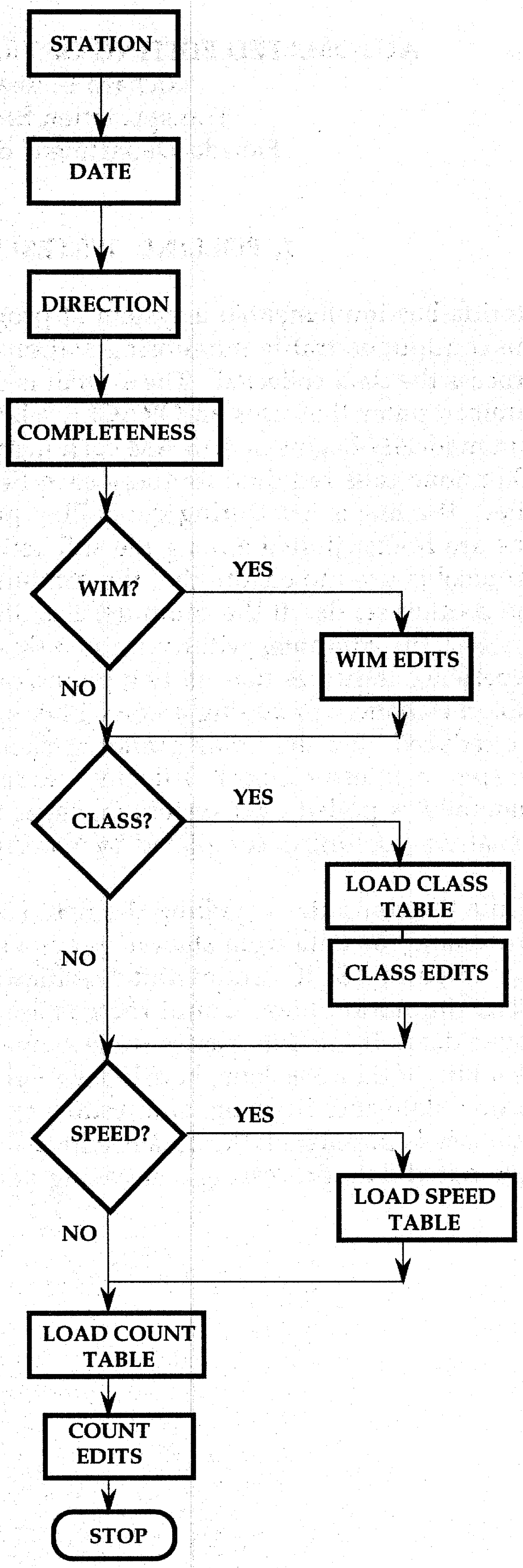
1. POLLING SYSTEM INTRODUCTION

Florida has implemented a system of programs that automatically poll each of the continuous traffic monitoring stations every night and automatically process the data collected. The system is designed to operate on a VAX minicomputer that uses an ORACLE relational database. The polling routine automatically begins at 1:15 AM each night. It distributes the approximately 200 phone calls required to query each field counter among seven telephone lines. If a line is lost during the polling process, the stations allocated to that line are re-distributed among the still active lines. A CHECKSUM error protocol is used to ensure that the computer captures the exact same data that the counter sends. If the computer has difficulty capturing the data from a counter, the computer will try up to 3 times to download the data. Our experience indicates that no two phone calls are routed along the same lines, thus the chances of getting a noisy phone line the second time a site is called are reduced. If a site's data cannot be captured within 3 attempts, a message is written to an error report. All sites that failed to successfully poll can be manually re-polled by a system manager the next morning, if desired. Usually all polling is completed by 6:30 AM.

While the computer is polling the field counters for their data, it is also processing the data from stations previously captured. All binary files are converted to ASCII. Count and classification records are generated from weigh-in-motion files. Count records are generated from classification or speed data. If the data passes some elementary edits (valid station, valid date, 24 hours of data per lane, hourly lane volumes < 9999) it is summarized by station, date and direction, and written to the database tables. Once the database is populated, the data is edited for quality. Figure 1.1 illustrates the automated data processing concerning data quality control.

FIGURE 1.1 POLLING EDIT PROCESS



2. COUNT EDITS

In an effort to conserve the amount of database storage required to save the continuous count data, a decision was made to place only a single flag on each daily record. This saved millions of bytes of valuable online storage by not adding a flag to each hour. In order to indicate if the hour's data is BAD, the incorrect data is replaced with a -1. Since all traffic volumes must be positive numbers, it is a simple matter to weed out the bad data when performing end-of-year calculations. The edit program can be run automatically each night as the data is polled, or can be executed manually. As we are unable to manually review on a daily basis all of the potential errors found by the program each night, we routinely manually submit the editing program. When the editing program is submitted manually, the program asks for the beginning and ending dates of the records to be reviewed. We usually edit seven days of data at a time. Figure 2.1 is a flowchart of the count editing process.

Edit for Zeros

The first edit of the traffic count data is for the occurance of 0's. Since low volume highways may experience no traffic during the early hours of the night, this edit is restricted between the hours of 5:00 AM and Midnight. Between these active hours, the program searches for four consecutive hours each having a count of zero. If such an occurance is found, the record is flagged BAD and further processing stops.

Consecutive Hours with Same Volume

The second traffic count edit is for four consecutive hours of the same non-zero count. If an occurance of this type is found, the record is flagged BAD and processing stops.

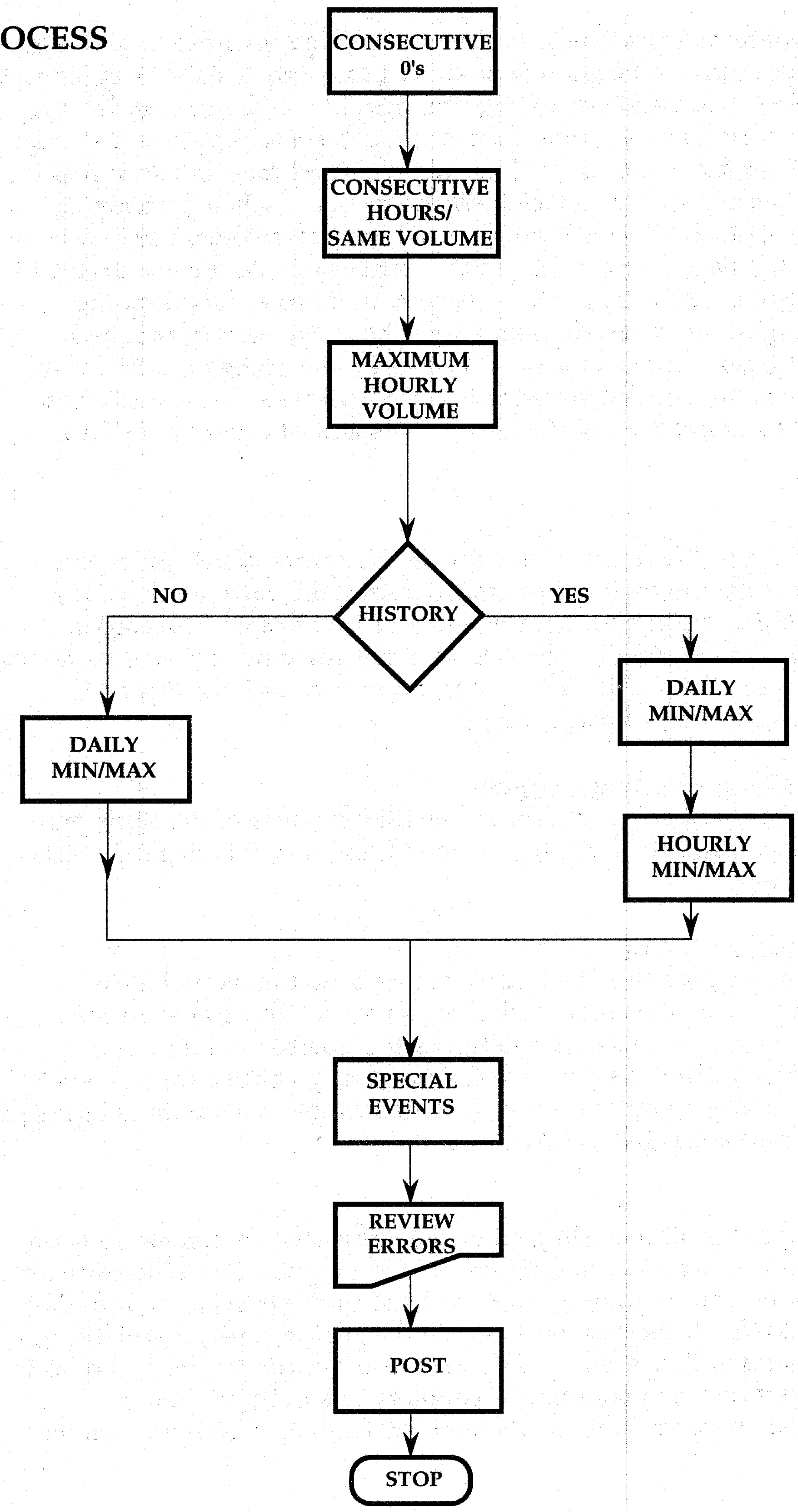
Maximum Hourly Volumes

The third edit makes sure that the hourly volumes do not exceed 2500 vehicles per lane. Since the count data is summarized and stored in the database by direction, the program multiplies the number of lanes in a direction at a site by 2500 to set the maximum hourly volume for that site's direction. Any hourly count that exceeds the allowable maximum is changed to -1, and the record is flagged as BAD.

Daily Edits

If the count has passed all preceding edits, the daily count is compared to an average count for the same station, direction, and day of week. The software is designed to only look back for up to 8 weeks to find four records from days flagged as NORMAL. If the program can't find 4 such records, it will average what it can, either 3 or 2 or even 1. If no historical records can be found, as is the case for newly installed continuous counters, the daily volume is compared against an upper limit of (Number of lanes X 25,000) and a lower

FIGURE 2.1
COUNT
EDIT PROCESS



limit of (Number of lanes X 200). If an historical average daily count can be calculated, the daily volume is compared to it. If the count falls within a certain band around the average, the count is flagged NORMAL. If the count falls outside the NORMAL band, but within the outer permissible limits, the daily count is flagged as ATYPICAL. If the count falls outside of the maximum allowable limits, the daily count is flagged as BAD. The upper and lower limits are selected depending upon the value of the historical average. The higher the average count, the lower the tolerance allowed. Figure 2.2 shows the limits and volume ranges currently being used to edit the daily directional counts.

FIGURE 2.2 DAILY DIRECTIONAL VOLUME EDIT CRITERIA

AVERAGE VOLUME	NORMAL RANGE	ATYPICAL RANGE
<2000	+- 20%	+- 40%
2000 - 9999	+- 15%	+- 30%
10000 - 25000	+- 10%	+- 20%
>25000	+- 5%	+- 10%

Hourly Edits

If there is sufficient historical data available for use in setting the standard against which the new count is edited, after the total daily directional volume is edited each of the directional hourly volumes are then edited. This edit is performed on each hour, regardless of any flag that has been assigned by the daily edit. The purpose of this edit is to catch all hours that may be bad but whose overall impact doesn't radically change the daily volume. Figure 2.3 shows the edit criteria used for the hourly directional volume edits.

FIGURE 2.3 HOURLY DIRECTIONAL VOLUME EDIT CRITERIA

AVERAGE VOLUME	NORMAL RANGE	ATYPICAL RANGE
<100	+- 30 VEH	+- 50 VEH
100 - 200	+- 30%	+- 60%
201 - 1000	+- 20%	+- 40%
>1000	+- 10%	+- 20%

If the historical average is less than 100, a count within 30 vehicles of the average is flagged as NORMAL. A count greater than 30 but less than 50 from the average is flagged as ATYPICAL, and a count that differs from the average by more than 50 vehicles is considered BAD. Again, wider tolerances are allowed for the lower volume groups, because experience has shown them to have the most variable volumes. Any hourly count that is determined to be

BAD is changed to a -1, and that day's record is flagged as BAD if not previously flagged as such. An example of the hourly count edit is shown in Figure 2.4.

FIGURE 2.4 HOURLY COUNT EDIT EXAMPLE

STATION 132 -- I95, 2 MI S OF STATE LINE

? Is a count of 1073 for 11:00 - 12:00 on 6/16/94 for the Southbound direction good?

Program retrieves 4 prior same hour, same day-of-week NORMAL counts:

PRIOR	DATE	COUNT
1	6/9/94	976
2	6/2/94	1003
3	5/26/94	970
4	5/19/94	869

Program computes the average: 955

Program computes decision bands around the average:

NORMAL	=	+- 20%	=	+- 191
ATYPICAL	=	+- 40%	=	+- 382

0 - 572	=	BAD	
573 - 763	=	ATYPICAL	
764 - 1146	=	NORMAL	
1147 - 1337	=	ATYPICAL	
1338 - 5000*	=	BAD	(*= 2 LN X 2500 VEH/LN)

The count of 1073 falls within the NORMAL range of 764 - 1146. The program therefore decides this is a good count.

Special Events

The last automated edit to the count records compares the station and date to a special events table. This table allows the system manager to enter the dates for holidays when traffic is expected to be lower or higher than normal, such as Thanksgiving, Christmas, Memorial Day, Labor Day, and Independence Day. It also allows the system manager to enter the dates of events that only affect selected continuous counters, such as the Apalachicola Seafood Festival, Calvary (Ga.) Mule Day, University of Florida home football game, etc. Only the records considered as NORMAL or ATYPICAL are edited for special events. The counts for any station falling within the dates for the Special Events table are flagged ATYPICAL.

Final Review
All records that have been marked ATYPICAL or BAD are written to a hold file for final review. A printout of all ATYPICAL and BAD records is provided to the system manager for use in reviewing these records. If, in the judgement of the reviewer, a record has been incorrectly marked ATYPICAL or BAD, the reviewer can call up the record in question on a formatted screen and change the flag. If the edit program has changed any hourly counts to -1, the reviewer can change these numbers back to their original values. After all manual corrections are made to the review file, the contents of this file are then written to the database.

3. CLASS EDITS

Vehicle classification survey data is edited to catch the obviously bad records. At this time, we have insufficent experience with class data to attempt to distinguish between NORMAL, ATYPICAL, and BAD data, so if the data is obviously BAD it is flagged as such; otherwise it is flagged as NORMAL. Figure 3.1 is a flowchart of the class data editing process.

Check Counts
The first step in editing vehicle classification data is to examine the count database for the same station, direction, date. If a matching count record has previously been flagged as ATYPICAL or BAD, that flag is pulled over to the class record, and the program moves to the next record.

Group Classes
Those class records not flagged as ATYPICAL or BAD are passed to a program that groups the 15 vehicle classifications (13 FHWA Scheme "F" categories plus a 14th state specified and a 15th unknown) into just 7 categories. This consolidation is undertaken because the numbers of vehicles in each classification can be quite small, and thus quite variable. By combining certain classes, the numbers of vehicles per group are increased. Hopefully the larger groups are less variable in their volumes and allow automated editing. The seven classification groups used for editing are: motorcycles, passenger vehicles, single unit trucks, single trailer trucks, twin trailer trucks, very large trucks, and unknown vehicles. The classes of vehicles in each of these groups are shown in Figure 3.2.

FIGURE 3.1
CLASS
EDIT PROCESS

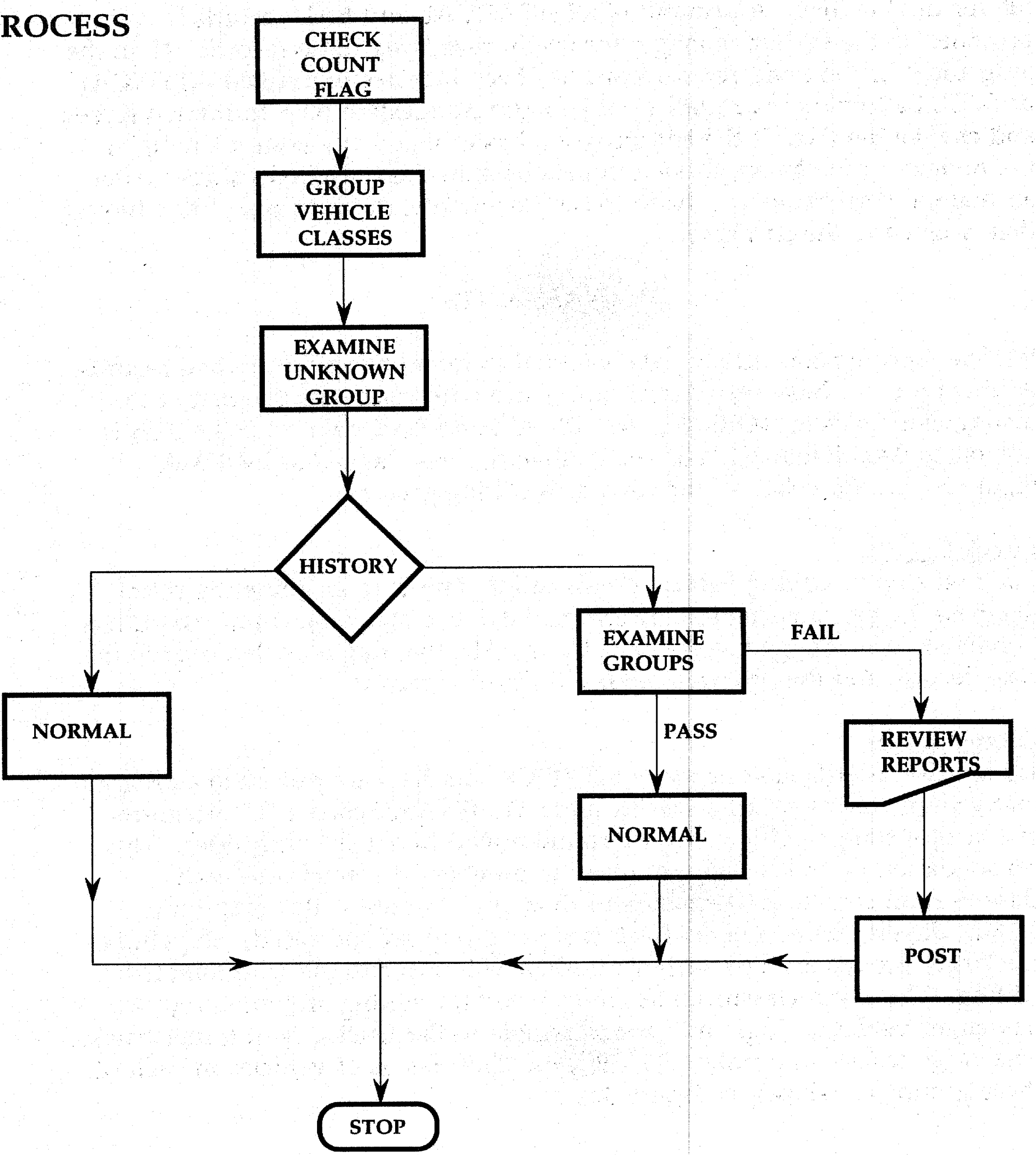


FIGURE 3.2 CLASS EDIT GROUPS

GROUP	VEHICLE CLASSES
MOTORCYCLES	1
PASSENGER VEHICLES	2 - 3
SINGLE UNIT TRUCKS	4 - 7
SINGLE TRAILER TRUCKS	8 - 10
TWIN TRAILER TRUCKS	11 - 12
VERY LARGE TRUCKS	13
UNKNOWN VEHICLES	14 - 15

Examine Unknowns

If the number of vehicles in the unknown vehicles group exceeds 5% of the total number of vehicles, the record is marked BAD.

Historical Edit

Classification records remaining unmarked are edited against prior class data at the same site. An average volume for each of the seven groups is calculated by using data from up to four NORMAL surveys taken at the same station, direction and day-of-week. The program only searches back for up to 8 weeks to find the prior data. If four NORMAL surveys cannot be found, the program averages what it can find. If any of the group volumes exceed the prior week averages by more than 25%, that record is marked BAD; otherwise it is marked NORMAL. If no historical class surveys matching the criteria are found, the record is marked as NORMAL.

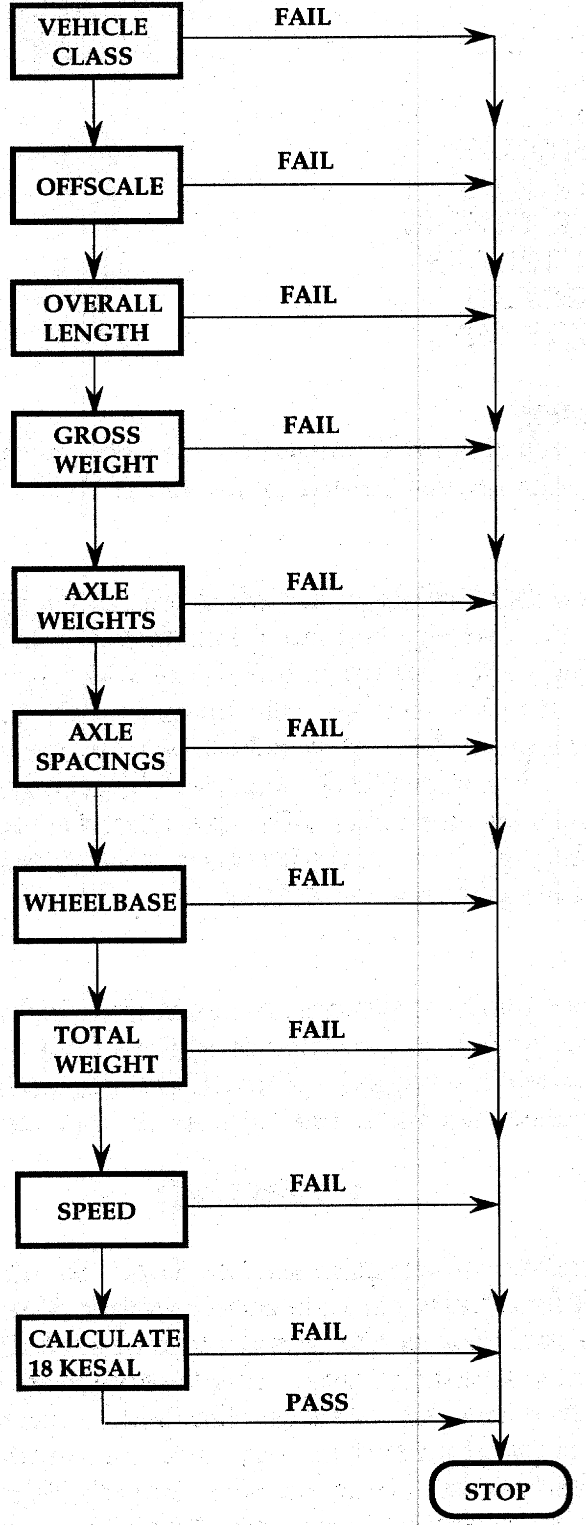
Final Review

All records marked BAD are written to a hold file for final review. If the reviewer disagrees with the computer program's data quality determination, the flag can be manually changed. After all changes are made to the hold file, a program is executed that places the flags on the database table.

4. WIM EDITS

Florida has 13 continuous weigh-in-motion sites. Six of the sites collect weight data in all four lanes, six sites collect weight data in two lanes (either both lanes in one direction or the outside lane in each direction), and one site collects weight data in just one lane. To conserve memory and shorten the time required to transmit the data from the field to the polling computer, the WIM equipment is programmed to only save the individual vehicle data for trucks (classes 4 and above). Even so, with continuous truck weight data collected in 37 lanes on some heavily travelled highways, there are a lot of truck weight records to process every night. Figure 4.1 illustrates the edit process for truck weight records.

FIGURE 4.1 TRUCK WEIGHT EDIT PROCESS



The truck weight edits are designed to weed out the bad records so that only the good truck weight records are used to calculate the 18 Kip Equivalent Single Axle Load (18K ESAL) factors. Truck weight records that are rejected by the edits are written to a hold file for review. However, we have found that we rarely have time to try and correct any of the rejected records. The edit program prints a report that summarizes the results of the edits. See Figure 4.2 for a sample report. Typically, from 10% to 30% of the truck weight records are rejected by the edit program.

FIGURE 4.2 WIM EDIT SUMMARY REPORT

```
72 9923 N Lane: 1 8/23/94
     Total truck records:      02402
     Number passed edits:      02212
     Number failed edits:      00190      7.91%

Class  Total  | Class  Speed  OAL  OFFSC  AXWT  GVWT  AXSP
              |---------------------------------------------
1      0      | 0      0      0    0      0     0     0
2      3      | 3      0      0    0      0     0     0
3      9      | 9      0      0    0      0     0     0
4      21     | 0      0      2    0      1     0     0
5      423    | 0      1      8    3      9     0     0
6      257    | 0      1      33   3      0     1     0
7      12     | 0      0      0    0      0     0     0
8      176    | 0      0      1    1      1     1     11
9      1400   | 0      3      17   27     2     0     0
10     7      | 0      0      0    0      1     0     0
11     34     | 0      0      0    0      0     0     0
12     9      | 0      0      0    0      0     0     0
13     3      | 0      0      1    0      2     0     0
14     0      | 0      0      0    0      0     0     0
15     48     | 48     0      0    0      0     0     0
              |
Total  2402   | 60     5      62   34     16    2     11
```

Invalid Class
Only vehicles of class 4 - 13 are allowed to pass this edit. Since the WIM equipment is programmed to save individual vehicle records for classes 4 and above, the edit usually catches a number of class 15 (unknown type) vehicles.

Offscale
A sensor in each wheelpath separately weighs each side of each axle. If these weights differ by more than 40%, the WIM equipment places a code in the

record indicating that the truck was offscale. The edit program excludes from further processing any truck that the WIM equipment thinks is offscale.

Overall Length

Based upon the speed of the vehicle and the length of time one of the loops remained active, the WIM equipment computes a bumper-to-bumper length of each vehicle. If the overall length of the vehicle exceeds a maximum length for that type of vehicle, the record is excluded from further processing. See Figure 4.3 for the maximum allowable lengths for each type of vehicle.

Gross Weight

The vehicle's gross weight is compared to an allowable maximum weight for that type of vehicle. The maximum weights have no relation to the legal maximum weights, because the WIM equipment has no way of distinguishing between legally permitted and illegal overweight trucks. Besides, the purpose of collecting the weight data is to determine the magnitude of the loads applied to the pavements. The pavements experience the loads regardless of whether or not the load is legal. This edit is designed to eliminate obvious errors. See Figure 4.3 for the maximum allowable gross weights for each type of vehicle.

Axle Weights

If the individual axle weights of a vehicle don't fall within the minimum and maximum limits in Figure 4.4, the record is considered incorrect and excluded from further processing. Different limits are set for each axle of each type of vehicle.

Axle Spacing

If the axle spacings of a vehicle don't fall within the minimum and maximum limits in Figure 4.5, the record is considered incorrect and excluded from further processing. Different limits are set for each axle spacing of each type of vehicle.

Wheelbase

The overall vehicle length is compared to the sum of the individual axle spacings. If the overall vehicle length is shorter than the wheelbase the record is considered in error and excluded from further processing.

Total Weight

The vehicle's gross weight is compared to the sum of the axle weights. If they are not identical, there is a problem with the record and it is excluded from further processing.

Speed

All of the calculated measurements (overall length, gross weight, axle weights, axle spacings) are directly dependent upon the speed of the vehicle. If the WIM equipment incorrectly measures the vehicle speed, all of the other measurements are suspect. Minimum and maximum allowable speeds are set for each WIM site. If the vehicle's speed exceeds these values, that record is excluded from further processing. Fairly liberal bands are allowed. For example, at the WIM site on I-10, which has a posted speed limit of 65 MPH, truck records are accepted from 40 MPH to 95 MPH.

FIGURE 4.3 **VEHICLE LENGTH and GROSS WEIGHT EDIT CRITERIA**

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	NUMBER AXLES	MAXIMUM LENGTH	MAXIMUM WEIGHT
1	1	2	10.0	1000
2	2	2	22.0	5000
2	3	3	32.0	7000
2	4	4	36.0	10000
3	5	2	26.0	7000
3	7	3	60.0	10000
3	9	4	60.0	14000
4	10	2	42.5	28000
4	11	3	52.0	40000
5	20	2	40.0	50000
6	24	3	40.0	86000
7	28	4	40.0	99900
8	30	3	75.0	50000
8	34	4	75.0	100000
8	38	4	75.0	100000
9	40	5	80.0	120000
9	44	5	80.0	120000
10	50	6	85.0	140000
10	54	7	85.0	140000
11	60	5	85.0	100000
12	70	6	110.0	100000
13	80	7	110.0	160000
13	84	8	120.0	160000
13	88	8	120.0	160000
13	90	9	120.0	160000

FIGURE 4.4 AXLE WEIGHT EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE NUMBER	MINIMUM WEIGHT	MAXIMUM WEIGHT
1	1	1	100	1000
1	1	2	100	1000
2	2	1	500	3000
2	2	2	500	3000
2	3	1	500	3000
2	3	2	500	3000
2	3	3	200	5000
2	4	1	500	3000
2	4	2	500	3000
2	4	3	300	5000
2	4	4	300	5000
3	5	1	1500	5000
3	5	2	1500	5000
3	7	1	1500	5000
3	7	2	1500	5000
3	7	3	500	5000
3	9	1	1500	5000
3	9	2	1500	5000
3	9	3	300	5000
3	9	4	300	5000
4	10	1	5000	12000
4	10	2	7000	20000
4	11	1	5000	14000
4	11	2	7000	22000
4	11	3	2000	12000
5	20	1	2000	16000
5	20	2	4000	36000
6	24	1	2000	26000
6	24	2	2400	30000
6	24	3	2400	30000
7	28	1	2000	20000
7	28	2	1500	20000
7	28	3	4000	36000
7	28	4	4000	36000
8	30	1	4000	12000
8	30	2	2000	24000
8	30	3	1200	24000
8	34	1	4000	16000
8	34	2	2000	24000
8	34	3	1200	24000
8	34	4	1200	24000

FIGURE 4.4 cont. AXLE WEIGHT EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE NUMBER	MINIMUM WEIGHT	MAXIMUM WEIGHT
8	38	1	4000	16000
8	38	2	2000	30000
8	38	3	1200	30000
8	38	4	2000	30000
9	40	1	4500	16000
9	40	2	3000	34000
9	40	3	3000	26000
9	40	4	1200	26000
9	40	5	1200	30000
9	44	1	5000	16000
9	44	2	3000	24000
9	44	3	3000	24000
9	44	4	3000	24000
9	44	5	1200	24000
10	50	1	6000	16000
10	50	2	4000	24000
10	50	3	4000	24000
10	50	4	4000	24000
10	50	5	3000	24000
10	50	6	3000	24000
10	54	1	6000	16000
10	54	2	4000	24000
10	54	3	4000	24000
10	54	4	4000	24000
10	54	5	3000	24000
10	54	6	3000	24000
10	54	7	3000	24000
11	60	1	6000	16000
11	60	2	4000	24000
11	60	3	4000	24000
11	60	4	4000	24000
11	60	5	4000	24000
12	70	1	6000	16000
12	70	2	4000	24000
12	70	3	4000	24000
12	70	4	4000	24000
12	70	5	4000	24000
12	70	6	4000	24000
13	80	1	6000	16000
13	80	2	4000	24000
13	80	3	3000	24000

FIGURE 4.4 cont. AXLE WEIGHT EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE NUMBER	MINIMUM WEIGHT	MAXIMUM WEIGHT
13	80	4	3000	24000
13	80	5	3000	24000
13	80	6	3000	24000
13	80	7	3000	24000
13	84	1	6000	16000
13	84	2	4000	24000
13	84	3	3000	24000
13	84	4	3000	24000
13	84	5	3000	24000
13	84	6	3000	24000
13	84	7	3000	24000
13	84	8	3000	24000
13	88	1	6000	16000
13	88	2	4000	24000
13	88	3	3000	24000
13	88	4	3000	24000
13	88	5	3000	24000
13	88	6	3000	24000
13	88	7	3000	24000
13	88	8	3000	24000
13	90	1	6000	16000
13	90	2	4000	24000
13	90	3	3000	24000
13	90	4	3000	24000
13	90	5	3000	24000
13	90	6	3000	24000
13	90	7	3000	24000
13	90	8	3000	24000
13	90	9	3000	24000

FIGURE 4.5 AXLE SPACING EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE SPACE NUMBER	MINIMUM AXLE SPACE	MAXIMUM AXLE SPACE
1	1	1	0.1	6.6
2	2	1	6.6	10.0
2	3	1	6.6	10.0
2	3	2	6.7	16.7
2	4	1	6.6	10.0
2	4	2	6.7	13.3
2	4	3	0.1	6.7
3	5	1	10.1	13.3
3	7	1	10.1	13.3
3	7	2	6.7	16.7
3	9	1	10.1	13.3
3	9	2	6.7	13.3
3	9	3	0.1	6.7
4	10	1	23.1	40.0
4	11	1	23.1	40.0
4	11	2	0.1	6.0
5	20	1	10.3	23.0
6	24	1	6.1	23.0
6	24	2	0.1	6.0
7	28	1	6.1	23.0
7	28	2	0.1	6.0
7	28	3	0.1	13.0
8	30	1	6.0	23.0
8	30	2	11.0	40.0
8	34	1	6.1	23.0
8	34	2	0.1	6.0
8	34	3	6.1	44.0
8	38	1	6.1	17.0
8	38	2	11.0	40.0
8	38	3	0.1	10.9
9	40	1	6.1	26.0
9	40	2	0.1	6.0
9	40	3	6.1	46.0
9	40	4	0.1	10.9
9	44	1	6.7	22.0
9	44	2	0.1	6.7
9	44	3	6.7	26.7
9	44	4	10.0	26.7
10	50	1	6.7	26.0
10	50	2	0.1	6.0
10	50	3	0.1	46.6

FIGURE 4.5 cont. AXLE SPACING EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE SPACE NUMBER	MINIMUM AXLE SPACE	MAXIMUM AXLE SPACE
10	50	4	0.1	11.0
10	50	5	0.1	11.0
10	54	1	6.7	16.7
10	54	2	0.1	6.7
10	54	3	13.3	40.0
10	54	4	0.1	13.3
10	54	5	0.1	13.3
10	54	6	0.1	13.3
11	60	1	6.1	26.0
11	60	2	11.1	26.0
11	60	3	6.1	20.0
11	60	4	11.1	26.0
12	70	1	6.1	26.0
12	70	2	0.1	6.0
12	70	3	11.1	26.0
12	70	4	6.1	24.0
12	70	5	11.1	26.0
13	80	1	1.0	45.0
13	80	2	1.0	45.0
13	80	3	1.0	45.0
13	80	4	1.0	45.0
13	80	5	1.0	45.0
13	80	6	1.0	45.0
13	84	1	1.0	45.0
13	84	2	1.0	45.0
13	84	3	1.0	45.0
13	84	4	1.0	45.0
13	84	5	1.0	45.0
13	84	6	1.0	45.0
13	84	7	1.0	45.0
13	88	1	1.0	45.0
13	88	2	1.0	45.0
13	88	3	1.0	45.0
13	88	4	1.0	45.0
13	88	5	1.0	45.0
13	88	6	1.0	45.0
13	88	7	1.0	45.0
13	90	1	1.0	45.0
13	90	2	1.0	45.0
13	90	3	1.0	45.0
13	90	4	1.0	45.0

FIGURE 4.5 cont. AXLE SPACING EDIT CRITERIA

VEH CLASS SCHEME "F"	VEHICLE TYPE NO.	AXLE SPACE NUMBER	MINIMUM AXLE SPACE	MAXIMUM AXLE SPACE
13	90	5	1.0	45.0
13	90	6	1.0	45.0
13	90	7	1.0	45.0
13	90	8	1.0	45.0

UTILIZING EXPERT SYSTEMS TO EVALUATE TRAFFIC VOLUME DATA

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Utilizing Expert Systems to Evaluate Traffic Volume Data

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EXECUTIVE SUMMARY

Local, state and national demands for accurate traffic data are increasing geometrically in response to numerous programs such as congestion management, air quality, design, pavement management, safety and resource allocation. To keep pace with these demands, there have been advancements in traffic counting hardware. However, the corresponding analysis process required to assure data integrity and quality has not kept pace.

Currently, traffic data are collected by two means: continuous counts, which are permanent installations counting traffic volumes for every hour of the year, and coverage counts, which are portable counters recording a short sample of traffic volumes. The analysis practices used to evaluate these data throughout the country are varied. Some states utilize statistical packages to identify anomalistic data, while others utilize their own software to look for data beyond certain thresholds. In all cases, there are significant investments in human resources to review these voluminous data files and apply evaluation practices developed over the years, which are referred to as “rules of thumb.”

These practices have a number of problems:

- The difficulty in maintaining “Truth In Data,” that is, a consistent and documented process of analysis that result in data of a know quality.
- The available software packages are generally too rigid to respond to the “Rules of Thumb” utilized by the experts.
- The process is extremely labor intensive.
- The knowledge to do this analysis is vested in only a few individuals.
- The difficulty in training new staff.

The Colorado Department of Transportation (CDOT), in cooperation with the Federal Highway Administration (FHWA), is pursuing new methodologies to improve the data analysis process. A number of alternative solutions have been considered. Existing traffic software and conventional software programs can address certain parts of the problem but can not provide a complete solution.

Specifically, a flexible, cost effective approach is required which allows for changing traffic conditions, and facilitates the incorporation of human "rules of thumb" (heuristics). Moreover, this approach would have to be based upon existing traffic analyses to ensure credibility, yet be extensible as the analysis process is improved. A rule based expert system data analysis approach was chosen after a detailed review of all alternatives. The expert system utilizes artificial intelligence computing technology to emulate the traffic data analysis process.

Through an intensive systems development program, technical specialists (domain experts) and systems developers (knowledge engineers) collectively developed a series of English language rules that replicate the process and logic patterns followed in the analysis of data. Numerous data sets were evaluated and a number of enhancements to the process were instituted.

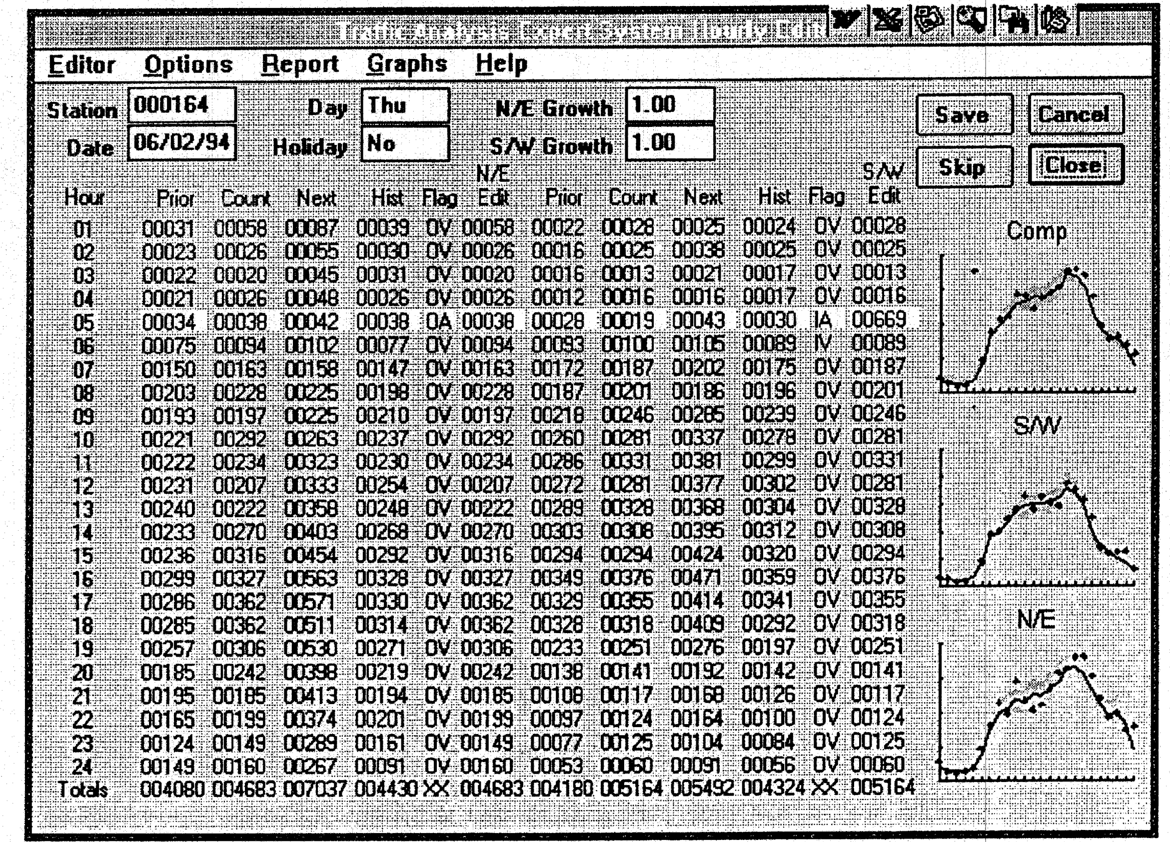
The expert system is embedded within an easy to learn graphical user interface that allows point and click operation with a mouse. The user can choose to display plots, tables and charts of data and analysis results with the click of a mouse button. The system was developed under Microsoft Windows™ 3.1 in C++ and Nexpert Object. Learning to use the system is very easy because the user interface is just like that of other Windows™ software programs such as word processors or spreadsheets. The system requires at least an 80386 computer running Windows™ 3.1 or better.

In 1992 a proof of concept version of the system was developed by CDOT. The system was tested by operating it in parallel with the normal analysis processes. The test findings were promising and indicated that the system:

- Improved data and analysis consistency;
- Improved data and analysis accuracy;
- Saved significant amounts of time and labor;
- Reduced analysis cost by 35%;
- Improved the ease with which data could be accessed;
- Provided clear and complete documentation of the analysis process;
- Improved the transfer of knowledge from the experts to less experienced data analysts.

These promising findings led CDOT and FHWA in the spring of 1993 to initiate the development of a fully operational system that would be installed in multiple states. Their objective was to determine if this system could provide a national solution to the ATR data analysis needs of all 50 states. The system's knowledge base was revised to handle the wide range of ATR traffic conditions found in different regions of the country, the data input requirements were modified to a standard already supported by almost all states and the data analysis capabilities were integrated with data editing functions to create a seamless analysis and editing environment. The Kansas Department of Transportation and the Minnesota Department of Transportation joined CDOT and the FHWA in the development and testing of this extended system.

As the first step in these enhancements, additional knowledge engineering sessions were held in the participating states. While there was significant commonality on how data were evaluated, nonetheless there were a number of key areas where a common analysis approach had to be developed. In all cases a consensus approach was achieved and often the new approach was judged to be considerably better than prior state specific techniques. In addition an extensive graphical user interface (GUI) was developed to facilitate the review of the system analysis and to simplify the editing of anomalous data. Below is an example of one of the editor/data screens.



Station 000164
Date 06/02/94
Day Thu
Holiday No
N/E Growth 1.00
S/W Growth 1.00

Hour	Prior	Count	Next	Hist	Flag	N/E Edit	Prior	Count	Next	Hist	Flag	S/W Edit
01	00031	00058	00087	00039	OV	00058	00022	00028	00025	00024	OV	00028
02	00023	00026	00055	00030	OV	00026	00016	00025	00038	00025	OV	00025
03	00022	00020	00045	00031	OV	00020	00016	00013	00021	00017	OV	00013
04	00021	00026	00048	00026	OV	00026	00012	00016	00016	00017	OV	00016
05	00034	00038	00042	00038	OA	00038	00028	00019	00043	00030	IA	00669
06	00075	00094	00102	00077	OV	00094	00093	00100	00105	00089	IV	00089
07	00150	00163	00158	00147	OV	00163	00172	00187	00202	00175	OV	00187
08	00203	00228	00225	00198	OV	00228	00187	00201	00186	00196	OV	00201
09	00193	00197	00225	00210	OV	00197	00218	00246	00285	00239	OV	00246
10	00221	00292	00263	00237	OV	00292	00260	00281	00337	00278	OV	00281
11	00222	00234	00323	00230	OV	00234	00286	00331	00381	00299	OV	00331
12	00231	00207	00333	00254	OV	00207	00272	00281	00377	00302	OV	00281
13	00240	00222	00358	00248	OV	00222	00289	00328	00368	00304	OV	00328
14	00233	00270	00403	00268	OV	00270	00303	00308	00395	00312	OV	00308
15	00236	00316	00454	00292	OV	00316	00294	00294	00424	00320	OV	00294
16	00299	00327	00563	00328	OV	00327	00349	00376	00471	00359	OV	00376
17	00286	00362	00571	00330	OV	00362	00329	00355	00414	00341	OV	00355
18	00285	00362	00511	00314	OV	00362	00328	00318	00409	00292	OV	00318
19	00257	00306	00530	00271	OV	00306	00233	00251	00276	00197	OV	00251
20	00185	00242	00398	00219	OV	00242	00138	00141	00192	00142	OV	00141
21	00195	00185	00413	00194	OV	00185	00108	00117	00168	00126	OV	00117
22	00165	00199	00374	00201	OV	00199	00097	00124	00164	00100	OV	00124
23	00124	00149	00289	00161	OV	00149	00077	00125	00104	00084	OV	00125
24	00149	00160	00267	00091	OV	00160	00053	00060	00091	00056	OV	00060
Totals	004080	004683	007037	004430	XX	004683	004180	005164	005492	004324	XX	005164

This new system has been installed and is undergoing a one year testing program in Colorado, Kansas and Minnesota. Preliminary findings indicate that:

- The system identified the anomalies determined by the experts. Further, the system accurately identified anomalies overlooked by the experts.
- The graphics provided an expeditious tool for the operators to evaluate the anomalistic data.
- The system allowed the operator to focus on the anomalistic data.
- The graphical user interface minimized the number of key strokes required to review and edit anomalous data. This resulted in a significant savings of operator time.
- The system provided a single point of analysis and edit for the states.
- The system fully supports "truth in data" by providing an automated audit trail for the analysis and all editing.

INTRODUCTION

Traffic data represents a critical element for: management systems, pavement design, determination of roadway geometrics, safety considerations, the determination of roadway capacity needs, and the allocation of limited construction and maintenance funds. Realizing the importance of this information, the Federal Highway Administration (FHWA) developed the Traffic Monitoring Guide that provides state transportation agencies with common guidelines for traffic data collection, processing, and analysis. In addition, FHWA has encouraged state transportation agencies to move toward automating equipment for collecting this data. To this end, the Colorado Department of Transportation (CDOT) has made staff commitments and substantial investments in traffic data acquisition equipment. CDOT is moving not only to improve its methods of collecting traffic data but also to improve its processing and analysis to ensure data integrity.

A significant step in this direction is the traffic count analysis expert system. whose proof of concept prototype was developed in 1992. Time motion studies of the proof of concept prototype in parallel with the standard analysis practices indicated that the expert system provided significant cost and accuracy improvements. Based on these findings the Departments of Transportation from Kansas and Minnesota joined CDOT and FHWA in the next phase of the project. A national demonstration prototype was developed and installed in the three states and extensive long term testing is ongoing. This paper will trace the history of the development of this system, discuss key design issues, illustrate:

- Problem Statement
- Proof of Concept System
- Software
- Proof of Concept Results
- National Demonstration
- Example Analysis and Editing Screens
- Initial Results

PROBLEM STATEMENT

Over the last several years, there has been an increase in the requirements for various forms of traffic-related data. To address these needs, substantial improvements in the area of traffic data acquisition equipment have occurred. However, the processing capabilities have not kept pace with hardware improvements. As more data are collected in different configurations by more sophisticated types of equipment, existing processes are becoming increasingly complicated and ineffectual.

The current process of reviewing and analyzing traffic data is labor intensive and very cumbersome. With the intensive human intervention and the vast amount of traffic data to be processed, it is difficult to maintain consistent and accurate analyses. These "Truth In Data" issues coupled with expertise vested in only a few senior staff has driven CDOT to consider new methodologies for improving data quality and staff efficiencies.

COLORADO'S TRAFFIC COUNTING PROGRAM

The Colorado Department of Transportation traffic data collection efforts have two distinct components: permanent (continuous) and short-term (coverage).

Permanent Count Program

The permanent traffic counting program uses 72 automated traffic records (ATRS) to record traffic volumes for every hour of the year. Station locations are designed to provide representative samples reflecting geographic distribution and functional classification groups. Each station, via telemetry, is poled weekly. These data are then used to develop seasonal adjustment factors for short term counts, design hour volumes, reporting programs and many other functions.

Short-Term Count Program

Annually during the summer and fall, over 2,000 short term counts of either 24 or 48 hour duration are collected throughout the state. Generally, sampling at these locations is done on a three-year cycle.

Using a battery of programs developed by the hardware vendor and CDOT, the ATR and short-term count data are imported, sorted, arranged, reviewed and edited. Besides being very cumbersome and time consuming, these programs are dependent upon staff identifying bad and anomalous data. For each permanent count station, senior technical staff reviewed a monthly summary of hourly readings to screen for anomalistic data (example summary Figure 1). At completion of the review and edit, these data are stored directionally and as a composite or total volumes in the dBase structured Colorado Traffic Analysis Management System (CTAMS).

Five Week Summary
Figure 1

Site: 11020000 Location: ON I-76 NE/O SH 385, JULESBURG, NORTHEAST BOUND
FIVEWEEK REPORT for the period: 01/23/1993 through 02/26/1993
Format of data lines: Day of week, Date, an H if the date is a holiday, and then the Count for each hour starting with the hour ending at 01:00 am (24 values), ending with the Total Count for the day
There are 35 lines for the five weeks, followed by a line with by two lines that detail the average of weekdays and the average of all days.

Day		Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Sat	1/23/93		25	22	11	23	14	17	21	37	51	63	91	101	95	132	86	84	93	93	69	59	59	45	30	20	1341
Sun	1/24/93		17	21	7	11	9	20	30	29	43	81	100	124	120	114	102	99	103	84	68	63	50	46	46	18	1405
Mon	1/25/93		16	17	14	4	8	17	11	37	24	81	91	112	112	104	120	87	103	86	74	85	56	61	27	19	1366
Tue	1/26/93		14	16	15	11	16	15	18	26	47	74	85	89	85	72	86	83	77	81	61	55	40	42	41	23	1172
Wed	1/27/93		13	11	21	25	12	9	15	25	51	80	82	50	92	70	75	86	83	97	74	69	56	48	30	24	1198
Thu	1/28/93		26	20	20	12	13	8	23	40	50	86	84	94	96	88	91	107	94	85	102	69	76	64	50	33	1431
Fri	1/29/93		24	27	6	15	13	25	23	32	51	87	78	121	122	119	113	109	123	134	91	97	70	82	52	31	1645
Sat	1/30/93		34	16	19	20	17	23	22	41	50	82	113	115	103	101	104	88	90	92	76	63	53	46	27	23	1418
Sun	1/31/93		35	18	11	18	21	17	24	36	44	83	112	120	127	110	87	81	82	83	68	51	42	35	34	25	1364
Mon	2/1/93		24	18	6	17	12	14	13	35	46	72	78	126	124	96	88	84	113	119	92	61	48	55	46	32	1419
Tue	2/2/93		16	29	16	16	7	10	10	34	57	78	89	82	86	80	77	70	85	81	68	87	49	46	29	28	1230
Wed	2/3/93		26	23	11	12	18	17	19	29	47	60	73	75	90	75	91	83	91	83	73	56	54	43	23	22	1194
Thu	2/4/93		25	20	17	18	12	11	24	28	60	61	79	78	94	88	99	78	93	86	87	70	65	53	41	34	1321
Fri	2/5/93		27	18	21	16	19	12	28	35	42	77	88	113	123	115	132	105	103	110	94	94	79	91	70	43	1655
Sat	2/6/93		25	22	24	12	15	21	20	43	62	64	110	120	117	107	102	83	86	88	63	80	56	49	31	13	1413
Sun	2/7/93		26	10	17	15	14	16	19	37	46	70	99	121	135	110	118	116	126	115	87	73	52	59	39	19	1539
Mon	2/8/93		18	20	18	7	16	17	19	41	62	71	118	111	119	108	89	102	96	92	85	85	62	48	27	32	1463
Tue	2/9/93		16	12	20	19	11	10	16	26	57	64	86	97	94	98	94	75	97	86	94	64	44	59	38	29	1306
Wed	2/10/93		20	15	13	10	12	7	23	19	47	42	43	58	73	68	66	68	34	70	44	37	31	28	20	24	872
Thu	2/11/93		12	16	11	21	13	18	11	25	52	57	108	96	102	123	89	87	73	71	73	51	52	57	54	26	1298
Fri	2/12/93		19	11	13	14	23	14	22	40	76	117	119	143	138	125	137	148	148	136	137	91	111	81	62	50	1975
Sat	2/13/93		22	24	14	19	33	19	39	43	54	86	118	156	170	128	118	112	101	82	78	57	54	54	32	25	1638
Sun	2/14/93		18	23	20	11	11	22	16	38	46	62	114	146	134	131	102	113	122	99	93	77	64	62	33	28	1585
Mon	2/15/93		27	21	16	19	9	17	12	27	54	80	111	152	149	136	111	120	91	81	84	73	56	40	30	19	1535
Tue	2/16/93		24	16	7	13	13	16	19	26	42	76	90	101	133	125	109	96	84	78	63	77	47	29	40	26	1350
Wed	2/17/93		31	14	25	19	15	24	20	25	56	81	82	86	118	110	90	88	96	79	73	61	58	43	43	28	1365
Thu	2/18/93		14	10	15	24	16	17	23	40	63	70	96	103	106	95	80	112	86	87	98	83	70	64	42	43	1457
Fri	2/19/93		32	21	13	14	20	12	32	47	62	73	108	81	135	125	126	124	140	141	107	84	77	78	47	32	1731
Sat	2/20/93		31	28	14	16	16	16	21	38	54	71	108	110	130	152	95	127	94	87	60	72	72	54	33	31	1530
Sun	2/21/93		25	23	21	18	19	9	31	42	68	66	88	127	158	134	112	122	92	94	64	62	41	47	24	26	1513
Mon	2/22/93	H	N/A	25	9	14	11	19	18	30	39	87	93	118	111	108	111	112	104	79	85	52	53	54	40	29	N/A
Tue	2/23/93		17	15	13	14	16	26	22	36	58	76	89	93	89	117	79	95	89	78	74	65	47	39	28	31	1306
Wed	2/24/93		28	28	13	10	15	12	23	21	36	70	84	103	92	95	87	87	83	82	70	67	53	41	28	17	1245
Thu	2/25/93		18	33	14	11	8	21	27	29	59	64	69	87	108	98	87	89	112	98	75	68	45	65	38	29	1352
Fri	2/26/93		31	21	22	14	13	10	25	35	71	111	98	133	106	128	131	136	117	108	102	90	88	74	63	43	1770
AWD			21	19	15	15	14	15	20	32	52	76	89	100	108	103	98	97	97	93	83	72	59	55	40	30	
AAD			23	20	15	15	15	16	21	33	52	75	94	107	114	108	100	99	97	93	80	70	58	54	38	28	

Grand total of complete days: 48402
Grand average of complete days: 1424

PROJECT HISTORY

Together with its day to day operations of the traffic monitoring system, CDOT pursued many solutions to improve the data efforts. An initial step taken was to establish objectives for an enhanced system:

- Streamline traffic data processing
- Improve data consistency
- Improve data accuracy
- Distribute knowledge of experts to others in the organization
- Formalize and codify the analysis process
- Provide flexibility and greater responsiveness to change

To meet these objectives three general options were explored:

- Enhancement of existing software: CDOT would have a variety of vendors make the necessary improvements to their software or obtain the source code and make the changes themselves.

- Replace existing software with conventional tools: CDOT would utilize conventional forms of software such as spreadsheets, database management, or special programming involving C or FORTRAN.

- Replace existing software system with an Artificial Intelligence Utilization of knowledge-based software. CDOT would develop a knowledge-base expert system to simulate the reasoning and decision-making processes of traffic experts.

CDOT concluded that the existing traffic software and conventional software programs could address certain parts of the problem but could not provide a complete solution to the problem nor could they be easily adapted as needs change. The knowledge-based system represented a flexible and cost-effective approach, which: can be modified as conditions change, provides a level of "intelligence," provides an efficient method for formalizing and codifying existing procedures and be utilized as a platform to improve the analysis process.

CDOT then initiated a pilot project in 1989 to test whether expert systems could address its needs. An abbreviated expert system was developed for two permanent count stations. The results clearly showed that an expert system was feasible and offered significant benefits. Based on these findings, CDOT applied for and was awarded federal funds to develop a proof of concept prototype expert system to analyze permanent and coverage count data. In 1992, BALLOFFET and Associates, Inc. (B&A) and Intelligent Decision Technologies, Inc. (IDT) were selected by CDOT to develop the proof of concept system.

PROOF OF CONCEPT SYSTEM DEVELOPMENT

Expert systems represent a form of artificial intelligence that emulates the human decision-making / problem solving process. This emulation is based on a series of heuristic rules and certain parameters, as defined by the human expert. The computer conducts analysis processes and formulates decisions much in the same manner as the human expert. The use of expert systems for transportation purposes has been greatly increased over the last several years. There are presently applications relating to pavement rehabilitation, traffic signalization, traffic network design, highway capacity analysis, highway safety analysis and many others.

The heart of an expert system is the English language rule base that is collectively developed by the system developer (knowledge engineer) and the technical specialist (domain expert). This rule base reflects the process and information used by the domain expert in decision-making; in this case, determining whether ATR data are anomalous. The knowledge engineer then reduces these rules into a computer language. "Knowledge Engineering" is the sharing, formalizing, and codifying of ideas and processes.

Knowledge engineering sessions with CDOT domain experts were held to develop and test a knowledge base that duplicated the human process used to screen traffic data. The CDOT domain experts were presented with case studies, asked to identify anomalous traffic count data and asked to explain how they knew that the data was anomalous. Rules were then developed and manually tested on new case studies.

To provide the range of potential classification and geographic conditions, test cases reflected a range of conditions on urban, rural, interstate and high recreation systems. Three years of historic data were analyzed for each station. Consequently, the appropriateness of a rule could be evaluated across station types and seasons. Where necessary, rules were limited to specific station types or seasons. Statistical review of historic data was used to identify trends and common data characteristics across multiple stations.

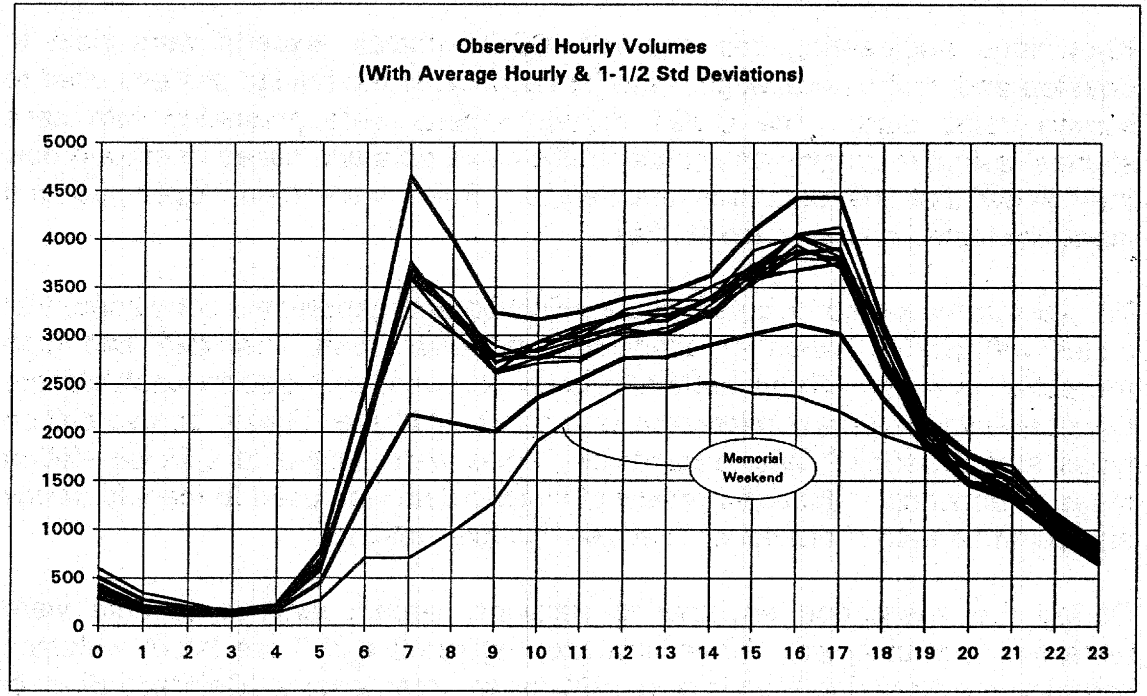
During the knowledge engineering sessions, large quantities of data were reviewed and analyzed. As an example, Figures 2 and 3 are hourly volumes sampled during spring Mondays in 1991 for an urban arterial (Colorado Blvd. in Denver) and an urban-fringe Interstate (I-25 north of Pueblo). These composite (travel in both directions) tables are for a single station, day, season and year. A complete historic data set includes directional and composite data by every hour, every day, every season for three years. By comparing the figures, the complexity of the consideration needed for the system becomes apparent. These elements include variations in total volumes, time and magnitude of peak hour(s), directional orientation, holidays and special events, and road classification.

Statistical Review - Colorado Boulevard, Denver

Figure 2

Spring Monday (1991) ***Colorado Boulevard***

Monday	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
High 1 1/2-std	503	276	204	158	223	790	2505	4646	3993	3235	3165	3251	3384	3454	3626	4096	4439	4436	3120	2156	1776	1587	1169	862
4-Mar	346	180	156	113	192	580	2030	3579	3244	2630	2772	2786	2980	3019	3225	3571	3682	3757	2682	1991	1509	1368	917	642
11-Mar	339	197	132	131	201	613	2064	3606	3250	2742	2783	2909	3077	3012	3328	3632	3671	3744	2747	1921	1508	1341	998	661
18-Mar	330	210	134	139	175	629	2043	3613	3228	2608	2720	2746	2989	3084	3266	3544	3831	3901	2945	1942	1474	1327	1155	705
25-Mar	368	192	150	128	193	664	2029	3588	3049	2625	2939	3113	3212	3278	3511	3719	4052	3879	2779	1851	1608	1510	1118	753
1-Apr	365	219	143	133	175	635	2086	3347	3027	2732	2868	3045	3207	3287	3256	3549	3890	3778	2811	2071	1488	1467	1086	797
8-Apr	380	189	171	153	209	670	1951	3699	3227	2897	2749	2912	3076	3235	3187	3590	3945	3700	2721	2077	1616	1382	1082	768
15-Apr	403	193	141	169	204	675	2103	3719	3264	2714	2862	3087	3232	3190	3378	3884	4033	3817	2790	2132	1797	1460	1139	809
22-Apr	403	202	122	127	207	679	2089	3739	3230	2811	2835	2972	3106	3156	3386	3744	3868	3800	2787	2032	1687	1417	1016	751
29-Apr	352	201	139	114	187	672	2117	3764	3176	2780	2790	2936	3031	3041	3243	3659	3803	3778	2680	2046	1600	1337	998	714
6-May	406	203	166	125	194	645	1973	3659	3273	2797	2860	3041	3221	3217	3392	3663	4059	4072	3033	2090	1621	1528	1050	781
13-May	433	222	175	143	204	701	2055	3693	3268	2640	2944	2996	3111	3170	3411	3694	3864	3917	2797	2090	1751	1523	1086	843
20-May	440	226	155	142	212	684	2029	3673	3390	2783	2925	2990	3268	3371	3370	3616	4058	4135	2918	2064	1756	1684	1134	861
27-May	600	344	249	139	134	275	711	704	987	1280	1914	2221	2467	2466	2533	2409	2385	2224	1980	1825	1632	1403	1086	816
Low 1 1/2-std	292	152	108	112	160	460	1384	2182	2098	2002	2367	2557	2766	2781	2910	3023	3121	3025	2384	1865	1459	1294	984	661
Std Dev	70	41	32	15	21	110	374	821	632	411	266	231	206	224	239	358	439	470	252	97	105	98	68	67
Median	380	202	150	133	194	664	2043	3659	3230	2732	2835	2972	3106	3170	3328	3632	3868	3800	2787	2046	1616	1417	1086	768
High 1 1/2-std	503	276	204	158	223	790	2505	4646	3993	3235	3165	3251	3384	3454	3626	4096	4439	4436	3120	2156	1776	1587	1169	862
High 1-std	468	255	188	150	212	735	2318	4235	3677	3030	3032	3136	3281	3342	3507	3917	4220	4201	2994	2107	1723	1538	1135	828
Average	397	214	156	135	191	625	1945	3414	3046	2618	2766	2904	3075	3117	3268	3560	3780	3731	2742	2010	1617	1441	1067	762
Low 1-std	327	172	124	120	170	515	1571	2593	2414	2207	2500	2673	2869	2893	3029	3202	3341	3261	2490	1913	1512	1343	998	695
Low 1 1/2-std	292	152	108	112	160	460	1384	2182	2098	2002	2367	2557	2766	2781	2910	3023	3121	3025	2384	1865	1459	1294	984	661

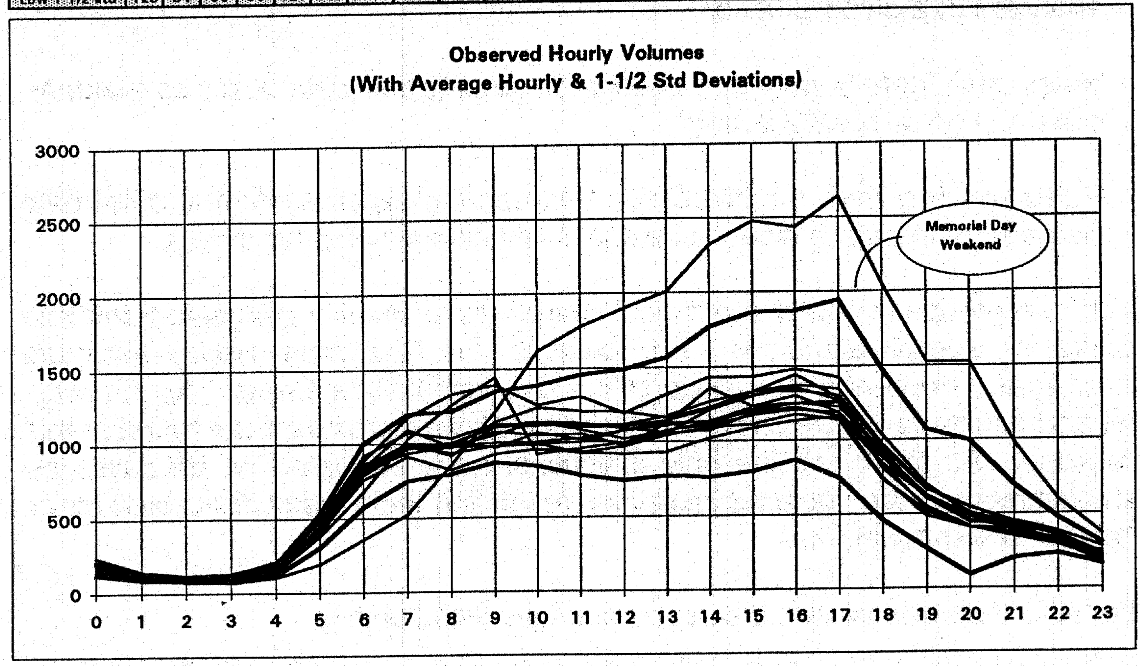


Each line depicts the hourly counts for a different Monday in the Spring of 1991 at the Colorado Boulevard ATR.

Statistical Review - I-25 Pueblo
Figure 3

Spring Mondays (1991) *I-25 Pueblo*

Monday	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
High 1 1/2-std	213	142	118	132	203	531	1002	1199	1216	1347	1388	1458	1491	1570	1771	1866	1875	1941	1471	1068	991	694	473	305
4-Mar	154	97	93	83	147	418	757	915	824	927	954	932	916	929	1019	1085	1133	1153	741	485	406	368	298	175
11-Mar	143	110	91	111	153	429	829	935	977	977	991	933	971	1042	1089	1112	1173	1134	733	514	413	347	290	190
18-Mar	171	125	103	114	163	449	844	1092	976	1055	1138	1086	1023	1072	1122	1200	1250	1263	806	550	411	361	335	235
25-Mar	138	109	116	118	181	448	864	976	973	1141	1237	1212	1204	1158	1226	1328	1444	1281	971	675	504	424	298	249
1-Apr	178	134	105	128	220	483	888	1173	1329	1389	1252	1309	1192	1318	1435	1430	1484	1420	1027	694	486	413	361	238
8-Apr	189	122	108	100	146	384	677	1029	1257	1444	919	960	992	1054	1071	1182	1221	1157	834	535	411	395	312	208
15-Apr	142	108	94	104	154	389	833	983	969	1076	1046	1058	974	1126	1130	1228	1254	1248	891	603	482	385	337	232
22-Apr	164	115	95	101	168	435	804	984	1008	968	1069	1022	994	1079	1107	1170	1207	1185	880	601	455	401	328	221
29-Apr	154	108	110	121	174	438	815	976	936	978	990	1004	1078	1107	1135	1206	1246	1220	932	603	441	434	356	222
6-May	165	102	85	84	152	450	803	1002	984	1003	1009	1027	1075	1127	1359	1234	1299	1184	838	617	481	428	352	203
13-May	203	146	106	130	182	493	924	1072	1034	1127	1125	1103	1101	1138	1215	1332	1336	1304	953	662	547	437	365	217
20-May	173	115	97	112	177	449	852	1004	918	1113	1142	1128	1089	1057	1208	1301	1356	1266	911	621	491	453	379	277
27-May	241	148	124	74	106	196	358	527	855	1209	1616	1780	1898	2008	2320	2478	2436	2645	2049	1530	1526	982	600	366
Average	170	118	102	106	163	420	788	973	1003	1108	1115	1120	1116	1170	1264	1330	1372	1343	967	668	543	448	355	233
Low 1 1/2-std	128	94	86	80	124	309	574	747	790	869	841	781	741	771	758	793	870	745	482	269	95	203	236	162
Std Dev	28	18	11	17	26	74	143	151	142	159	182	226	250	266	338	358	335	399	336	266	299	164	79	48
Median	165	115	103	111	163	438	829	983	976	1076	1069	1058	1075	1107	1135	1228	1254	1248	891	603	481	413	337	222
High 1 1/2-std	213	142	118	132	203	531	1002	1199	1216	1347	1388	1458	1491	1570	1771	1866	1875	1941	1471	1068	991	694	473	305
High 1-std	199	134	113	124	190	494	931	1124	1145	1268	1297	1346	1366	1437	1602	1687	1708	1742	1303	935	841	612	434	281
Average	170	118	102	106	163	420	788	973	1003	1108	1115	1120	1116	1170	1264	1330	1372	1343	967	668	543	448	355	233
Low 1-std	142	102	91	89	137	346	646	822	861	949	932	894	866	904	927	972	1037	944	630	402	244	285	276	186
Low 1 1/2-std	128	94	86	80	124	309	574	747	790	869	841	781	741	771	758	793	870	745	482	269	95	203	236	162



Each line depicts the hourly counts for a different Monday in the Spring of 1991 at the I-25 ATR.

Throughout the process the domain experts usually agreed on whether a data item was anomalous. At times, the domain experts differed on the thought process or intuitions used to identify anomalous data. Consequently, rules would often be rewritten several times, and on occasion, discarded as the experts re-analyzed and re-formalized their own thought process. Of the initial 68 rules developed, 17 were discarded upon further evaluation and almost all of the remaining 51 rules were significantly modified in later knowledge engineering sessions

The rules for the ATR programs are grouped into six major categories.

- Rules that use composite traffic data to search for data anomalies.
- Rules that use directional traffic data to search for data anomalies.
- Rules that specifically addresses traffic counts on holidays. Holidays had to be treated as a special case with a separate rule set because of the extraordinary and inconsistent traffic patterns found on holidays.
- Rules (meta-rules) that control which rule groups and subgroups are analyzed in a given situation.
- Rules that identify potential causes for anomalous data such as weather, construction or special events.
- Rules which govern the interaction between the expert system and the data files and other miscellaneous internal system housekeeping chores.

Each rule group is divided into topical subgroups to simplify debugging and rule access for special situations. For example, the Directional Hourly Minimum Count Rule Group is a sub group of the Directional Rule Group. All the rules that address the analysis of the direction hourly minimum count are found in this subgroup. As these are the only directional rules evaluated on holidays, the establishment of the subgroup simplifies restricting the holiday directional count analysis to just these rules.

The major rule groups with their subgroups are listed below:

Composite Traffic Data	**Directional Data Rules**	**Holiday Rules**	**Control Rules**	**Miscellaneous Rules**	**Causes Rules**
Control Rules	Control Rules	Control Rules	Rules Group Control Rules		
Daily Total Rules	Daily Total Rules	Holiday Identification Rules	Analysis Interrupt Control Rules		
	Hourly Total Rules	Daily Total Rules			
	Peak Traffic Rules				
	Minimum Count Rules				
	Reset Count Rules				

SOFTWARE

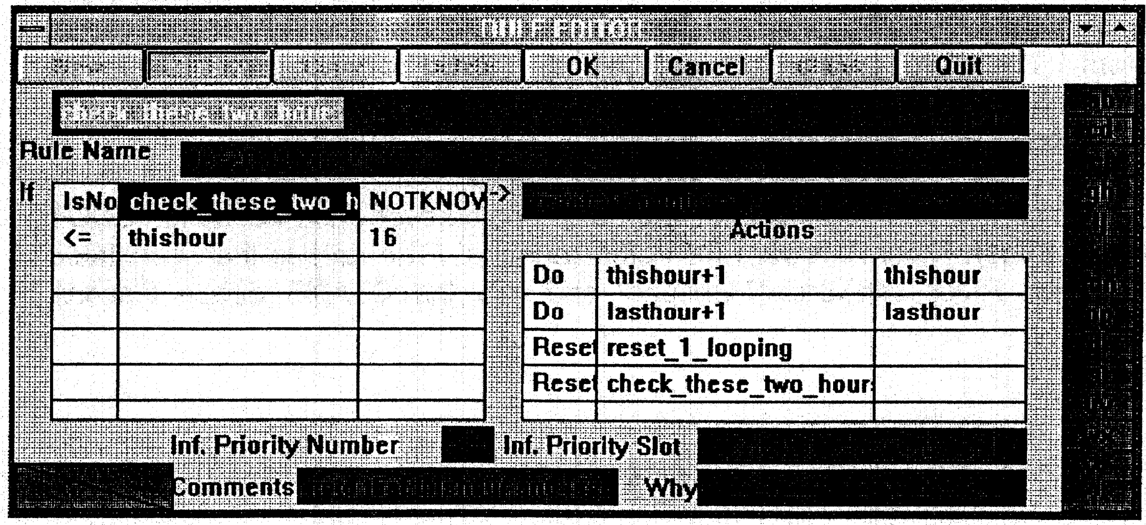
Concurrent to the knowledge engineering activities, a review and analysis of potential expert system software development environments was completed. Highly desirable software development environments were identified and included:

- A wide range of knowledge representation capabilities;
- Easily imbedable within another application;
- Relatively low cost distribution;
- Excellent vendor support;
- Flexible user interface;
- Easily portable across hardware platforms;
- Reasonably priced;
- Flexible reasoning strategies;
- Superior performance;

From the initial 20 candidates, Nexpert Object for Windows was selected. The system will operate on a 80386 computer under MS DOS and Microsoft Windows 3.x or better. It will need to regularly access over 450 data and other files over a PC network.

The knowledge engineer and programmer then reduced the rule base into the Nextpert computer language. Figure 4 is an example screen from the rule editor and shows a global rule for composite traffic specifying what minimum condition should be met for average hourly traffic. Figure 5's screen illustrates the complexity of the network used in the expert system. The software system is relatively user friendly and will allow for future system enhancements by CDOT staff.

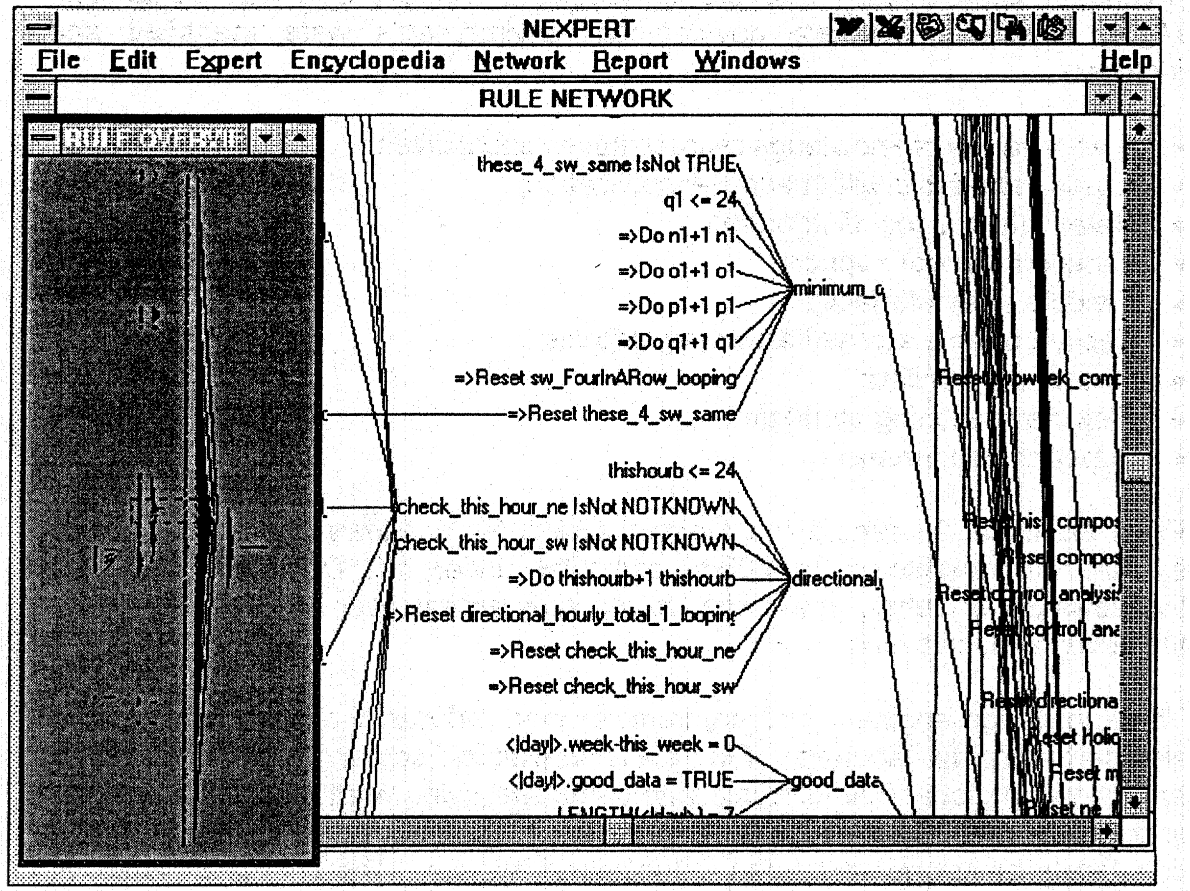
Nexpert Rule Editor Screen
Figure 4



IsNo	check_these_two_h	NOTKNOV
<=	thishour	16

Do	thishour+1	thishour
Do	lasthour+1	lasthour
Reset	reset_1_looping	
Reset	check_these_two_hour	

Nexpert Rule Network
Figure 5



The knowledge engineering team spent a considerable amount of time in defining the best points of interaction with existing CDOT systems and processes. For example, CDOT had made a considerable investment in the CTAMS system. The CTAMS dBase system was found to be well-structured and provided useful editing capabilities not available in the proof of concept expert system. Therefore, a data transfer link from CTAMS to the expert system was developed which also demonstrated that the system could be integrated with existing program elements.

For each continuous count station, the data is poled over each weekend. CDOT utilizes Golden River hardware for traffic counting. The data is then translated by Golden River software “Transpac” and into the CTAMS dBase Record.

A number of enhancements have been made to the CTAMS system:

- Parallel files have been established to provide indicators, or "Flag Files," to identify when a specific hour is influenced by external conditions such as weather, a special event, holidays, construction or whether the data is anomalistic but has been confirmed as accurate (Verified) or whether the data was incorrect and was imputed.

- A missing data file is utilized to provide a mechanism to adjust the data by deletions or imputations without modifying the original data. This facilitates an audit trail of the systems.

- A historic statistical data file has been added to provide input for the expert system analysis. The file includes 3 years of information by season for each station including hourly values for: minimum, maximum average and standard deviation.

The CTAMS dBase system provides the best mechanism for data management and statistical routines. The expert system then utilizes this data for the analysis. Upon completion the system produces an Exception Report identifying anomalistic data. The report is displayed on the screen and can also be printed. The system also provides a ASCII file which can be cycled back through CTAMS for editing.

The system was designed to be user friendly and utilize graphics as a tool to facilitate communication and ease of use. The system also provides a daily summary of data found acceptable or identified as anomalous and explains why each datum was questionable.

PROOF OF CONCEPT RESULTS

The expert system was tested by analyzing 12 sites that represented the full range of geographic and classification cases. The test sites were analyzed using both the traditional manually intensive process and the expert system.

The findings of the parallel tests included:

- The previous data analysis process required two staff members (senior and junior). In our test cases the junior staff member identified several anomalies, while the senior professional located significantly more exceptions. In addition to all anomalies identified by staff, the expert system found a number of additional occurrences. The CDOT experts confirmed that the additional cases were anomalies that had been overlooked by the human review. It is important to note that data may be anomalistic and still be accurate.

- By extension, the expert system approach allowed the users to focus only on the problem data thus making more effective use of the experts time.

- The time motion study showed that weekly between 12 and 20 minutes of human review time could be saved per station. With 72 stations at a minimum, this accounts for 14 hours per week. The time savings is realized by allowing the computer to conduct the necessary but time-consuming reviews of the data and the efficiencies realized by its identification of problem areas.

- The expert system realized a 35% state cost savings over the manual data analysis approach. These savings are the result of staff time savings and the ability to allow more junior level staff to operate most aspects of the system. The true cost sayings may be greater as traffic data for projects and planning purposes are improved.

- The expert system allowed other users easier access to traffic count information.

- In the manual data analysis process a significant amount of subjective judgments or "rules of thumb" are applied, resulting in a lack of a clear and documented procedure. The expert system approach not only "captures" these rules but also documents the procedures and concepts. Further, the concepts are displayed in a logical decision-making matrix that displays the relationship of the data items and provides a pathway that can be audited to assure quality performance.

- The expert system allows others to more easily learn and conduct the analysis.

NATIONAL DEMONSTRATION

The proof-of-concept project confirmed that the expert system provides a successful means of improving analysis and handling of ATR traffic data. Upon this finding the Federal Highway Administration expanded the Colorado effort to include the Departments of Transportation from Kansas and Minnesota.

The new mandate was to enhance the functionality of the system and confirm the potential of its national application. Working with technical staff from the three states, a new series of knowledge engineering and design sessions were initiated. The states were found to be confronted with similar problems associated with collecting and analyzing traffic data:

- Processing required a significant of amount of staff time.
- The processes had little documentation.
- Accuracy of the analysis tended to be a function of the experience of the technical staff.
- It was difficult to train new staff to perform these analysis accurately.
- The processes tended to be a compilation of disjointed data analysis systems and handling tools.

There was however, a large degree of commonality among the states for identifying anomalistic data and determining whether it should be approved or rejected. From these sessions the rule base was expanded and enhanced.

SYSTEM DEVELOPMENT

A number of principal elements needed to be addressed, including:

- Variety of hardware including Golden River and Streeter,
- Unique state analysis practices,
- Diverse data management, editing and reporting systems.

Input Structure

Key to the success of a national application was identifying a data input system requiring little alteration of the existing state data handling processes. While there was a variety of data collection hardware systems, each state formatted the raw data for submission of a monthly report to the FHWA. The FHWA requires that this report provide data in a standard format by hourly traffic volumes for each ATR counter. The reporting format is titled a Card 3. This format provided a universal data entry structure for the system.

Rule Base

The rule base was modified and enhanced to address:

- Avoiding reanalyzing previously analyzed and accepted data.
- Historical data for each station became the basis for many analyses. These data provide the expected daily patterns to compare against actual readings.
- The history structure was further refined from the proof-of-concept seasonal history file structure to a monthly base.
- The earlier proof-of-concept system utilized a roadway classification system to set parameters for unique types of roadways. Because of the increased use of site history files, these classifications could be abandoned except when historical data was unavailable for the stations.
- The proof-of-concept system utilized a series of holiday rules to address the influence of not only the holiday but preceding and following days. The knowledge engineering sessions illustrated a different set of rules would be required by each state. The system was modified to allow each state to directly specify the days to be considered as holidays or holiday influenced days.

The rules for the ATR programs remained grouped into six major categories as in the proof-of-concept system:

- Rules that use composite traffic data to search for data anomalies.
- Rules that use directional traffic data to search for data anomalies.
- Rules that specifically addresses traffic counts on holidays. Holidays had to be treated as a special case with a separate rule set because of the extraordinary and inconsistent traffic patterns found on holidays.
- Rules (meta-rules) that control which rule groups and subgroups are analyzed in a given situation.
- Rules that identify potential causes for anomalous data such as weather, construction or special events.
- Rules which govern the interaction between the expert system and the data files and other miscellaneous internal system housekeeping chores.

Editor and Record Structure Concepts

To be successful, the editor and data record structure used by the editor had to be designed to provide a significant amount of data and present the data in a series of easily understandable screens. For example, the data record structure needed to maintain the original data, the edited data and track the source and verification of the data.

Flags

The flag convention is utilized to track what actions were taken during the analysis and edit process. Two hourly flags are maintained for each hourly directional count. The first flag is either an **O** or **I**. The character **O** is utilized to indicate that the data in the edited record is original. The character **I** indicates that the data is imputed. Removing an anomalous data point and replacing it with a blank or a value is imputing data.

The second flag identifies whether the system or operator approved the use of the hourly value. The character **V** indicates that the system verified that the data was within reasonable parameters while the character **A** indicates that the system did not verify the data and upon review the operator accepted the value as being possibly anomalistic but reasonable. Whenever the operator imputes data by choosing another value or deleting the data point the system automatically changes the **O** to an **I**, and the **V** or **A** to an **R**, indicating that this data point should be reevaluated. The next time the station is analyzed, the expert system will automatically evaluate all data without an **A** or **V** flag.

File Structure

The output structure needed to allow capture of a number of important pieces of information. To accomplish the file objectives the Card 3 structure was utilized and expanded to include original data, edited data, flags for each hour and direction, and general user entered flags. The new record structure is referred to an extended Card 3 record. The file can include data for any period of time from one month to multiple years.

Editor Screens and Functionality

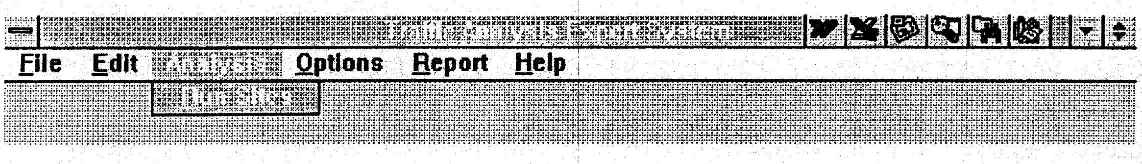
The editor provides a medley of tools to assist in the review of data identified anomalistic by the expert system. These include windows for selecting sites to be analyzed or edited, windows and menus for setting system and editing options, multiple editing formats, multiple graphs depicting actual and historical count information and on-line help capabilities.

EXAMPLE ANALYSIS AND EDITING SCREENS

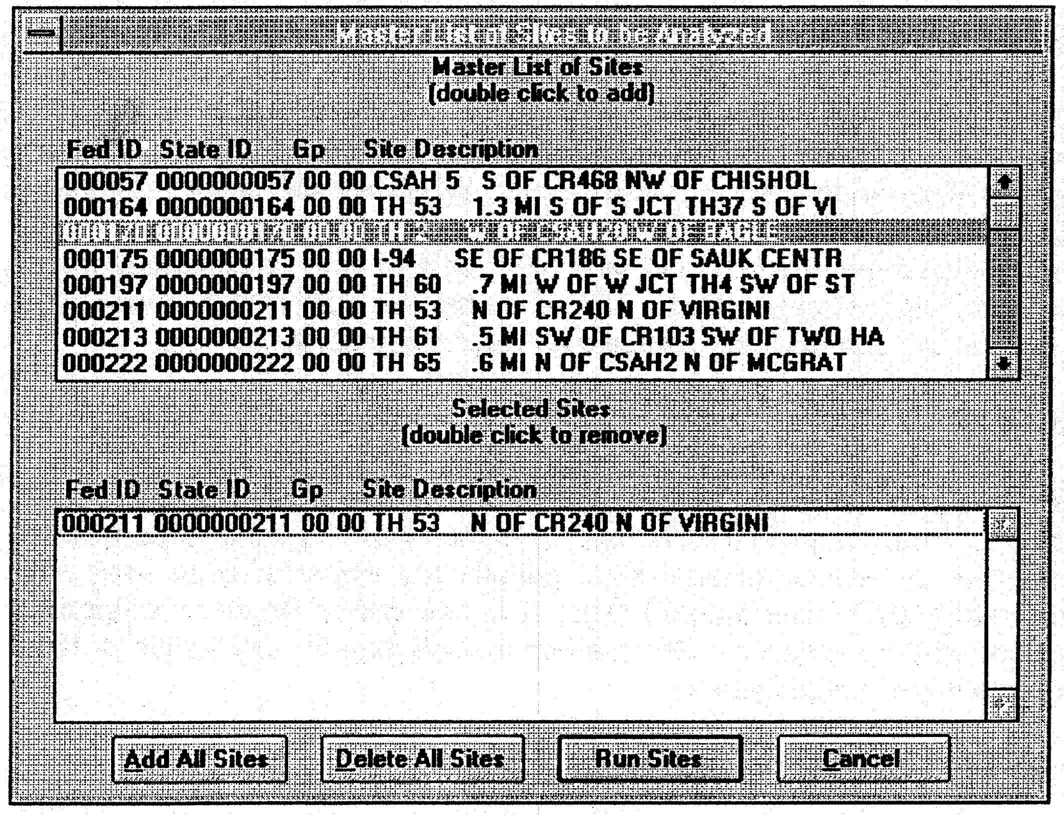
To demonstrate the features of the system, the following illustrates the steps a user would likely take during the analysis and editing process.

- The operator will pull down the File menu and select New Data. This will update previously analyzed and edited data with recent count information.

- The operator then selects Analysis and Run Sites as shown below.



- The operator is then prompted to identify the stations desired for analysis.



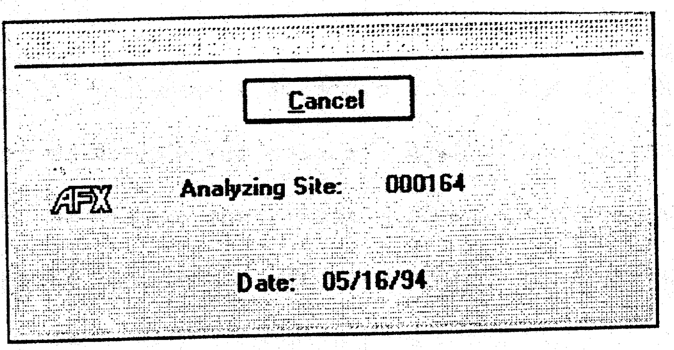
Master List of Sites
(double click to add)

```
Fed ID  State ID    Gp   Site Description
000057 0000000057 00 00 CSAH 5   S OF CR468 NW OF CHISHOL
000164 0000000164 00 00 TH 53    1.3 MI S OF S JCT TH37 S OF VI
[illegible]
000175 0000000175 00 00 I-94     SE OF CR186 SE OF SAUK CENTR
000197 0000000197 00 00 TH 60    .7 MI W OF W JCT TH4 SW OF ST
000211 0000000211 00 00 TH 53    N OF CR240 N OF VIRGINI
000213 0000000213 00 00 TH 61    .5 MI SW OF CR103 SW OF TWO HA
000222 0000000222 00 00 TH 65    .6 MI N OF CSAH2 N OF MCGRAT
```

Selected Sites
(double click to remove)

```
Fed ID  State ID    Gp   Site Description
000211 0000000211 00 00 TH 53    N OF CR240 N OF VIRGINI
```

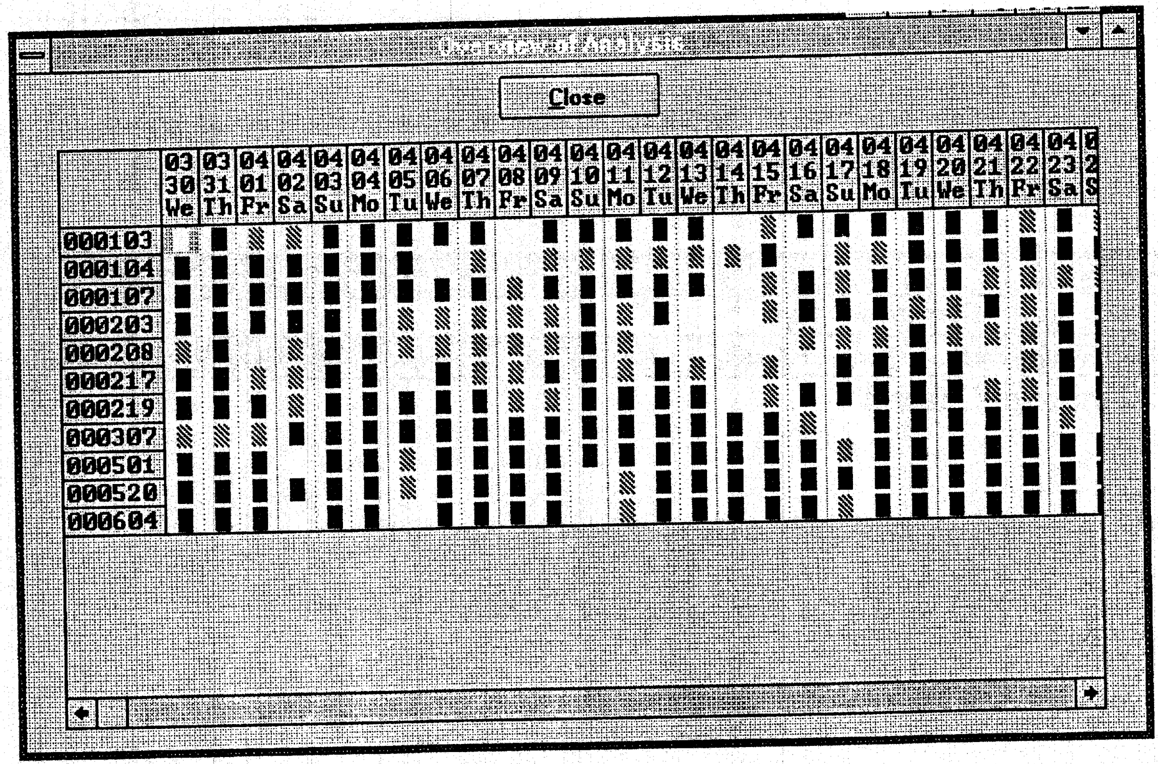
Depending on the computer system, the system analyzes between 3 to 7 days of data for a given station per minute. While the system is running the operator will be informed of the status by a small dialogue box. The box indicates the site being analyzed and the day being evaluated. (shown below)



Analyzing Site: 000164

Date: 05/16/94

- Under the Report menu an Overview is available that highlights by day all stations reviewed during the most recent analysis and presents a snapshot of the number of anomalies identified by the system. (Shown below) A black box indicates that 6 or more hours for that day had anomalistic data, a half-tone box indicates between 1 and 6, while an open box illustrates a day with no identified anomalistic data.



	03 30 We	03 31 Th	04 01 Fr	04 02 Sa	04 03 Su	04 04 Mo	04 05 Tu	04 06 We	04 07 Th	04 08 Fr	04 09 Sa	04 10 Su	04 11 Mo	04 12 Tu	04 13 We	04 14 Th	04 15 Fr	04 16 Sa	04 17 Su	04 18 Mo	04 19 Tu	04 20 We	04 21 Th	04 22 Fr	04 23 Sa
000103	▨	■	▨	▨	■	■	■	■	■		■	■	■	■	■		▨	■	■	■	■	■	■	▨	■
000104	■	■	■	■	■	■	■		▨		▨	▨	▨	▨	▨	▨	■		▨	▨	■	■	■	■	■
000107	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■		▨	■	▨	■	■	■	▨	▨	▨
000203	■	■	■	■	■	■	▨	▨	▨	▨	▨	■	▨	■			▨	■	■	■	▨	▨	■	▨	■
000208	▨	■		▨	■	■	▨	▨	▨	▨	▨	■	▨					▨	▨	▨	■	▨	▨	▨	■
000217	■	■	▨	▨	■	■		■	▨	▨	■	■	▨	■	▨		▨		■	■	■	■		▨	■
000219	■	■	■	▨	■	■	■	■	■	▨	▨	■	■	■	■		▨	■	■	■	■	■	▨	▨	■
000307	▨	▨	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨		■	■	■	■	■	▨
000501	■	■	■		■	■	▨	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■	■
000520	■	■	■	■	■	■	▨	■	■	■	■		▨	■	■	■	■	■	■	■	■	■	■	■	■
000604	■	■	■		■	■		■	■	■	■		▨	■	■	■	■	■	▨	■	■	■	■	■	■

- Also under Report is an Exceptions Report which provides written descriptions of the analysis by day and hour. As shown below, the reason and rule that caused a count to be identified as anomalous.

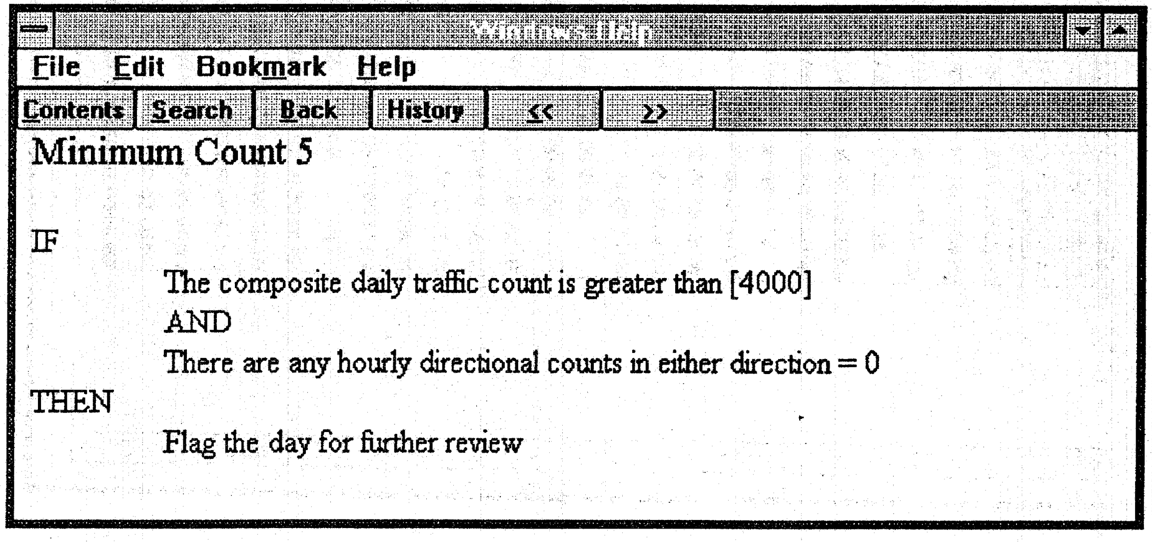
```
04/03/93  OK

04/04/93  FAILED: >, N/E hourly count of 0 on a high volume road: rule
minimum count 5a
  Hour 2 >, Missing hourly data - entire day should be reviewed: rule
control3a
  Hour 3 >, Missing hourly data - entire day should be reviewed: rule
control3a
  Hour 4 >, Missing hourly data - entire day should be reviewed: rule
control3a

04/05/93  FAILED: >, N/E hourly count of 0 on a high volume road: rule
minimum count 5a
  Hour 12 >, Missing hourly data - entire day should be reviewed: rule
control3a

04/06/93  FAILED: >, N/E hourly count of 0 on a high volume road: rule
minimum count 5a
  Hour 12 >, Missing hourly data - entire day should be reviewed: rule
control3a
```

- The operator may utilize the Help window to identify the details of the rule that failed. In this case the most common failure was the Minimum Count Rule 5.



Minimum Count 5

IF

The composite daily traffic count is greater than [4000]

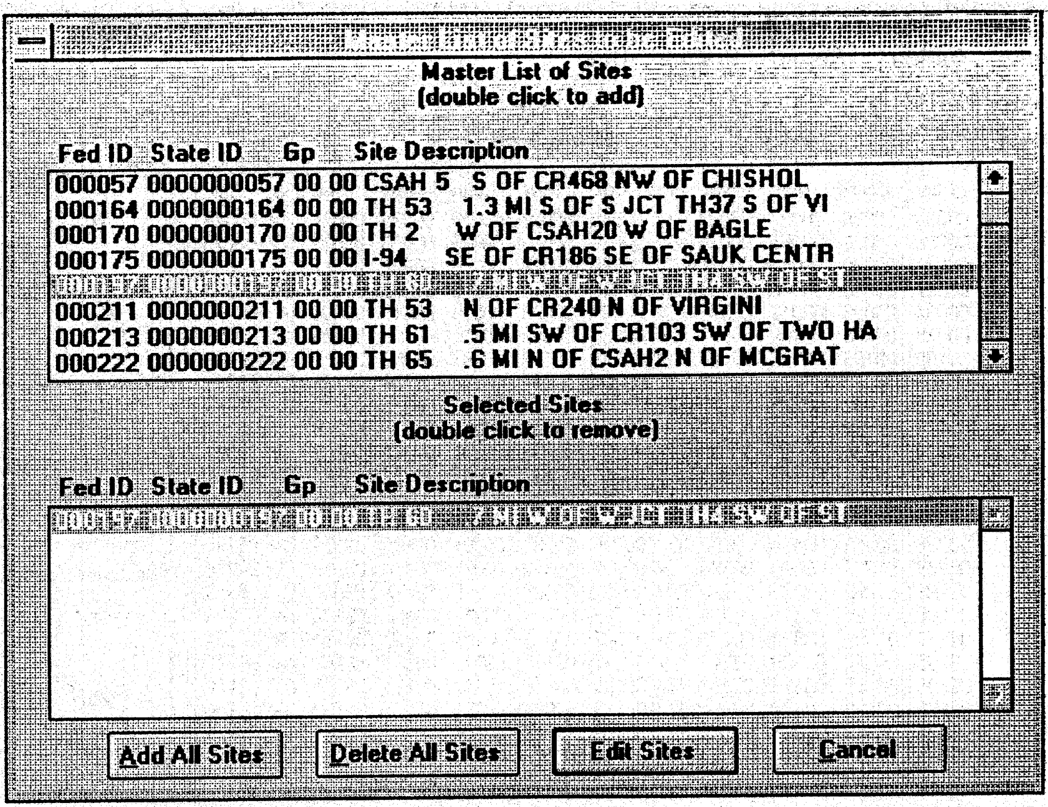
AND

There are any hourly directional counts in either direction = 0

THEN

Flag the day for further review

- At this point the operator will likely wish to initiate the editing of specific sites. After selecting the Hourly Editor from the Editor menu, the following selection table appears. The system will automatically select the sites from the most recent run.



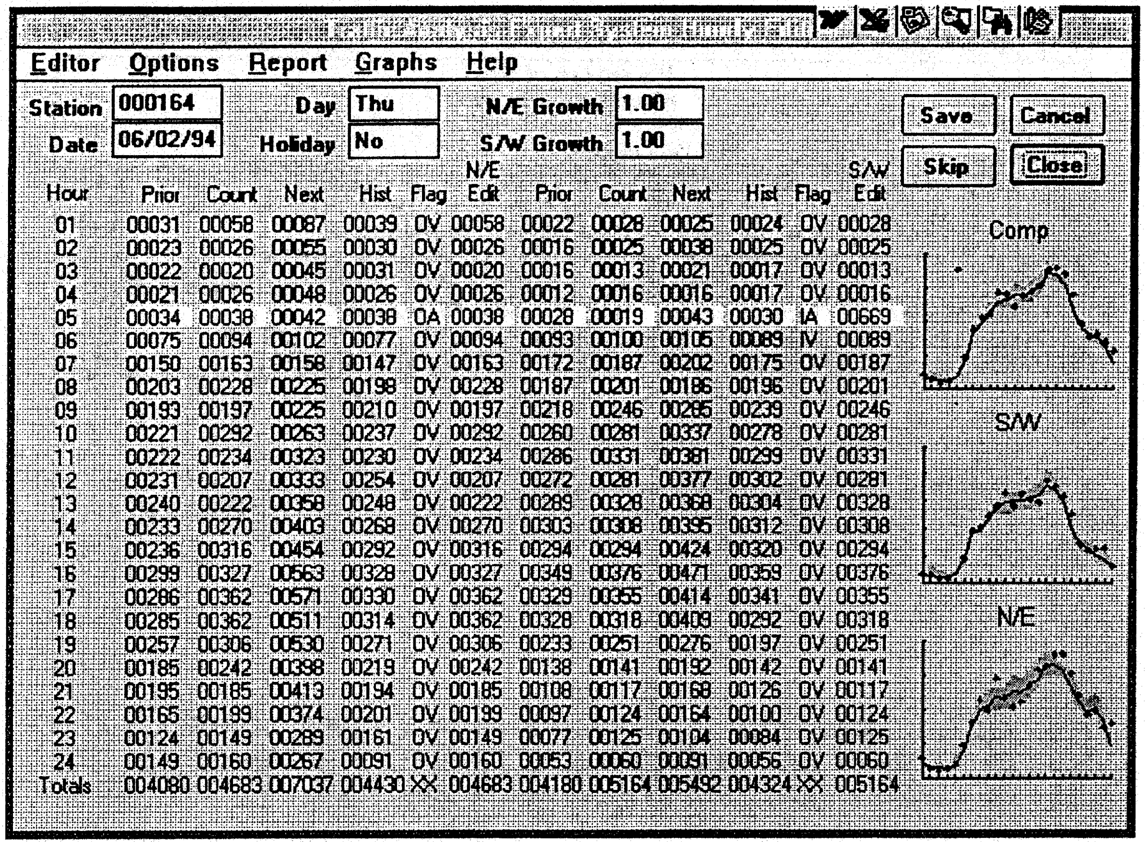
Master List of Sites
(double click to add)

```
Fed ID  State ID    Gp   Site Description
000057 0000000057 00 00 CSAH 5   S OF CR468 NW OF CHISHOL
000164 0000000164 00 00 TH 53    1.3 MI S OF S JCT TH37 S OF VI
000170 0000000170 00 00 TH 2     W OF CSAH20 W OF BAGLE
000175 0000000175 00 00 I-94     SE OF CR186 SE OF SAUK CENTR
000197 0000000197 00 00 TH 60    .7 MI W OF W JCT TH4 SW OF SI
000211 0000000211 00 00 TH 53    N OF CR240 N OF VIRGINI
000213 0000000213 00 00 TH 61    .5 MI SW OF CR103 SW OF TWO HA
000222 0000000222 00 00 TH 65    .6 MI N OF CSAH2 N OF MCGRAT
```

Selected Sites
(double click to remove)

```
Fed ID  State ID    Gp   Site Description
000197 0000000197 00 00 TH 60    .7 MI W OF W JCT TH4 SW OF SI
```

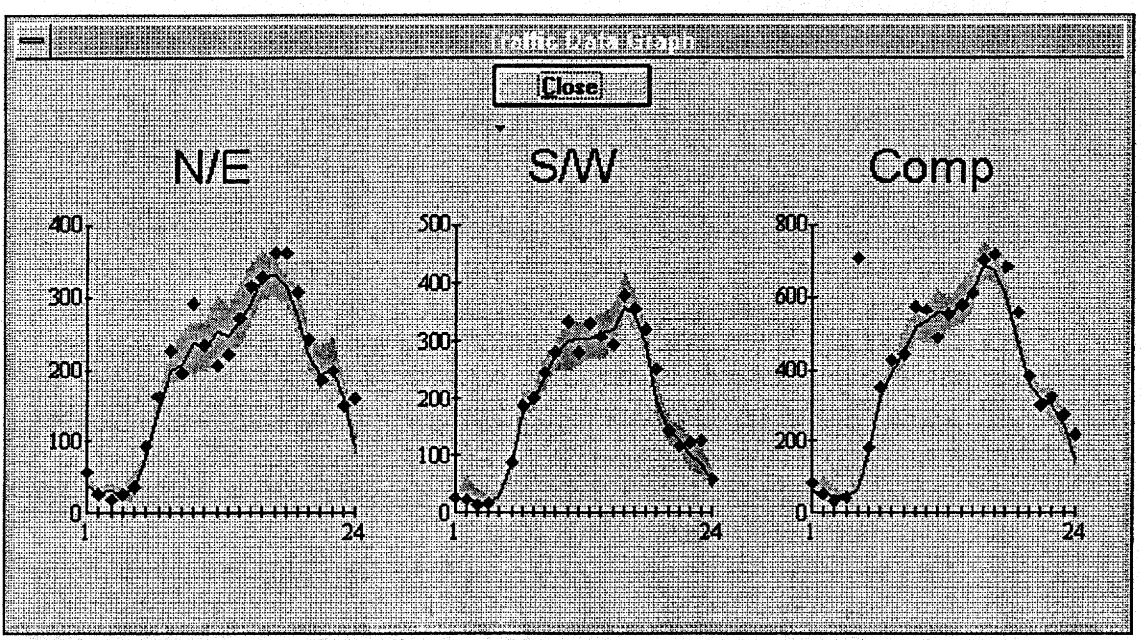
- The system will automatically go directly to the first site and day with anomalistic data. The hourly editor window provides over three hundred individual pieces of information (shown below). These include:
    - General information on the top of the window includes the station identifier, the date of the count, the day of the week and whether the day was a holiday.
    - The system highlights the hours that the operator should review. In the example below, Hour 5 has been identified as anomalistic.
    - The window provides the operator with the hourly volumes for each direction for the prior day, the next or following day and the historic average for that day.
    - Utilizing the mouse, the operator can edit the hour simply by clicking on any of the hourly fields and this value will be placed in the edited count field. The operator could also simply type in an imputed value.
    - If the operator clicks the historic value, the system will automatically project the data to a current period utilizing the growth factors shown on the top of the screen. These growth factors are automatically read from the history files or can be set by the user.
    - N/E refers to traffic in either the North or East directions and the S/W refers to South or Westbound traffic.
    - Directional and composite hourly volumes are graphed to provide additional information. The points are count data, the single line is the historic average and the area chart represents the maximum and minimum values as recorded in the history file.



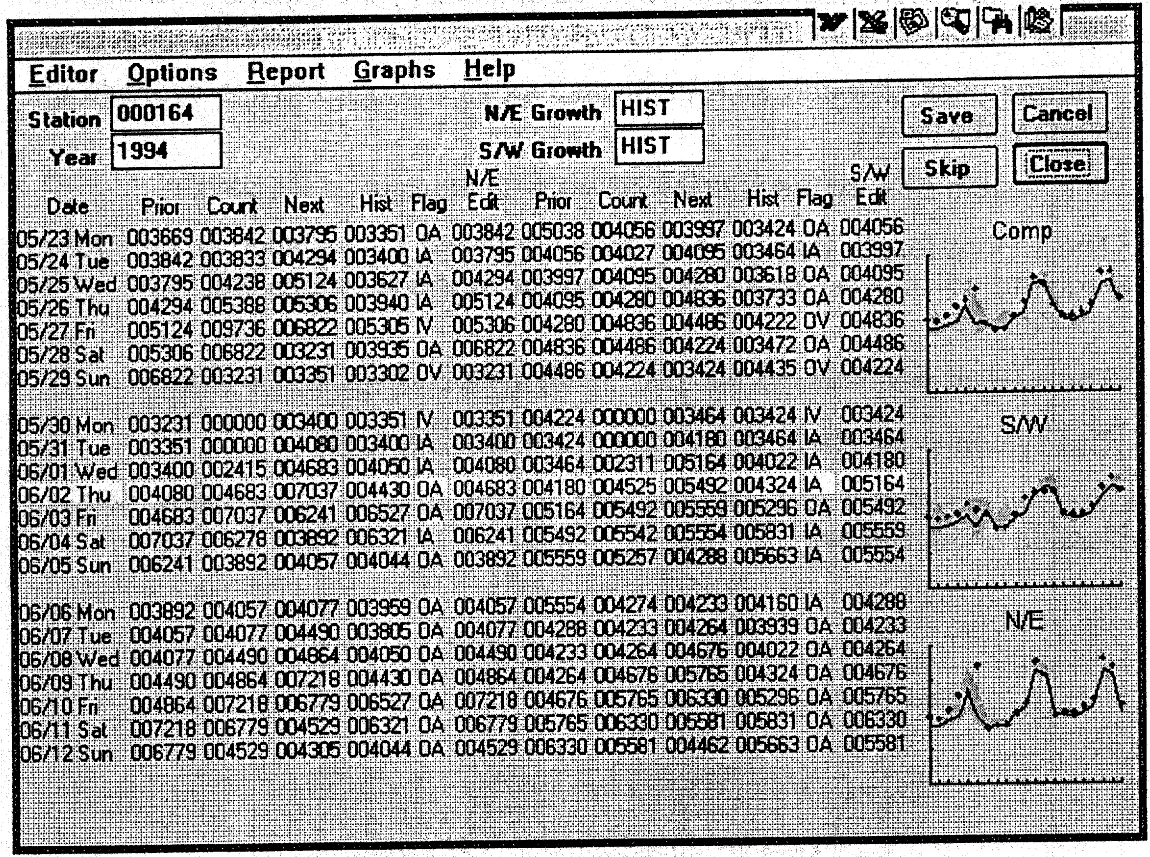
Station 000164
Date 06/02/94
Day Thu
Holiday No
N/E Growth 1.00
S/W Growth 1.00

					N/E						S/W
Hour	Prior	Count	Next	Hist	Flag	Edit	Prior	Count	Next	Hist	Flag	Edit
01	00031	00058	00087	00039	OV	00058	00022	00028	00025	00024	OV	00028
02	00023	00026	00055	00030	OV	00026	00016	00025	00038	00025	OV	00025
03	00022	00020	00045	00031	OV	00020	00016	00013	00021	00017	OV	00013
04	00021	00026	00048	00026	OV	00026	00012	00016	00016	00017	OV	00016
05	00034	00038	00042	00038	OA	00038	00028	00019	00043	00030	IA	00669
06	00075	00094	00102	00077	OV	00094	00093	00100	00105	00089	IV	00089
07	00150	00163	00158	00147	OV	00163	00172	00187	00202	00175	OV	00187
08	00203	00228	00225	00198	OV	00228	00187	00201	00186	00196	OV	00201
09	00193	00197	00225	00210	OV	00197	00218	00246	00285	00239	OV	00246
10	00221	00292	00263	00237	OV	00292	00260	00281	00337	00278	OV	00281
11	00222	00234	00323	00230	OV	00234	00286	00331	00381	00299	OV	00331
12	00231	00207	00333	00254	OV	00207	00272	00281	00377	00302	OV	00281
13	00240	00222	00358	00248	OV	00222	00289	00328	00368	00304	OV	00328
14	00233	00270	00403	00268	OV	00270	00303	00308	00395	00312	OV	00308
15	00236	00316	00454	00292	OV	00316	00294	00294	00424	00320	OV	00294
16	00299	00327	00563	00328	OV	00327	00349	00376	00471	00359	OV	00376
17	00286	00362	00571	00330	OV	00362	00329	00355	00414	00341	OV	00355
18	00285	00362	00511	00314	OV	00362	00328	00318	00409	00292	OV	00318
19	00257	00306	00530	00271	OV	00306	00233	00251	00276	00197	OV	00251
20	00185	00242	00398	00219	OV	00242	00138	00141	00192	00142	OV	00141
21	00195	00185	00413	00194	OV	00185	00108	00117	00168	00126	OV	00117
22	00165	00199	00374	00201	OV	00199	00097	00124	00164	00100	OV	00124
23	00124	00149	00289	00161	OV	00149	00077	00125	00104	00084	OV	00125
24	00149	00160	00267	00091	OV	00160	00053	00060	00091	00056	OV	00060
Totals	004080	004683	007037	004430	XX	004683	004180	005164	005492	004324	XX	005164

- Under the Graph menu the operator may select Large Graph to enlarge the view of graph.



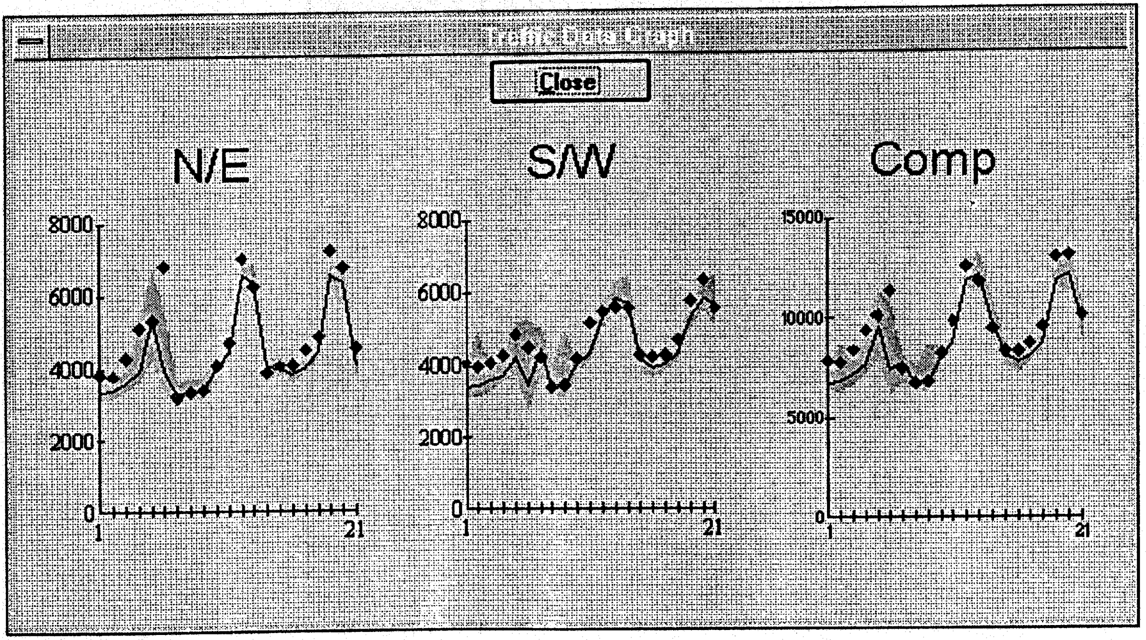
- To obtain additional perspectives of the data, the operator may go to the weekly editor window to determine how these data vary over a three week period. This editor screen allows daily editing of data. This editor also highlights the data that appear anomalistic (June 2nd.)



Station 000164
Year 1994
N/E Growth HIST
S/W Growth HIST

Date	Prior	Count	Next	Hist	Flag	N/E Edit	Prior	Count	Next	Hist	Flag	S/W Edit
05/23 Mon	003669	003842	003795	003351	OA	003842	005038	004056	003997	003424	OA	004056
05/24 Tue	003842	003833	004294	003400	IA	003795	004056	004027	004095	003464	IA	003997
05/25 Wed	003795	004238	005124	003627	IA	004294	003997	004095	004280	003618	OA	004095
05/26 Thu	004294	005388	005306	003940	IA	005124	004095	004280	004836	003733	OA	004280
05/27 Fri	005124	009736	006822	005305	IV	005306	004280	004836	004486	004222	OV	004836
05/28 Sat	005306	006822	003231	003935	OA	006822	004836	004486	004224	003472	OA	004486
05/29 Sun	006822	003231	003351	003302	OV	003231	004486	004224	003424	004435	OV	004224
05/30 Mon	003231	000000	003400	003351	IV	003351	004224	000000	003464	003424	IV	003424
05/31 Tue	003351	000000	004080	003400	IA	003400	003424	000000	004180	003464	IA	003464
06/01 Wed	003400	002415	004683	004050	IA	004080	003464	002311	005164	004022	IA	004180
06/02 Thu	004080	004683	007037	004430	OA	004683	004180	004525	005492	004324	IA	005164
06/03 Fri	004683	007037	006241	006527	OA	007037	005164	005492	005559	005296	OA	005492
06/04 Sat	007037	006278	003892	006321	IA	006241	005492	005542	005554	005831	IA	005559
06/05 Sun	006241	003892	004057	004044	OA	003892	005559	005257	004288	005663	IA	005554
06/06 Mon	003892	004057	004077	003959	OA	004057	005554	004274	004233	004160	IA	004288
06/07 Tue	004057	004077	004490	003805	OA	004077	004288	004233	004264	003939	OA	004233
06/08 Wed	004077	004490	004864	004050	OA	004490	004233	004264	004676	004022	OA	004264
06/09 Thu	004490	004864	007218	004430	OA	004864	004264	004676	005765	004324	OA	004676
06/10 Fri	004864	007218	006779	006527	OA	007218	004676	005765	006330	005296	OA	005765
06/11 Sat	007218	006779	004529	006321	OA	006779	005765	006330	005581	005831	OA	006330
06/12 Sun	006779	004529	004305	004044	OA	004529	006330	005581	004462	005663	OA	005581

The weekly editor also provides an enlarged graph.



INITIAL FINDINGS

The system has recently been installed at the Departments of Transportation in Colorado, Kansas and Minnesota. Initial findings include:

- The system identified the anomalies determined by the experts. Further, the system accurately identified anomalies overlooked by the experts.
- The graphics provided an expeditious tool for the operators to evaluate the anomalistic data.
- The system allowed the operator to focus on the anomalistic data.
- The mouse application to edit data minimized the number of keystrokes required to impute data. This resulted in significant overall savings of operator time.
- The system provided a single point of analysis and edit for the states.
- The system provided an audit trail not previously available.

Testing will continue over a one-year period to provide a more detailed evaluation of the system.

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PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

Mr. Eugene A. Martin
Virginia DOT

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PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

Eugene A. Martin, Virginia DOT

In Virginia, at present, there are 13 weigh-in-motion sites. All but one are part of the LTPP program. The one site which is not part of the program is located within the central part of the state, and is used for various in-house studies. When we installed the weigh-in-motion sites with LTPP for SHRP, we went ahead with the concept that we want to use all the sites for as much data as we could handle for in-house purposes. We have assigned each one of the LTPP sites as a continuous count station, and from them, we are collecting continuous classification data. We also use them for 55-mile-an-hour speed compliance, as well as for supplying average weights of vehicles to our materials lab. We try to use all that we can from these sites. Therefore, it is very important to us to keep them up and running because they are part of our traffic monitoring program.

I will discuss the way that we go about trying to assure that the data we send to LTPP is of reasonable quality. We would like to call it a common sense approach. The first point to make is the understanding of weigh-in-motion versus static weighing. This is important when you first have these systems installed. The second point is to note the characteristics of all the vehicles in your area. From this you can make logical assumptions of the data that you collect. Once that is done, you can then identify the problem equipment. And you do that by reviewing the data, and going back to see when your problems start. Upon completion of that, the next step would be to conduct an on-sight study of the particular equipment. The last step that we do is to segregate the questionable data from the submission to LTPP.

We feel that it is very important to have an understanding of the different concepts of static weighing and WIM. Because after all, when we feel that data is subject to error, what we are doing is making a comparison to static weight data. We feel it is very important that we and our technicians understand the difference between the two systems.

The illustration of a truck on a pogo stick may be a little extreme, but it is really not that far off. What we are asking weigh-in-motion to do for us is to dynamically weigh a solid mass out on the highway. We are doing that in various environmental conditions at speeds up to 65 miles an hour, and we are doing it on a sensor about the size of a postage stamp (the typical piezo sensor installation). I have heard lots of talk the last couple days about whether or not the data that we are collecting is accurate. To even enter into a conversation like that you have to understand what we are trying to do when we are collecting this data with the equipment that we are using.

The normal procedure is that we use static weight with static scales for the acceptance of WIM products. And one of the obvious things about a static scale is the size of the sensors. You have weighing elements that typically weigh the entire vehicle, which most of us from past experience know is referred to as single draft weighing, versus the multi-draft weighing that we actually do with piezo sensors. We have the vehicle pull up on static scales. All wheels are on all elements of static scales. The truck is directed to stop. He sits there. He is asked to release his brakes, and if all goes well, after a certain period of time, a balance is obtained and a weight readout is taken. One of the correlations that I like to make is that for a static scale the criteria which is used all the time is the National Bureau of Standards Handbook 44 versus, the ASTM specs for WIM. If you look at them, you can see the difference in acceptance criteria and maintenance criteria.

Handbook 44 states that for each increment of 500 graduations you are given one graduation of tolerance. As far as acceptance tolerance, that works out to be one-tenth of one percent of the gross weight. For maintenance tolerance it works out to be two tenths of one percent of the weight. For a typical 80,000 pound truck on static scales you are looking at plus or minus 160 pounds on gross weight. With the ASTM spec, which is what we use on weigh-in-motion equipment, we are looking at a ten percent tolerance on gross, which if you were to look at that same 80,000 pound gross vehicle would be plus or minus 8,000 pounds. If you were to go up even further on axle loads, there would be a twenty percent tolerance. One of the things that we stress to our technicians, as far as looking at the quality of the data, is to understand what you are looking at. As my daughter tends to remind me all the time when I ask her how come she does not help her mother more often, she says "get real, daddy." I think this is one of the questions that we need to ask ourselves when we sit down and ponder how accurate the data that we collect on our weigh-in-motion equipment is. It may be that we, through meetings like NATDAC '94, need to reevaluate our position and enforce some type of more stringent standards as far as acceptance and operation of weigh-in-motion equipment.

The next thing that we like to do is to emphasize to our technicians to learn the different characteristics of vehicles which operate in our state. This is real easy to do because one of the ways that we come up with standards is by going to all our static scales and collecting samples. We have compiled thousands of samples from static scales. We send the technicians out who actually work with weigh-in-motion data so they can be familiar with the type 7s, the type 8s, the tractor-trailers and the double trailer configurations; so they are actually seeing the trucks pull on static scales. Then they have some idea of what they are supposed to weigh; what an average weight would be. Then they fully understand what they see when they are in the office looking at mass amounts of data on paper.

As previously stated, we go around to all the static scales and collect samples. We are presently trying to compile a set of figures to see how much variation there may be on a seasonal basis. We also, like many other people, have determined from samples that we have taken on static scales, the average empty weights, the average full weights and the overall middle range weights of vehicles. We use these figures when we evaluate the data that we collect, and try to assess its accuracy.

We have collected and compared average weight data from static scales, which would represent gross vehicle weight and tandem weights and steering axle weights, and correlated that with the averages obtained from our weigh-in-motion sites. Once that information was correlated and put in spreadsheet form, it was occasionally indicated that there was a problem at a site. That data was then subject to further inquiry. Now at that point, we do not rule out the data as invalid, but it sets up a flag to tell our technicians that the next step is to look at that data a little closer; go out to the site and check the equipment.

Upon site inspection, some of the problems which may be seen with the weigh-in-motion equipment, are with the actual sensors themselves. In many cases the separation of the sensor from the pavement is the problem. And of course when that happens the sensor becomes loose, and the weights thereafter are subject to error. We have had this problem at most of our weigh-in-motion sites.

We, like many of the states, have two or three people (we actually have one person) who is assigned permanently to weigh-in-motion, and from time to time we feed him other tasks. So it may be some time before he gets to the WIM sites. We have one site that is 250 miles away from the office, so it may be some time before he gets to that site, even though he may have realized that the data at that site is subject to scrutiny. By the time he does get out there he may notice that there is actually full deterioration of the sensor.

Once we have found a piezo sensor installation where the asphalt has come away from the sensor, we segregate all the data from these sites until repairs are completed. If you can catch these sites relatively early, there is a sealing process that we have found to extend the life of the sensors. It is kind of similar to the sealing process that you would do on your asphalt driveway at home. However, if you do not get to it quick enough, the sensor can come completely out of the ground. At one of our sites a technician found part of the sensor up three or four inches; the rest of it in pieces on the side.

As far as quality assurance, it is very important to know what you are looking at. Once you have determined that the data is subject to error, that there are some problems with the data, what to do with it as far as submission is pretty clear. That data does <u>not</u> need to go to LTPP. We feel that data should not be submitted until appropriate corrective measures are taken. We take a relatively elementary approach to data. We have the graphs that we plot, but what we tend to use is average axle weights and average gross weights from samples that have been obtained from static scales. Because when you look at it, that is what we use for determining the accuracy of weigh-in-motion.

I do not know what the answer is. Hopefully I have given some food for thought. As I mentioned, we try to use a common sense approach; knowing the vehicles that we are weighing, understanding what the system is capable of doing, under what circumstances and criteria that we bought the equipment, what criteria factors that we are using. We, just like many states, have technicians who are overburdened right now, and it is very hard for them to sit down and go over every piece of data. We use the normal software that comes from the vendor, do site summary reports, and compare that to a standard that we have developed from static scales. It is a relatively easy task. All I can give you is the express wish that over the upcoming years we will look further into the approaches that we do take with weigh-in-motion equipment.

One of the questions I feel we need to ask ourselves is what are we doing? Are we putting this equipment down to measure vehicles statically, or to measure the dynamic impact that these vehicles do to the highways?

PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

Speaker: Mr. Mark S. Flinner
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Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

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ABSTRACT

Weigh-in-Motion (WIM) has been in use for a number of years. Questions are now being raised about the quality of the data. This has prompted efforts to address those concerns. Over the past 2 years, the Minnesota Department of Transportation (Mn/DOT) has formulated a plan for an edit program. The premises used for this program is that the rules must have a solid logical foundation, checking must be done on groups of records of vehicles as well as on individual vehicles, and the data itself, when used in combination with knowledge about the truck fleet, should be used to indicate its validity.

The 5 axle semi is the vehicle around which the edits for weight data are being developed. Some facts about them or the characteristics of their use which assist in building the edits are that when unloaded they weigh about 30 kips and when loaded they weigh close to 80 kips; on major routes, they repeat trips week after week; and the peaks for unloaded and loaded should be in the same place in side-by-side lanes heading the same direction.

The distribution of gross weight of 5 axle semis is utilized for analysis purposes. This can be used to detect drift in calibration, system failure or erratic patterns. Once problems with the data are identified, they can then be dealt with as desired.

Assuring the quality of data collected by WIM is a difficult task. Other techniques which can be used to check truck weight data include a) the use of are enforcement weigh stations to see what weights they monitor for unloaded and loaded 5 axle semis, b) monitoring specific truck types which carry loads of generally known weights, and c) analyzing the weights of 5 axle semis on major routes covering several states.

INTRODUCTION

The Minnesota Department of Transportation (Mn/DOT) and other states and provinces have been using Weigh-in-Motion (WIM) for a number of years. As more data is collected, the issue of the validity of that data has been raised. WIM data quality is a complex issue which is difficult to handle. The primary reason for this is the problem involved in establishing the proper scale calibration and then maintaining and tracking that calibration over time. The objective of calibration is of course to accurately weigh traffic stream trucks. Due to limited resources and practical limitations, calibration is most frequently approximated by using one or more test trucks. The system is then calibrated to those trucks and it is assumed that it is properly calibrated for all traffic stream trucks. That assumption may be correct for some lanes or truck types while it is incorrect for others. Even if it is correct, one still has the problem of monitoring that calibration over time.

Because of this issue of calibration, WIM data quality assurance rules must be developed and structured to effectively deal with it. Mn/DOT has been working on this for 2 years. There are three general elements needed in these rules. They are:

1) The necessity for a solid foundation for the rules. They need to be based on sure knowledge and facts.

2) The need to check grouped or summarized data as well as individual vehicle records. Summarized data can give a better indication of the functioning of a system than individual vehicle records.

3) The need to formulate rules which allow the data itself to indicate to the user whether or not it is valid. A procedure internal to the system is needed for continuous monitoring as opposed to test trucks which are infrequently used. Test trucks can indicate only what is happening on the specific days when they are used and not on the intervening days between their use.

KNOWLEDGE OF 5 AXLE SEMIS

This paper deals primarily with the weight portion of WIM data quality analysis. It does not deal with vehicle class, axle spacing, speed or length data collected by WIM. However, the weight portion is only a part of the edit. The intension is to check all traffic components in a coordinated effort. The basic components are total traffic, vehicle class and weight. In developing rules for weight data, one first needs to determine the critical vehicle type. In Minnesota, that is the 5 axle semi. They typically contribute between 70 and 90 percent of the ESAL's on many of the state's Trunk Highways (TH). Furthermore, of all 5 axle semis, those that are loaded near the legal limit contribute most of the ESAL's on a typical route.

Once it has been determined what truck to focus on, the next question is what is known about them that will assist in developing rules which can be used to check on the validity of weight data. Some of the things known about 5 axle semis or the characteristics of their use are as follows:

1) Static Gross Vehicle Weight (GVW) data indicates that, <u>on the average</u>, unloaded they weigh about 30 kips and loaded they weight just under 80 kips. This latter weight assumes a legal limit of 80 kips. A plot of the distribution of their gross weight will generally show peaks at both of those points.

2) This truck is usually used to haul freight long distances. Many of them make repeat trips week after week on major routes, often carrying the same load. Consequently, site specific GVW distributions should repeat week after week. However, seasonal hauls of various products can make those patterns change.

3) As a group, the unloaded trucks have few opportunities to obtain very light loads (2 to 4 kips). A few individual trucks can find those loads, but most can not. If most of the group did, the peak for the average unloaded 5 axle semi would shift to 32 or 34 kips. Because of the improbability of most finding this small a load, if the shift is observed, it is likely due to a drift in the scales calibration.

4) The peaks for the unloaded and loaded trucks in side-by-side lanes heading the same direction should occur at the same GVW values on the GVW distribution. The magnitudes of the peaks may be different, but their placement should be the same.

5) WIM systems located on the same route may have the same GVW weight patterns. Mn/DOT has 3 WIM systems located on TH 2 where this is the case (1). Other routes may not exhibit such tightly grouped weight data.

EXAMPLES OF THE DISTRIBUTION OF GROSS WEIGHT OF 5 AXLE SEMIS

There are various patterns of gross weight distribution for 5 axle semis. When using one week of data as the unit to study, the patterns at some sites repeat nearly exactly from one week to another. Others show slight variations from week to week, and yet others will exhibit very different patterns. Some do not even seem to have identifiable patterns. Yet others show a definite pattern one week but a totally different one in a succeeding week. The data for the second week likely indicates system failure.

However, in general, if the WIM system is operating properly and if the sample size is large enough, the distribution will have two peaks. One will be for the unloaded and the other for the loaded. If the calibration is correct, the peak for the unloaded will be close to 30 kips and just under 80 kips for the loaded. There are instances where only one of the peaks occur such as in Figure 3. A route like this has predominantly loaded trucks heading one direction and unloaded trucks going the other direction.

A WIM edit program might be expected to label weight data as valid, questionable, or invalid. Data can be invalid due to an erratic pattern or system failure. In using the check on individual vehicle records in a WIM edit, it is best to permit as many of the records to pass as is possible. The edit on groups of vehicles should be used to screen out large groups of data where needed. The individual vehicle edit can not effectively and <u>should not</u> be used for this purpose. If too high a percentage of vehicles are deemed bad by the individual vehicle edit, either the parameters are set too tight or the WIM system is faulty. It is counterproductive to force individual truck weights to fit a narrowly defined view of where they should fall.

Figure 1 shows how static gross weights distribute for 5 axle semis. This data were collected in Minnesota in 1985. That is the last year when it was collected in that manner. Note the peaks for the unloaded and loaded at 30 and nearly 80 kips respectively. There are about 3100 vehicles represented here. In experimenting with sample size, it appears that a minimum of 150 5 axle semis are needed for a stable pattern. A larger sample may be needed if the weights in that lane have a high degree of variability.

An analysis of WIM data using the distribution of gross weight of 5 axle semis must be done on an individual lane basis. Equipment failure and calibration drift can occur at the same time on all lanes at a site. However, these problems, especially calibration drift, most frequently occur to the individual lane. Consequently, that is the unit which must be examined. Once this analysis has been performed on a lane's data, the data can be judged as valid and the data can be combined if so desired.

Figure 2 shows 8 consecutive weeks of WIM data collected on I-94 located northwest of Minneapolis. The scale is an International Road Dynamics (IRD) hydraulic load cell. The repeatability shown here is excellent. There are about 5500 vehicles represented in each week. This data are for the right westbound lane only.

Figure 3 shows 6 consecutive weeks of WIM data collected on TH 2 located near Bemidji. The scale is an IRD hydraulic load cell. The repeatability of this data are also very good. There are about 1600 vehicles represented in each week. This data are for the right eastbound lane only. Figures 2 and 3 show perhaps the best that can be expected from WIM systems. There are two elements necessary for this to occur. First, there must be weights which are in fact similar from week to week. Second, the WIM system must be functioning properly with no drift in calibration and no other problems.

Figure 4 shows an example of system failure. This is from the same WIM on I-94 as is shown in Figure 2. The week of October 22-29 is the good week. It has the same pattern observed in Figure 2. The week of December 3-10 is bad. It has what might be considered a slight peak at 30 kips and the line tapers down from there. There is too high a percent of vehicles at the lowest weight entry. A WIM edit program would identify that week as invalid. In Minnesota, this would be considered a system failure with the data being unusable. There are about 5000 vehicles represented in each week.

Figure 5 shows an erratic pattern. This is from the TH 65 WIM located south of Cambridge. The scale is IRD piezo cable installed in flexible pavement. One of the piezo cables was inadvertently installed too close to a major crack in the pavement. As a result, the weight data collected by the system are erratic. A WIM edit program would probably indicate that this data has questionable validity. There are about 200 vehicles represented in each week.

Figure 6 shows a drift in calibration. This is from the I-494 WIM in Bloomington. The scales are IRD hydraulic load cell. The unloaded peaks for the two weeks are about 19 percent different while the loaded peaks are about 23 percent different. This is a classic example of shift in calibration. Most shifts are much smaller. Mn/DOT feels that a shift of 3 or 4 percent is significant and needs to be corrected. A shift of 4 percent translates into a change in ESAL's of about 16 percent. A WIM edit program would detect and note the shift in calibration illustrated in Figure 6. There are about 7500 vehicles represented in each week.

Figures 7 and 8 show data in side-by-side lanes with Figure 7 being the right lane and Figure 8 the left. This data are from the WIM located on I-90 west of Dakota in the southeastern part of the state. These are the westbound lanes. The scales are IRD bending plate. Note that the peaks for the unloaded and loaded are in the same spot respectively for both lanes. They are not the same height, but that does not make the data in one of the two lanes invalid.

These scales are located at the crest of a long hill. Note that there is a higher percentage of loaded trucks in the right lane (19 percent) than there is in the left lane (13 percent). This is because some loaded trucks climbing the hill move over into the right (slower) lane. Conversely, unloaded trucks tend to use the left lane at a higher rate than the right at this particular site because they are better able to maintain their desired speed. A WIM edit program should probably label this data valid. However, there is one problem with this data set. The peak for the loaded is at 72 kips for both lanes. This problem will be discussed in the next section of this paper. There are about 5000 vehicles in the right lane in each of these weeks and 500 in the left lane.

PROBLEMS AND DIFFICULTIES IN COLLECTING QUALITY WIM DATA

There are several issues which the traffic community need to resolve in order to feel comfortable with WIM and quality assurance programs which check on the validity of the data. One issue which was discussed in the introduction to this paper is the difficulty in calibrating a system for traffic stream vehicles, maintaining that calibration and monitoring it. Research continues on this issue.

The second issue which has been observed in Minnesota but not yet thoroughly investigated is the non-linearity of measured weights produced by WIM at some sites. A typical illustration of this is shown in Figures 7 and 8. It is typical in that the unloaded trucks are usually observed where they belong at about 30 kips while the loaded are in the 60 to low 70 kip range. There are then very few or sometimes no weights in the upper 70's or low 80's. This does not make sense, particularly on the rural interstate.

A check with the State Patrol operating a weigh station which is located close to another of our WIM sites confirmed that the unloaded 5 axle semis weigh about 30 kips while the loaded ones weigh in the upper 70's. This phenomena appears to be taking place at some sites but not others. It is not erratic in that it seems to permanently affect a site. The origin of the problem is yet to be determined.

OTHER SUGGESTED SOURCES AND TECHNIQUES

The traffic community needs to broaden its thinking on what might prove useful in operating WIM systems and in evaluating the data they collect. Sources and techniques other than those normally used can provide at least some of what is needed in this area. One example discussed extensively in this report is to evaluate the gross weight distribution of 5 axle semis. It seems to provide the basis for an effective procedure to evaluate weight data collected by WIM. A second technique mentioned was to contact weigh stations operated by enforcement personnel to see what weights they are monitoring for unloaded and loaded 5 axle semis. Even though overweight vehicles do avoid them, they can often produce something worthwhile for making a comparison.

Another source that can be used in checking on the calibration is the monitoring of WIM weights of specific body types. In Minnesota, 5 axle semi grain trucks have quite predictable loads when transporting grain. A relevant evidence law permits the State Patrol to check weighbills at the elevator where the grain is hauled. If they are over the legal limits, they can be cited for a weight violation even though they were not actually stopped and weighed by enforcement personnel. This has put an effective cap on their weights. They all come in very close to 80 kips. If they are observed as a group weighing close to 70 kips on the average at the WIM, there is a good chance that the calibration is wrong. Very likely other areas of the country also have specific vehicles or body types which have quite predictable loads.

Another technique that can and should be investigated is the tracking of weights on major truck routes across portions of the country. For example, it would be interesting to compare the distribution of gross weight of 5 axle semis at various locations on I-80. One should begin with two or three states, figuring that the closer together the WIM sites, the more likely they are to have the same pattern. The locations of large cities and major intersecting routes which might funnel off a significant percentage of the trucks on the subject route has to be taken into account. It is almost a certainty that the traffic community could learn a great deal about WIM calibration and truck weight patterns from this type of analysis.

No one part of any of these procedures and techniques can by itself provide all of the answers to the question of data quality assurance. However, when taken together, they can form a solid basis for evaluating WIM data. Only then will the traffic community, pavement designers and researchers be able to use the data with a high degree of confidence.

Finally, most important of all, there must be much more sharing of experiences and studies between agencies. No one agency can do it all, but together problems can be solved. Many of the problems that Mn/DOT encounters are also experienced by others. Mn/DOT has been working with FHWA/SHRP/LTPP, their consultants and other states to come up with a first generation WIM edit program. The expectation is that this current effort will produce a significant step forward in the area of meaningful WIM edits. This effort should also lead to increased sharing of knowledge.

REFERENCES

1. C. Dahlin and M. Novak, Comparison of Weight Data Collected at Weigh-in-Motion (WIM) Systems Located on the Same Route, Transportation Research Board, 1994.

FIGURE 1

DIST. OF STATIC GW OF 5 AXLE SEMIS

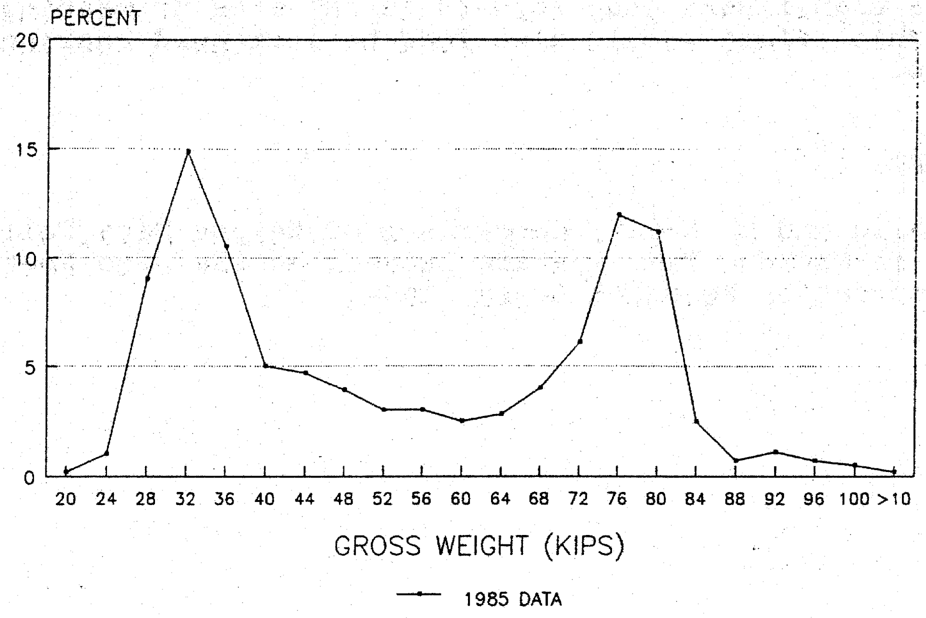
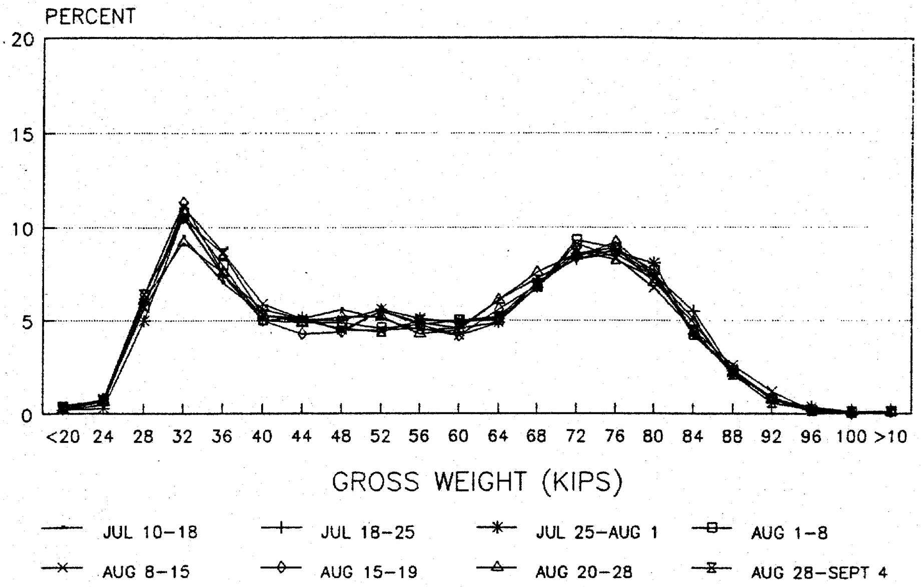


FIGURE 2

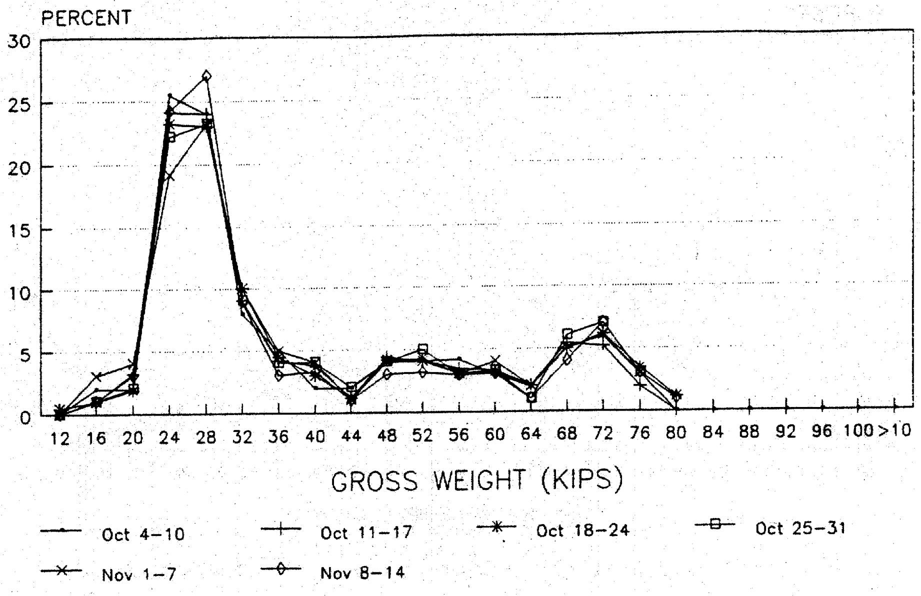
DIST. OF GW OF 5 AXLE SEMIS ON I–94



RIGHT LANE

FIGURE 3

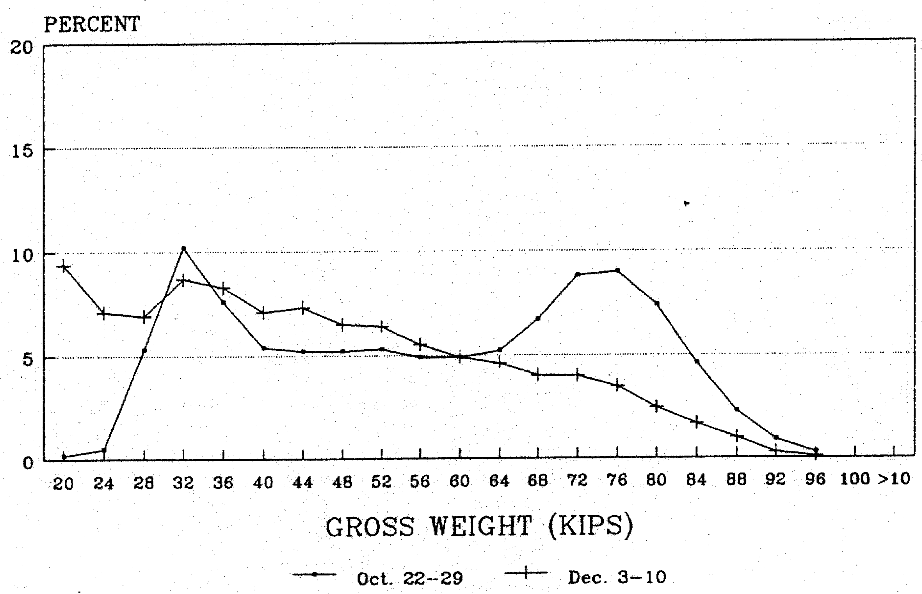
DIST. OF GW OF 5 AXLE SEMIS ON TH 2



EASTBOUND RIGHT LANE

FIGURE 4

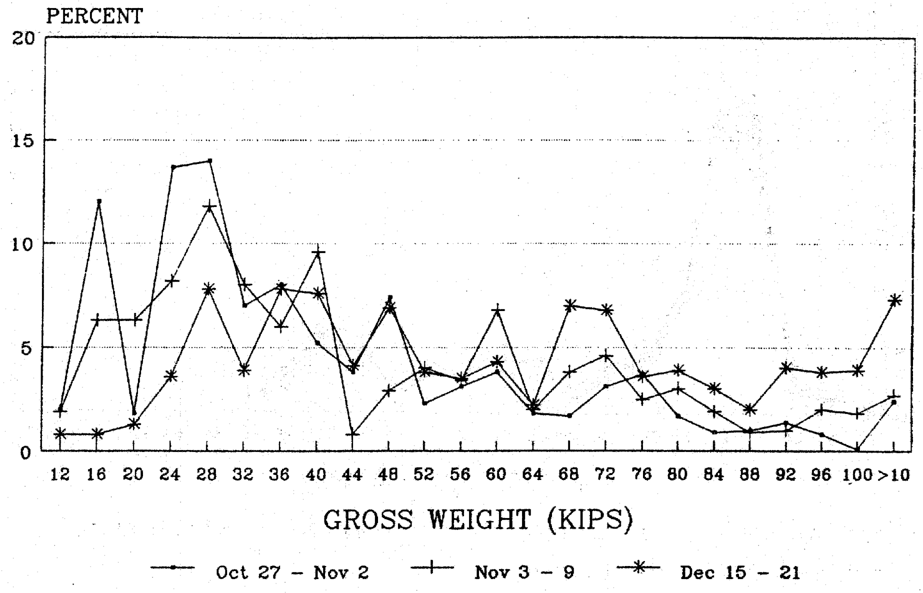
DIST. OF GW OF 5 AXLE SEMIS ON I–94



RIGHT LANE

FIGURE 5

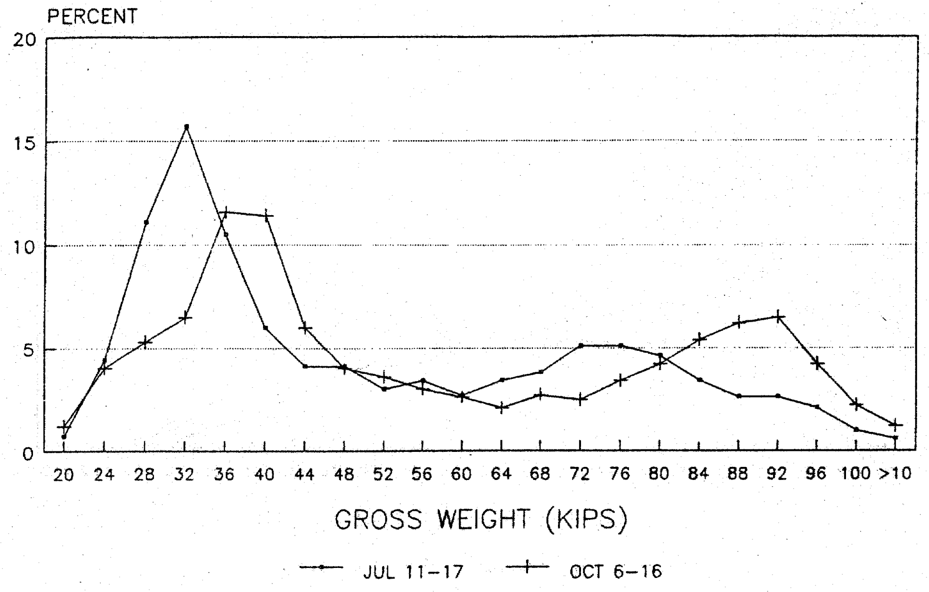
DIST. OF GW OF 5 AXLE SEMIS ON TH 65



NB RIGHT LANE, 1991

FIGURE 6

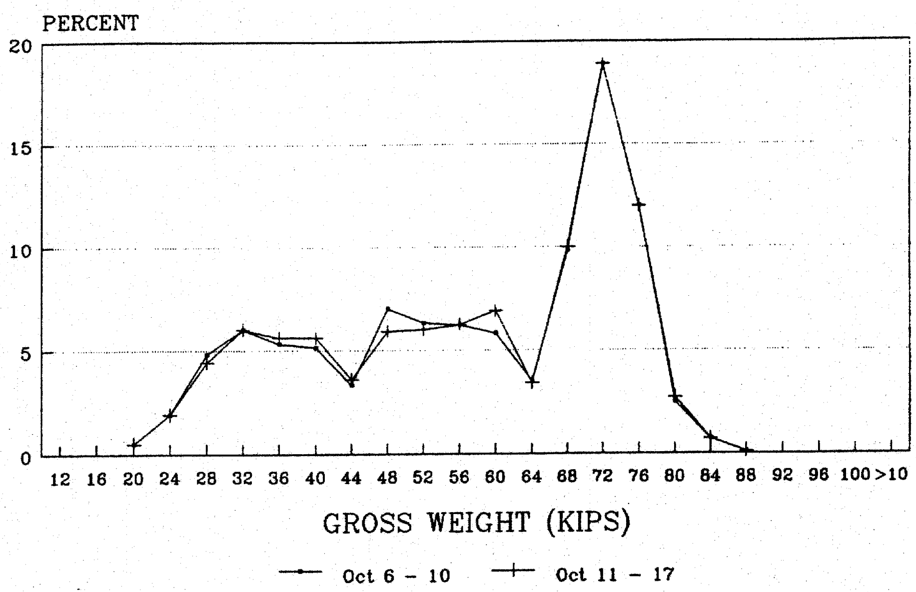
DIST. OF GW OF 5 AXLE SEMIS ON I–494



BOTH EB LANES COMBINED

FIGURE 7

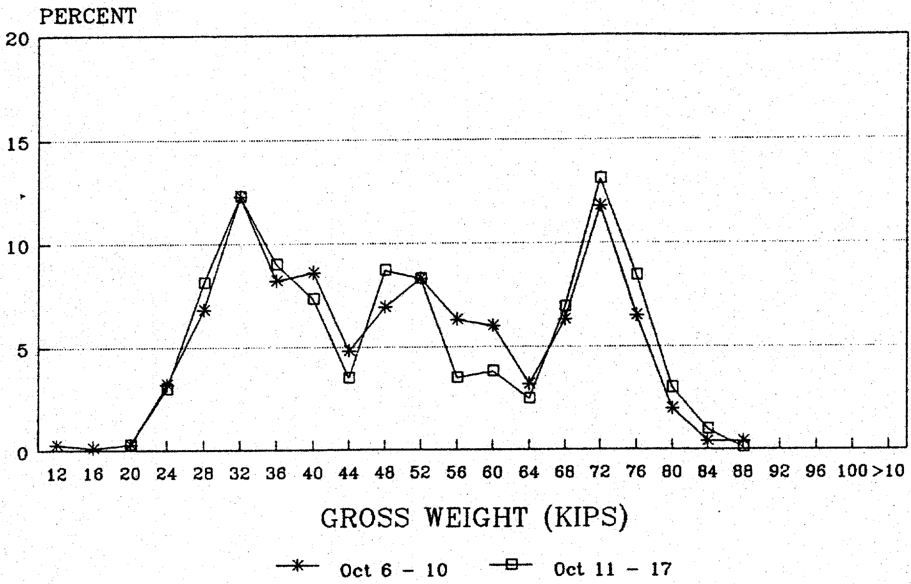
DIST. OF GW OF 5 AXLE SEMIS ON I-90



RIGHT WB LANE, 1992

FIGURE 8

DIST. OF GW OF 5 AXLE SEMIS ON I-90



LEFT WB LANE, 1992

PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

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ABSTRACT

Weigh-in-motion (WIM) systems, or in California's case, WIM system networks, are capable of producing massive amounts of data. Such data is, for the most part, unbiased, and requires only minimal manual effort to collect. Not only does WIM provide truck size and weight data, WIM provides traditional count, classification and speed data as well.

There is no question as to the need for and the value of this data. Questions do arise, however, as to the accuracy of the WIM data, particularly weight data.

Caltrans has taken the approach that WIM data will not be disseminated to users until such data has been reviewed and determined to be valid for its intended use. To accomplish such a task, Caltrans has attempted to develop review procedures as well as to define what constitutes "valid" data.

INTRODUCTION

The objective of this paper is twofold. As the title suggests, the main objective is to discuss methods used by Caltrans to validate weigh-in-motion (WIM) data. Such methods described herein are limited to high speed, mainline, single threshold bending plate WIM systems.

In that data validation procedures could conceivably vary based upon the extent of an agency's WIM system network and its attitude toward WIM, the secondary objective is to set the stage for the data validation discussion by informing the reader as to the size and nature of California's WIM system network as well as Caltrans' installation procedures, calibration "philosophy", and initial calibration procedures.

BACKGROUND

California WIM System Network

As of August 1994, Caltrans has installed and collected data from 52 bending plate WIM systems throughout the state. Several more systems are in various stages of construction and design and approximately another 40 systems are in planning stages. Of these 52 operational systems, 42 are Pat Traffic Control Corporation (PAT) systems and 10 are International Road Dynamics (IRD) systems. These systems have been located to reflect California's highly diversified geographic, climatic, roadway, traffic pattern, and truck operation characteristics. All WIM systems are equipped with modems and all data is downloaded to Sacramento and processed on PCs. Most of the data downloads are at 9600 bps, including cellular equipped sites. A few of the systems downloads are at higher or lower speeds depending upon phone line quality and type of system. Typically, 14 days of data per month per WIM system are downloaded for routine processing. This amounts to downloading approximately 60 MB per week to the "host" PC for the 52 systems.

WIM Installation Procedures

Caltrans experience confirms the WIM vendors' assertions that the pavement in which a WIM system is placed is an integral part of that WIM system. As such, all bending plate WIM systems in California are placed in concrete pavement sections. In AC and less than ideal PCC roadways, the structural section preceding and following the WIM system is replaced with high quality concrete pavement ground to a tight tolerance. Even existing PCC pavement which is in excellent condition is ground before installing the WIM system. This practice, and very rigid enforcement of installation specifications, provides the WIM vendor with the best opportunity to meet functional requirements for accuracy and provides Caltrans with the best possible opportunity for long life performance and minimal maintenance for each WIM system.

Calibration Philosophy

The Caltrans techniques for initial calibration and on-going calibration monitoring of a WIM system are based upon the following premises derived from seven years experience:

1. Bending plates are very consistent at reporting what they "feel" (i.e.: dynamic weight) subject to some variation with temperature.

2. Weights reported by a WIM system for a particular vehicle will normally vary with that vehicle's speed.

3. Dynamic weights, as reported by WIM equipment, can never match static weights for every axle of every vehicle due to the many dynamic forces at play.

4. A WIM system should be calibrated to replicate, as closely as possible, the static weights of most "typical" vehicles at their most typical operating characteristics.

5. It is neither practical nor effective to attempt static weighing of a large sample of random vehicles from the traffic stream to calibrate a WIM system.

6. With rare exception, Caltrans does not have the resources to use more than one test truck to perform initial WIM site calibration or to perform periodic calibration checks using a test truck.

Initial Calibration Procedures

The most predominant truck at all but a few of California's WIM sites is the Class 9 five axle tractor semi combination. As such, this vehicle is used for initial calibration of the WIM systems. It is preferred that both tandem sets have air suspensions in that these suspensions provide the most consistent dynamic weight readings.

The steer axle and both tandem sets are statically weighed (the typical gross weight is 65,000 to 75,000 pounds) and axle spacings and overall length are measured. The test truck is run in each lane at various speeds over a range within which the truck traffic is operating (typically 45 to 65 mph) and the WIM readings are compared to the static weights and actual lengths. Ideally, the calibration parameters are then adjusted until the WIM readings match the static weights and lengths.

Figure 1 displays a typical plot of gross weight error by speed that clearly indicates the effects of speed on the WIM system's reporting of weight. In that this is a WIM system which makes no provision for factoring by speed ranges, WIM weights for the test truck are only accurate at 55 +- mph. It is very important to be cognizant as to how this system's initial calibration was determined in subsequent data analyses as will be discussed later.

Figure 2 displays another plot of gross weight error by speed that also portrays the effects of speed on the WIM's reporting of weight. However, this particular WIM system does provide for application of calibration factors by speed ranges to compensate for the effect of speed. Figure 3 displays the next set of test truck runs after adjustment of these factors. Although minor adjustments are still necessary, most of the effect of speed on the WIM weight readings were eliminated with the first adjustments to the calibration parameters.

It is recognized that calibrating a WIM system to a single test truck does not insure that the system will replicate static weights of all trucks in the traffic stream. However, the initial calibration is a "starting point" and will generally give an indication as to extraordinary dynamic effects caused by the roadway and/or any major problems in the WIM system itself.

DATA VALIDATION

In general, a WIM system's generation of valid data depends upon three things:

1. The integrity and smoothness of the pavement
2. Proper calibration of the system
3. Proper operation of all system components

The need for good pavement, as previously discussed, is obvious and need not be covered further. Although proper calibration and proper functioning of equipment are distinctly separate issues, the monitoring of each are, to a certain extent, performed concurrently by Caltrans. As such, validation procedures for each will also be discussed concurrently.

Knowledge of WIM Site Characteristics

To properly diagnose, interpret, and validate WIM data from any given system the analyst must consider:

1. Physical characteristics of site, including
    - Pavement condition and profile
    - Grade
    - Traffic flow restrictions
    - Weather, including wind
2. Truck traffic characteristics, including
    - Empty vs. loaded trends
    - Seasonal variations
    - Enforcement effects
    - Unique vehicles

Caltrans typically uses the time on site during calibration and acceptance testing to observe and record truck traffic characteristics and any noted effects from the site's physical characteristics. Such notes, in addition to photographs of "typical" trucks and annotated printouts of truck record data, can be very useful in subsequent analyses of downloaded data.

"Real Time" Review

WIM systems are accessed via phone lines from the host PC on a routine basis as a spot check of system performance. Such a review includes a check of:

1. Proper time and date
2. Proper accumulation and size of data files
3. Axle weights and spacings of vehicles in the traffic flow
4. System component diagnostics and check of calibration parameters if axle weights and/or spacings are questionable

Although a real time review is not "data validation", per se, this review can be a valuable tool in early identification of system component problems and determining which data files to download to obtain the best available data.

First Level Data Review

As previously noted, approximately 14 days of data per month per WIM system are typically downloaded. Except for special studies or special situations, this is normally enough data to fulfill users' needs. Data validation is normally performed on seven days' data.

For the first level review, reports are generated using the WIM vendor's application software. The contents and general format of such reports are as required by Caltrans specifications. In following the details of the forthcoming discussion on Caltrans' review of these reports, the reader needs to be aware of the following:

1. Caltrans requires that both summary ("binned") data as well as individual vehicle records for "trucks" be generated. Typically, any vehicle with a steering axle exceeding 3500 pounds is captured as an individual record.

2. California's classification scheme is slightly different than that of FHWA, as follows:

    The five axle truck trailer combination is captured as Class 14 instead of being included in Class 9 with the five axle tractor semi.

    California also uses a Class 15, which basically is any vehicle that cannot be classified otherwise by the WIM system.

    (California data submitted to FHWA is converted back to FHWA's 13 Class Scheme "F".)

3. As noted previously, Caltrans collects data from both PAT and IRD WIM systems. Due to differences in the methods of coding "error" and "invalid weight" vehicles, the PAT and IRD reports differ somewhat. As such, the review methods of these reports are also slightly different.

    In that attempting to discuss two different review procedures would be confusing, only the PAT data review process is covered.

Review of Daily Classification and Speed Summary Reports---

In terms of data validation, the review of these reports is intended to identify:

1. The extent of loop or loop processing problems
2. Any erratic weighpad behavior causing "ghost axles"
3. Missing data from a particular lane

Although the PAT system does not code system "errors" as does the IRD system, an analysis of the class and speed summary reports will provide a quick indication as to whether or not the system is functioning properly. At most WIM sites, less than 0.5 percent of the vehicles are truly "unclassifieds". Class 15 counts in excess of 0.5 percent are generally caused by loop errors. Additionally, the Class 1 count may jump if a loop is acting up. An increase in Class 13's usually indicates a weighpad problem (ghost axles).

Figure 4 is a classification summary report and Figure 5 is the accompanying speed summary report for a typical California freeway with a mix of rural and urban traffic characteristics. A review would indicate:

1. Figure 4 - The percentage of Class 15's (1.0 percent) is too high for this site and indicates that one or more lanes are experiencing minor loop problems.
2. Figure 5 - The speed distribution pattern makes it apparent that most of the vehicles exceeding 95 MPH are "error" vehicles. Less than half of these errors, however, have resulted in axle spacings such that the vehicles are "unclassified".
3. Figure 4 - A review of the Class 15 hourly distribution indicates that the loop errors are evenly distributed throughout the day and, as such, are probably not due to temperature or moisture.

Although the system errors revealed by these summary reports for all four lanes would not be deemed serious, a lane by lane analysis is in order (using the same procedures) to determine which loop (or loops) is causing the error vehicles. Caltrans has recently added a new "Class and Speed Counts by Lane" report (Figure 6) to the specifications which will quickly identify the lane (or lanes) that is having problems. It is apparent that almost half of the Class 15 "errors" are in Lane 1 whereas almost all of the speed "errors" are in Lanes 2 and 3.

In contrast to the "acceptable" level of system errors as displayed by Figures 4 and 5, the same reports for Lane No. 1 from another day are shown by Figures 7 and 8. By reviewing these reports, it is apparent that between the hours 1500 and 1700 either a loop or the processing of loop inputs was malfunctioning. In that counts for all the classifications are erroneous for this time period, the data for this lane would be usable only for vehicle counts purposes.

A review of the "Vehicle Counts by Lane" summary (Figure 9) can reveal if the system is not reporting data for a particular lane for one or more periods of the day. Such lack of data could be due to a system error (which would result in erroneous traffic counts) or could be due to a lane closure for maintenance or construction (which would not result in count errors but could result in atypical speeds). A review of the lane distributions can normally determine if the traffic has been shifted to an adjacent lane. It is apparent in reviewing the Lane 3 and Lane 4 distributions on Figure 9 that the "0" counts in Lane 4 are not due to traffic shifts to Lane 3. The identification of a lane closure can provide the reviewer with an excellent opportunity to perform extended truck calibration analyses, as will be discussed later.

Review of Individual Truck Record Reports---

The review of these reports is intended to identify:

1. Any classification problems due to a loop or loop processing malfunction

2. A bad weighpad

3. Any obvious calibration problem

4. Truck operation patterns

The Figure 10 report displays a compilation of truck record data for all lanes of this WIM system. For "truck" only data, the 2.3 percent unclassifieds indicates no major problem with classification. The eight speed data errors (out of range errors) also indicates no major loop problems. The unclassifieds will generally increase on weekends when many of the more "typical" trucks are not running and a higher number of recreational vehicles are on the road. For most California WIM sites, unclassifieds not exceeding four percent are usually acceptable for an overall review.

The 4.0 percent "invalid measurement" trucks is also acceptable for an overall review. Invalid measurements are coded when left and right wheel weights of an axle exceed a difference of 40 percent. Such an imbalance can be caused by:

1. A truck changing lanes or not driving in the middle of the lane
2. Bouncing, usually by empty trailers
3. Empty van trailers in heavy cross winds
4. An extremely bad weighpad calibration factor
5. A malfunctioning weighpad

Caltrans has performed extensive data analyses to determine at which WIM sites and to what extent bouncing and cross winds might effect a high percentage of invalid measurements. Although such analyses are beyond the scope of this discussion, it is again the matter of the data reviewer knowing the site and truck traffic characteristics to properly analyze the data. It is noted that Caltrans now requires that the WIM on-site software be programmable from the host PC to modify the algorithm that determines invalid vehicles.

If the extent of invalids is suspicious, a check of existing weighpad calibration parameters can be made via access from the host PC, as can diagnostics of the weighpads. A weighpad that malfunctions intermittently is a little more of a problem to track down in that it might be necessary to import the data into a database for screening.

The percent of overweight vehicles can be an indicator as to whether or not the system is correctly calibrated for weight. The percent of overweights can vary greatly depending upon the WIM site and the time of year. Heed this warning on reported overweight vehicle percentages! The actual percentage of overweight trucks, if the trucks were weighed statically, may be in the neighborhood of half of the WIM reported overweights. Some of the reasons for this are as follows:

1. Many of the trucks travel very close to their maximum legal weight; the slightest overread of static weight by the WIM will result in a violation coding.
2. Although a well calibrated WIM system may produce good <u>average</u> gross weights (say three percent), a violation coding due to a slightly high reading can <u>not</u> be averaged out by other low readings.
3. There is generally some weight transfer from the steer axle to the drive axle for most of the heavier trucks,

particularly if there is any uphill grade, which can effect a violation code due to heavier drive axle.

4. The weight violation look-up tables do not account for certain exceptions, particularly for the steer axle.

   This is particularly evident for Class 4 as displayed in Figure 10.

In a recent attempt to calibrate a WIM system so that the WIM gross weight distributions matched the static gross weight distributions of a nearby weigh station, it was noted that a two percent decrease in the calibration parameters dropped the WIM overweight percentage from 22 percent down to 10 percent.

It is important to note the total counts and distributions by class to gain a "feel" for the seasonal (or other) variations in truck operating characteristics. Knowledge of these characteristics can be very helpful in determining proper calibration, as will be discussed later. As an example, Figure 10 reports almost 3000 Class 11's which is twice the average for this site. These additional trucks are seasonal tomato haulers which are used, due to knowledge of their operating characteristics, to check the WIM systems calibration.

The "Truck Record Data by Lane" report (Figure 11) is a valuable tool for quickly checking the individual truck record data on a lane-by-lane basis. Of particular note are the Class 15 and the invalid vehicle percentages. In that only a small percentage of trucks use the inside ("fast") lanes at this site (Lane No's 2 and 3 on the report), a malfunctioning loop or weighpad from one of these lanes might not be evident in reviewing the "combined lanes" report (Figure 10). It is noted that the invalid percentages for Lane No's 2 and 3 are quite high. These higher percentages are common for the "fast" lanes due to trucks crossing the lane lines to pass.

Logging and Tracking of Reviewed Data---

As the reviewer performs the analyses of the reports covered under the first level data review, certain key elements are entered into log sheets along with any annotations deemed necessary. Figure 12 displays an example of a log sheet for the classification and speed summary reports and Figure 13 displays an example of the log sheet for the individual truck record reports.

These log sheets basically serve three purposes:

1. They show what data is available and what data has been validated.

2. They show any exceptions to otherwise "valid" data and show any warnings, if appropriate, as to the use of the data for general or specific use.

3. They track trends of traffic and truck characteristics that can be checked quickly by the reviewer for comparison reasons.

When data is requested, the logs can be used as "guides" for the purpose of determining whether or not available data is suitable for the intended use. In many cases data from a particular lane may be questionable or invalid whereas a requestor may need data only from lanes going the opposite direction. Only in extreme cases will Caltrans actually discard data.

Second Level Data Review

Typically, the second level review is performed on one day's individual vehicle records data per month per WIM system. If such review effects calibration parameter changes, an immediate follow-up review is normally performed to verify the results of such changes.

For the second level review, reports are generated using Caltrans' WIM System Analysis program. This program, written in C++ by part time students, was developed after several years of importing vehicle record data into a data base program and analyzing the different relationships between Class 9 and Class 11 trucks as well as relationships between speed and weight based upon observation at the WIM sites. The program can also provide statistical information on California's Class 14 (five axle tractor trailer combination).

Gross Weight Distribution by Lane Report---

The review of this report (see Figure 14) allows the analyst to evaluate gross weight relationships. Although the WIM vendor's application software is required to generate gross weight distribution reports, the Caltrans program displays the distributions for each lane in a single report and displays additional statistical data.

The usefulness of this report in analyzing whether or not a WIM system is properly calibrated for weight is dependent upon several site and truck characteristic factors, including:

1. How well defined the empty and loaded trucks are

2. How consistently the system reports accurate static weights for different types of vehicles

3. How linear the WIM weight accuracies are in ranging from lower weights to the higher weights

4. How consistent the truck speeds are

Another factor, or course, is the analyst's knowledge of these characteristics.

Figure 14 displays a report with well defined empty and loaded distributions for both Class 9 and Class 11 trucks in both truck lanes (1 and 4). Typically, the Class 9 empties are in the 25,000 to 35,000 pound ranges and the Class 11 empties are in the 20,000 to 30,000 pound ranges. Loaded Class 9 and Class 11 trucks vary, obviously, by commodity and type of haul. Typically, however, there is a large distribution of each in the 65,000 to 80,000 pound range. Many of the Class 11's in this report are seasonal tomato trucks which travel empty (26,000 pounds +-) in Lanes 1 and 2 and fully loaded in Lanes 3 and 4. Being that there is a weigh station between the tomato fields and the WIM site, counts exceeding 80,000 pounds should be minimal, as is reflected in the report. In reviewing the Figure 14 report, the analyst would feel confident that the system is well calibrated for weight. A review of the original test truck calibration runs will reveal that this system was very consistent in matching the test truck's static weights.

In contrast, Figure 15 displays a report that is quite difficult to analyze. An analysis of Lanes 1 and 4 might go something as follows:

Lane 1, Class 9:

Poorly defined empties distribution; too many loaded trucks exceeding 80,000 pounds.

Lane 1, Class 11:

Over half of the Class 11 trucks in this report are seasonal tomato trucks which travel empty in Lanes 1 and 2 and loaded in Lanes 3 and 4. Although the empties distribution may be a bit light, the loaded distribution appears to be too heavy.

Lane 4, Class 9:

a little better defined empties distribution in the proper range; again, too many loaded trucks exceeding 80,000 pounds.

Lane 4, Class 11:

> Too few empties to make judgement; the loaded tomato trucks are well defined in terms of distribution, but too many exceeding 80,000 pounds.

What makes this analysis difficult is the high number of trucks exceeding 80,000 pounds. In that much of the truck traffic at this site is short haul and there is no weigh station nearby, it is possible that many or most of the reported trucks exceeding 80,000 pounds are valid. Another factor to consider is this was one of California's initial WIM systems and there was no pavement preparation. Although the pavement is in very good condition by most standards, there might be enough bouncing to cause the seemingly high weights. a review of the initial system calibration will reveal that both Class 9 and Class 11 test trucks were used and that the system was not consistent in returning weight readings for the two truck types.

Weights and Axle Spacings by Speed Report---

This report (Figure 16) provides, for each lane, various data and relationships for weight, speed, axle spacings, and vehicle lengths. Specific uses for this information include:

1. Checking accuracy of axle spacings
2. Checking accuracy of overall vehicle lengths
3. Comparing the weights between the left and right weighpads of a lane
4. Reviewing the effects of speed on gross weights
5. Checking for any non-linear relationships between speed and axle spacings.

The Figure 16 report, which displays Lane 4 data for the same vehicles that were displayed in the Figure 14 gross weight distribution report, also indicates the WIM system to be in good calibration for this lane. Such determination is based upon the following analysis:

1. The Class 9 tractor tandem axle space averages 4.3 feet which indicates that the parameter for determining speed and axle spacings is correct. Caltrans has found, based upon many field measurements, that 4.3 feet is the most typical Class 9 tractor tandem spacing and its use has proven to be reliable in calibrating for speed and spacings.

2. The Class 11 average vehicle length of 66.1 feet is roughly five feet longer than the average wheelbase. This indicates that the parameter for determining overall vehicle length is correct. Obviously, the axle spacings must be correct for this method to be valid. As with the Class 9 tractor tandem spacing, the Class 11 is quite consistent in its overall length being approximately five to six feet longer than its wheelbase.

3. The left and right average steer axle weights match each other for both Class 9 and Class 11 trucks and the standard deviations are normal. Once the left and right weights are "balanced", any change in such balance or standard deviations could be an indication of a weighpad problem.

4. The average weights in the "Vehicle Gross" column are consistent for the different speed ranges for which there are large numbers of samples. As this WIM site is "wide open" freeway in flat terrain, the loaded and empty trucks travel at about the same speed. Any significant differences in the gross weight averages through different speed ranges would indicate that the calibration may need adjustment for a certain speed range (if the WIM system has such capability). For WIM systems not having such capability, the speed vs. weight documentation for the most recent test truck calibration runs should be reviewed for comparison with the report's speed vs. weight data to determine whether or not calibration parameters should be adjusted.

   For comparison, note the speed vs. weight relationships in the Figure 17 report. Lane 4 of this WIM system is on a long uphill grade and the heavier trucks are traveling at a lower speed than the lighter trucks. The reviewer needs to be cognizant of the site and truck characteristics in order to make the correct analysis.

Tracking of Reviewed Data---

Certain key elements and comments of the second level data review process are entered into a tracking sheet. Figure 18 displays an example of the tracking sheet for a WIM system that has been somewhat troublesome. As can be seen, however, the system has been operating with consistency since April 1994. Figure 19 displays an example of a tracking sheet for a WIM system that, with exception of some minor loop problems, has operated consistently for some time.

The tracking sheet is a valuable tool in several respects, including:

1. It shows the effects of calibration parameter changes on the WIM data for weight, axle spacings, and vehicle length.

2. It shows weight trends over a long period of time, including seasonal variations. By site to site comparisons the analyst can determine whether any seasonal variations are due to differences in truck operating characteristics (such as hauling heavy produce in the summer) or to the effect of temperature on the weighpads' reporting of weight.

3. It shows whether or not WIM weights "drift" over a period of time.

4. It shows any changes in axle spacings or vehicle lengths which may indicate problems with loops.

One particular note should be kept in mind in regard to the second level data review. In California, approximately 85 to 90 percent of the trucks stay in the outside lane or lanes at most of the WIM sites. this results in having small samples in the inner lanes on which to perform analyses. In performing the first level data reviews, the analyst should watch for traffic patterns that indicate lane closures which divert trucks to the inner lanes. Unless such diversion creates stop and go conditions or much slower speeds, this is an excellent opportunity to perform a second level review and compare the inside lane data to the data trends for the outside lanes.

SUMMARY

The discussion on data validation covers only the basic review philosophy and some of the more typical findings and their analyses procedures. What is presented are the "tools" in the form of both "canned" and custom reports with which the reviewer can determine to what extent the data is valid. Emphasis is placed on the need for the data analyst to be knowledgeable of the site and traffic characteristics for each WIM system. There is no intent to address all potential data problems or all analytical methods available to the reviewer.

Caltrans has found that the traffic patterns, and particularly the truck operating characteristics, are very repetitious at each WIM site barring "events" such as extreme weather, natural disaster, road work, etc. These patterns become very evident as time passes and the review tracking logs become more extensive. As the data reviewer develops a "feel" for these patterns and makes correlations with on-site traffic observations and test truck calibrations, a "tolerance" level should be established. Such tolerance level determines what accuracy of data is expected from each WIM system and at what point a more extensive analysis is in order.

Caltrans staff has reviewed and considered various proposals for the use of "edit" or "screening" programs which would, purportedly, perform the data validation task. Although such a program may have some use as a "third level" data review, the human element has proven to be too important in the data review process to be replaced by even "artificial intelligence" programs. For requests requiring the most accurate WIM data possible, Caltrans will import the data into a database and use filters to perform the data analysis.

Obviously, a WIM system that is well calibrated and has all components operating well (to the extent of their capabilities) still will not produce flawless data. Likewise, the Caltrans data validation process will not, nor is it intended to, guarantee flawless data. Given the limited resources which precludes extensive on-site calibration and immediate response to maintenance needs, and given the current state of high speed WIM technology, the data validation process is much more of an art than a science.

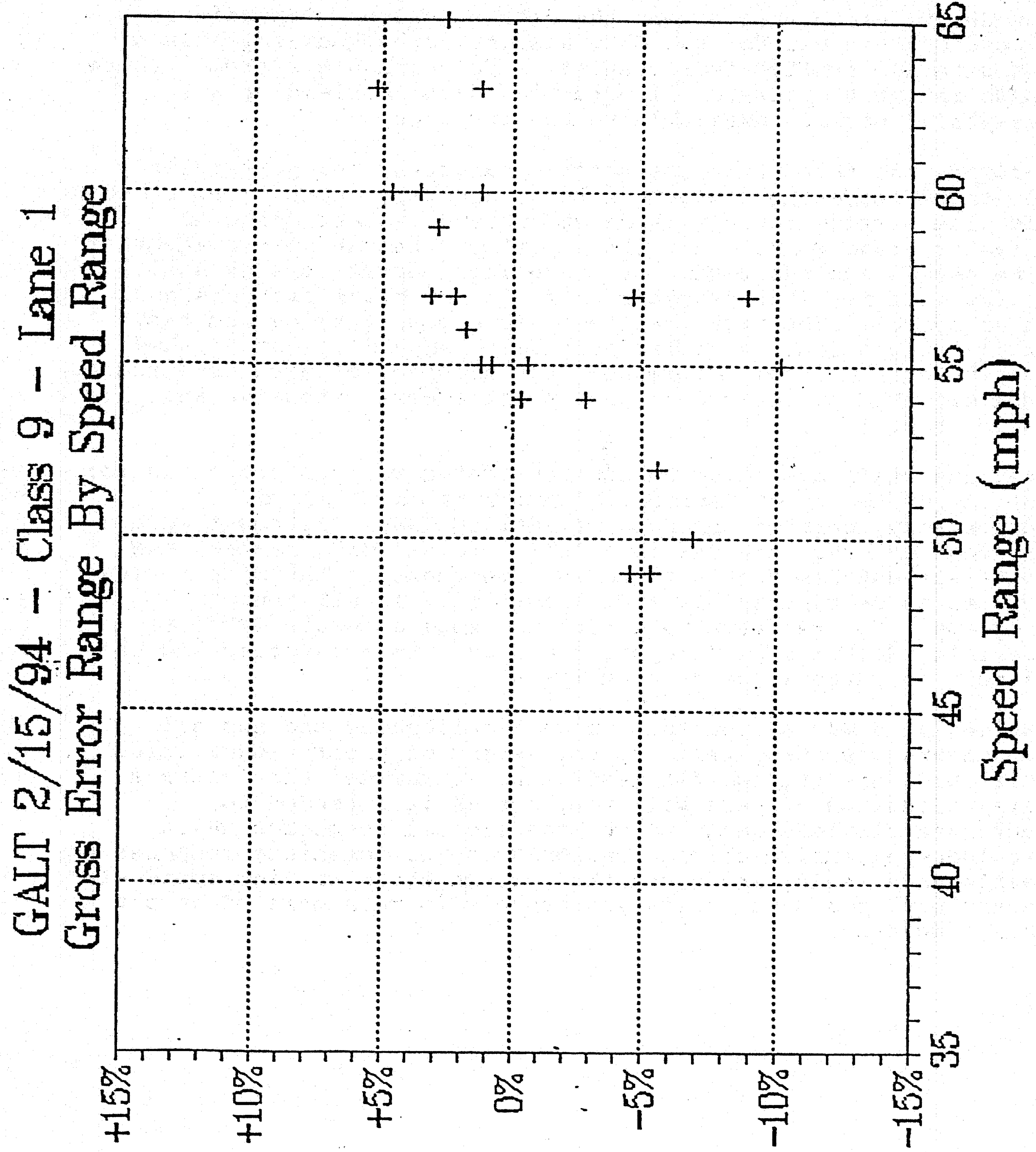

GALT 2/15/94 - Class 9 - Lane 1
Gross Error Range By Speed Range
+15%
+10%
+5%
0%
-5%
-10%
-15%
35
40
45
50
55
60
65
Speed Range (mph)

Figure 1

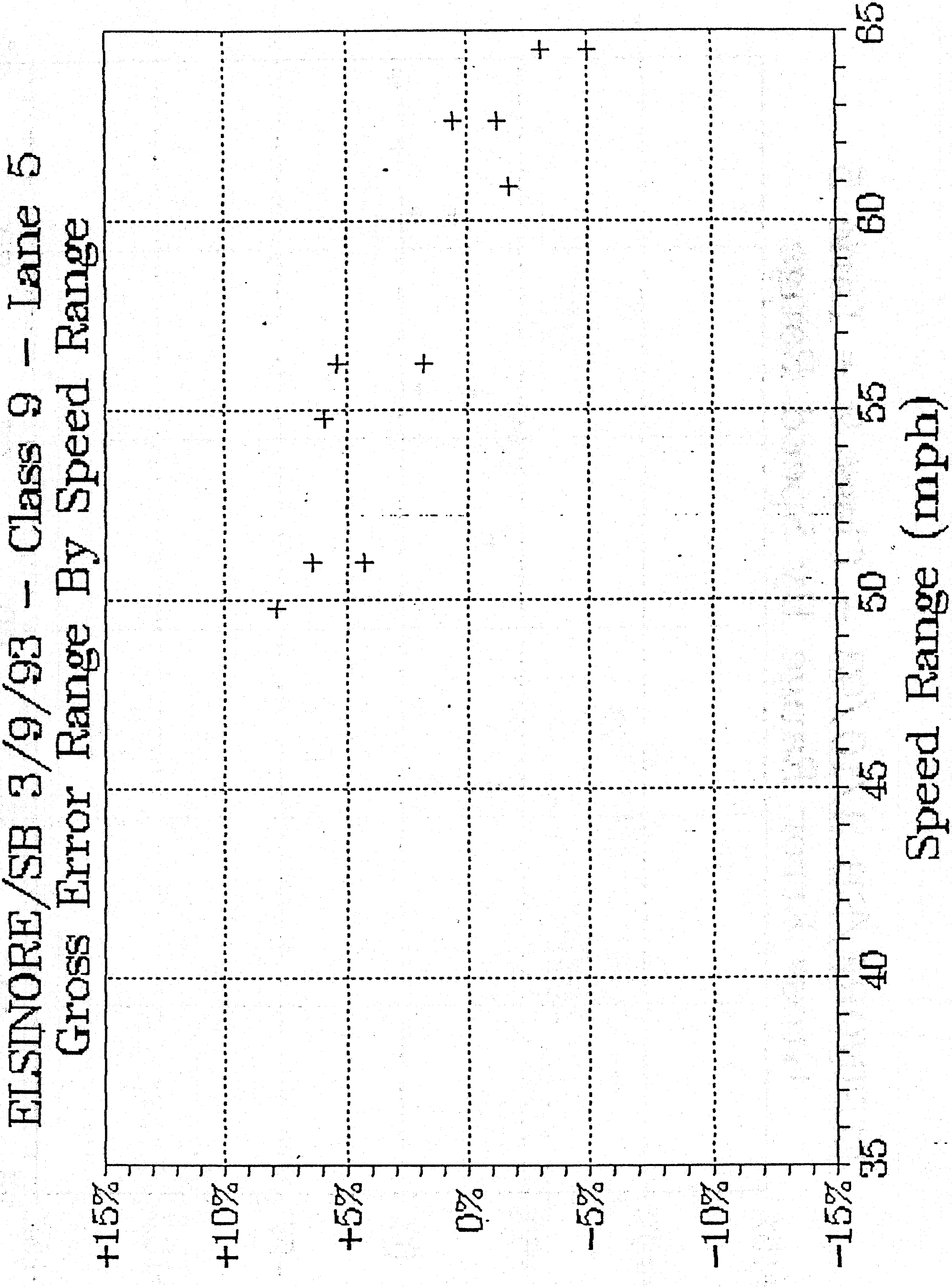

ELSINORE/SB 3/9/93 – Class 9 – Lane 5
Gross Error Range By Speed Range
+15%
+10%
+5%
0%
–5%
–10%
–15%
35
40
45
50
55
60
65
Speed Range (mph)

Figure 2

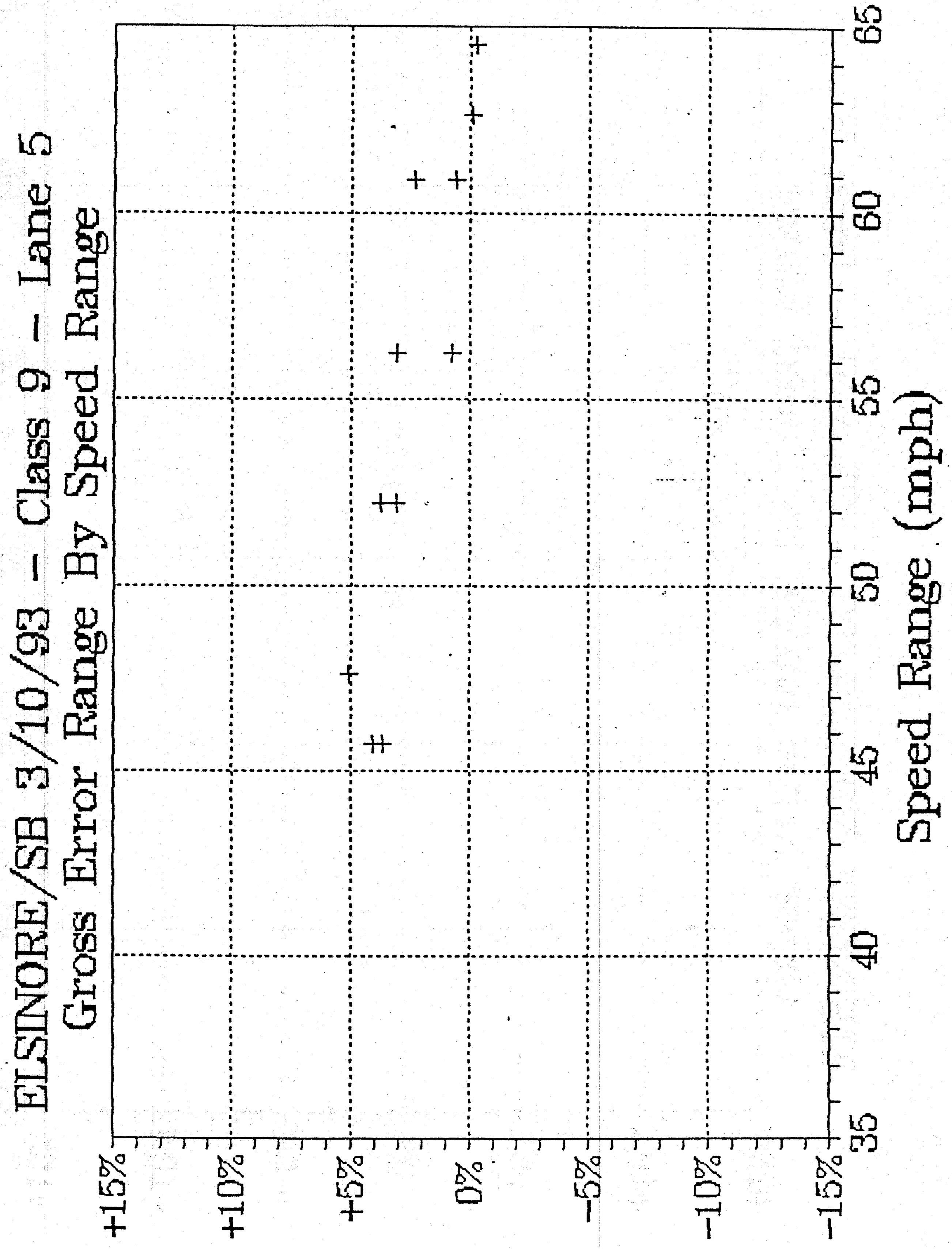

ELSINORE/SB 3/10/93 - Class 9 - Lane 5
Gross Error Range By Speed Range
+15%
+10%
+5%
0%
-5%
-10%
-15%
35
40
45
50
55
60
65
Speed Range (mph)

Figure 3

Quinley

DISTRIBUTION OF VEHICLE CLASSIFICATIONS BY HOUR OF DAY

SITE NO : 001
DATE : 08/10/94

Location : LODI - 005. 43.7
County : SJ State-ID : CA

Lane(s) : 1 2 3 4
Direction : N N S S

Report covers all lanes

HOURLY SUMMARY

VEHICLE COUNTS

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0- 1	0	300	33	3	11	1	0	6	121	5	82	8	0	1	6	577
1- 2	0	181	36	1	10	1	0	16	91	1	81	6	0	1	3	428
2- 3	0	144	18	1	6	0	0	7	97	0	71	3	0	2	1	350
3- 4	0	125	22	0	9	6	0	14	106	3	69	3	0	2	5	364
4- 5	0	320	71	0	21	3	0	19	128	3	75	4	1	2	4	651
5- 6	1	640	170	1	36	2	0	23	159	2	83	6	0	5	7	1135
QTR TOTALS	1	1710	350	6	93	13	0	85	702	14	461	30	1	13	26	3505
6- 7	0	1162	262	4	60	14	0	36	186	2	130	10	1	9	6	1882
7- 8	0	1783	306	3	84	12	0	39	210	3	133	12	1	9	22	2617
8- 9	0	1532	265	6	89	12	0	32	219	0	154	11	0	13	25	2358
9-10	0	1572	274	5	101	16	0	42	263	1	147	13	2	14	23	2473
10-11	0	1518	306	2	89	15	0	56	275	3	180	19	1	17	20	2501
11-12	0	1594	289	1	84	19	0	45	300	5	157	13	0	16	26	2549
QTR TOTALS	0	9161	1702	21	507	88	0	250	1453	14	901	78	5	78	122	14380
12-13	0	1525	300	0	74	14	0	37	307	8	174	7	0	14	34	2494
13-14	0	1626	314	1	95	17	0	60	330	4	173	12	2	11	39	2684
14-15	0	1681	313	1	95	17	0	39	317	7	145	10	0	19	38	2682
15-16	0	1995	390	0	104	13	0	65	289	5	140	9	2	8	34	3054
16-17	1	2074	399	3	109	17	0	44	296	6	151	2	0	17	37	3156
17-18	0	2161	319	0	84	13	0	46	265	7	123	12	1	15	26	3072
QTR TOTALS	1	11062	2035	5	561	91	0	291	1804	37	906	52	5	84	208	17142
18-19	0	1638	234	3	64	18	0	18	274	6	131	14	0	8	23	2431
19-20	0	1191	177	3	51	13	0	24	200	3	103	19	0	3	15	1802
20-21	0	936	152	3	27	8	0	24	207	4	117	5	0	4	17	1504
21-22	0	767	111	1	26	7	0	17	172	1	110	13	1	7	8	1241
22-23	0	665	96	2	17	4	0	16	158	2	125	12	0	0	6	1103
23-24	0	473	64	2	13	4	0	7	126	2	110	4	0	4	7	816
QTR TOTALS	0	5670	834	14	198	54	0	106	1137	18	696	67	1	26	76	8897

DAILY SUMMARY

VEHICLE COUNTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
TOTAL	2	27603	4921	46	1359	246	0	732	5096	83	2964	227	12	201	432	43924
PERCENT	0.0	62.8	11.2	0.1	3.1	0.6	0.0	1.7	11.6	0.2	6.7	0.5	0.0	0.5	1.0	100.0

No major loop problem

No "ghost axle" problems

A little high for this site

Figure 4

Station

DISTRIBUTION OF SPEEDS BY VEHICLE CLASSIFICATION

SITE NO : 001 Location : LODI - 005, 43.7 Lane(s) : 1 2 3 4
DATE : 08/10/94 County : SJ State-ID : CA Direction : N N S S

VEHICLE COUNTS

SPEED (Mph)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
1- 5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5
6- 10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3
11- 15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16- 20	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3
21- 25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26- 30	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
31- 35	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	4
36- 40	0	6	0	0	0	0	0	0	2	0	1	0	0	0	0	9
41- 45	0	17	6	0	9	2	0	1	2	0	8	0	0	0	5	50
46- 50	0	82	37	0	41	7	0	10	50	0	90	2	1	2	21	343
51- 55	0	723	248	0	182	53	0	172	1076	21	713	70	6	36	91	3391
56- 60	0	3837	880	6	473	108	0	377	2877	59	1610	114	3	126	125	10595
61- 65	0	9688	1652	26	437	67	0	153	971	3	497	39	2	34	50	13619
66- 70	0	9628	1487	14	171	7	0	17	113	0	45	1	0	3	21	11507
71- 75	0	2828	458	0	39	2	0	2	5	0	0	1	0	0	6	3341
76- 80	0	539	92	0	5	0	0	0	0	0	0	0	0	0	3	639
81- 85	0	91	19	0	0	0	0	0	0	0	0	0	0	0	2	112
86- 90	0	36	18	0	0	0	0	0	0	0	0	0	0	0	5	59
91- 95	0	8	6	0	1	0	0	0	0	0	0	0	0	0	3	18
96-100	0	11	10	0	0	0	0	0	0	0	0	0	0	0	7	28
> 100	0	104	7	0	0	0	0	0	0	0	0	0	0	0	83	194
TOTALS	2	27603	4921	46	1359	246	0	732	5096	83	2964	227	12	201	432	43924
AVG. SPEED	13	65	65	64	60	58	0	58	58	57	57	57	56	58	67	63

DAILY SPEED SUMMARY

TOTAL VEHICLES	43924	TOTAL VEHICLES >	55 Mph — 40112	PERCENTAGE OF VEHICLES >	55 Mph — 91.3
AVERAGE SPEED	63.4	TOTAL VEHICLES >	60 Mph — 29517	PERCENTAGE OF VEHICLES >	60 Mph — 67.2
MEDIAN SPEED	63.0	TOTAL VEHICLES >	65 Mph — 15898	PERCENTAGE OF VEHICLES >	65 Mph — 36.2
85th PERCENTILE	68.0	TOTAL VEHICLES >	70 Mph — 4391	PERCENTAGE OF VEHICLES >	70 Mph — 10.0

Circled vehicles are, for the most part, "error" vehicles.

Figure 5

Quinley

DISTRIBUTION OF CLASSIFICATION AND SPEED COUNTS BY LANE

SITE NO : 001 Location : LODI - 005, 43.7 Lane(s) : 1 2 3 4
DATE : 08/10/94 County : SJ State-ID : CA Direction : N N S S

LANE NUMBER

	1		2		3		4		5		6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
CLASS														
1	0	0.0	0	0.0	2	0.0	0	0.0	0	0.0	0	0.0	2	0.0
2	5592	47.3	8464	79.4	8196	81.8	5351	46.9	0	0.0	0	0.0	27603	62.8
3	1141	9.6	1419	13.3	1119	11.2	1242	10.9	0	0.0	0	0.0	4921	11.2
4	12	0.1	8	0.1	6	0.1	20	0.2	0	0.0	0	0.0	46	0.1
5	472	4.0	184	1.7	174	1.7	529	4.6	0	0.0	0	0.0	1359	3.1
6	103	0.9	17	0.2	14	0.1	112	1.0	0	0.0	0	0.0	246	0.6
7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
8	343	2.9	34	0.3	35	0.3	320	2.8	0	0.0	0	0.0	732	1.7
9	2400	20.3	273	2.6	245	2.4	2178	19.1	0	0.0	0	0.0	5096	11.6
10	45	0.4	5	0.0	2	0.0	31	0.3	0	0.0	0	0.0	83	0.2
11	1306	11.0	157	1.5	127	1.3	1374	12.0	0	0.0	0	0.0	2964	6.7
12	117	1.0	9	0.1	11	0.1	90	0.8	0	0.0	0	0.0	227	0.5
13	6	0.1	0	0.0	1	0.0	5	0.0	0	0.0	0	0.0	12	0.0
14	93	0.8	17	0.2	10	0.1	81	0.7	0	0.0	0	0.0	201	0.5
15	198	1.7	68	0.6	78	0.8	88	0.8	0	0.0	0	0.0	432	1.0
TOTAL	11828	100.0	10655	100.0	10020	100.0	11421	100.0	0	100.0	0	100.0	43924	100.0
SPEED (MPH)														
1- 5	0	0.0	0	0.0	5	0.0	0	0.0	0	0.0	0	0.0	5	0.0
6-10	0	0.0	0	0.0	3	0.0	0	0.0	0	0.0	0	0.0	3	0.0
11-15	0	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0
16-20	0	0.0	0	0.0	3	0.0	0	0.0	0	0.0	0	0.0	3	0.0
21-25	0	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0
26-30	1	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	2	0.0
31-35	3	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	4	0.0
36-40	3	0.0	4	0.0	1	0.0	1	0.0	0	0.0	0	0.0	9	0.0
41-45	29	0.2	6	0.1	0	0.0	15	0.1	0	0.0	0	0.0	50	0.1
46-50	188	1.6	6	0.1	6	0.1	143	1.3	0	0.0	0	0.0	343	0.8
51-55	1741	14.7	53	0.5	89	0.9	1508	13.2	0	0.0	0	0.0	3391	7.7
56-60	5239	44.3	980	9.2	778	7.8	3598	31.5	0	0.0	0	0.0	10595	24.1
61-65	3407	28.8	2248	21.1	3939	39.3	4025	35.2	0	0.0	0	0.0	13619	31.0
66-70	895	7.6	5382	50.5	3394	33.9	1836	16.1	0	0.0	0	0.0	11507	26.2
71-75	250	2.1	1503	14.1	1363	13.6	225	2.0	0	0.0	0	0.0	3341	7.6
76-80	45	0.4	286	2.7	256	2.6	52	0.5	0	0.0	0	0.0	639	1.5
81-85	11	0.1	44	0.4	50	0.5	7	0.1	0	0.0	0	0.0	112	0.3
86-90	2	0.0	39	0.4	14	0.1	4	0.0	0	0.0	0	0.0	59	0.1
91-95	2	0.0	8	0.1	8	0.1	0	0.0	0	0.0	0	0.0	18	0.0
96-100	1	0.0	11	0.1	15	0.1	1	0.0	0	0.0	0	0.0	28	0.1
> 100	11	0.1	85	0.8	92	0.9	6	0.1	0	0.0	0	0.0	194	0.4
TOTAL	11828	100.0	10655	100.0	10020	100.0	11421	100.0	0	100.0	0	100.0	43924	100.0
AVG SPEED	59		67		66		61		0		0		∞	

Figure 6

DISTRIBUTION OF VEHICLE CLASSIFICATIONS BY HOUR OF DAY

SITE NO : 001
DATE : 01/01/92
Location : LODI - 005, 43.7
County : SJ State-ID : CA
Lane(s) : 1
Direction : N

HOURLY SUMMARY

VEHICLE COUNTS

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0- 1	0	81	11	0	3	2	0	0	14	1	7	2	0	0	0	121
1- 2	0	87	8	0	1	0	0	3	9	0	8	2	0	0	0	118
2- 3	0	61	11	0	1	0	0	1	4	0	6	0	0	0	2	86
3- 4	0	29	2	1	2	0	0	0	8	0	5	2	0	0	0	49
4- 5	0	46	4	0	0	1	0	0	15	0	2	0	0	0	0	68
5- 6	0	66	8	0	2	0	0	0	7	1	8	2	0	3	1	98
QTR TOTALS	0	370	44	1	9	3	0	4	57	2	36	8	0	3	3	540
6- 7	0	87	19	1	2	0	0	1	12	0	5	4	0	0	0	131
7- 8	0	99	18	1	4	4	0	1	25	0	5	4	0	0	0	161
8- 9	0	129	17	0	5	4	0	3	16	1	2	0	0	0	4	181
9-10	0	218	28	1	3	2	0	4	32	0	1	5	0	0	4	298
10-11	0	294	46	0	5	3	0	1	25	0	4	0	0	2	3	383
11-12	0	368	36	1	8	2	0	6	33	0	3	4	0	2	1	464
QTR TOTALS	0	1195	164	4	27	15	0	16	143	1	20	17	0	4	12	1618
12-13	0	441	49	0	10	1	0	8	26	1	3	3	0	1	3	546
13-14	0	400	46	0	6	0	0	11	37	1	2	1	0	1	8	513
14-15	0	469	55	0	9	1	0	8	16	1	1	0	0	0	10	570
15-16	97	309	22	0	10	0	0	3	9	1	3	1	0	0	182	637
16-17	136	167	1	0	0	0	0	0	0	0	0	0	0	0	373	677
17-18	2	465	53	1	15	0	0	7	16	0	5	0	0	0	13	577
QTR TOTALS	235	2251	226	1	50	2	0	37	104	4	14	5	0	2	589	3520
18-19	0	373	48	0	7	3	0	6	22	0	2	1	0	0	3	465
19-20	0	368	46	0	10	0	0	1	15	0	5	1	0	0	1	447
20-21	0	338	35	0	11	3	0	3	15	0	1	0	0	0	1	407
21-22	0	251	24	0	8	0	0	2	18	0	1	0	0	0	1	305
22-23	0	191	15	0	2	0	0	2	21	0	7	0	0	0	1	239
23-24	0	150	9	0	4	2	0	1	15	0	8	1	0	0	0	190
QTR TOTALS	0	1671	177	0	42	8	0	15	106	0	24	3	0	0	7	2053

DAILY SUMMARY

VEHICLE COUNTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
TOTAL	235	5487	611	6	128	28	0	72	410	7	94	33	0	9	611	7731
PERCENT	3.0	71.0	7.9	0.1	1.7	0.4	0.0	0.9	5.3	0.1	1.2	0.4	0.0	0.1	7.9	100.0

1500 - 1700 major loop problem!

Figure 7

Quinley

DISTRIBUTION OF SPEEDS BY VEHICLE CLASSIFICATION

SITE NO : 001 Location : LODI - 005, 43.7 Lane(s) : 1
DATE : 01/01/92 County : SJ State-ID : CA Direction : N

VEHICLE COUNTS

SPEED (Mph)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
1- 5	148	175	0	0	0	0	0	0	0	1	0	0	0	0	311	635
6- 10	56	73	0	0	0	0	0	0	0	0	0	0	0	0	183	312
11- 15	16	17	0	0	0	0	0	0	0	0	0	0	0	0	24	57
16- 20	5	11	0	0	0	0	0	0	0	0	0	0	0	0	14	30
21- 25	5	3	0	0	0	0	0	0	0	0	0	0	0	0	11	19
26- 30	0	5	0	0	0	0	0	0	0	0	0	0	0	0	6	11
31- 35	4	4	0	0	0	0	0	0	0	0	0	0	0	0	2	10
36- 40	1	13	2	0	0	1	0	0	2	0	0	0	0	0	4	23
41- 45	0	14	1	0	0	0	0	3	2	0	1	0	0	0	3	24
46- 50	0	64	5	0	8	0	0	5	19	0	5	1	0	2	4	113
51- 55	0	346	77	2	30	7	0	25	147	1	42	18	0	3	8	706
56- 60	0	1331	187	1	56	10	0	33	185	5	40	10	0	4	13	1875
61- 65	0	1924	190	1	28	5	0	6	48	0	6	4	0	0	11	2223
66- 70	0	1169	113	1	5	5	0	0	7	0	0	0	0	0	3	1303
71- 75	0	225	20	0	0	0	0	0	0	0	0	0	0	0	0	245
76- 80	0	77	11	0	0	0	0	0	0	0	0	0	0	0	0	88
81- 85	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	9
86- 90	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	5
91- 95	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
96-100	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2
> 100	0	23	2	1	1	0	0	0	0	0	0	0	0	0	13	40
TOTALS	235	5487	611	6	128	28	0	72	410	7	94	33	0	9	611	7731
AVG. SPEED	6	60	62	66	58	59	0	55	56	49	55	56	0	54	12	54

DAILY SPEED SUMMARY

TOTAL VEHICLES : 7731 TOTAL VEHICLES > 55 Mph — 5791 PERCENTAGE OF VEHICLES > 55 Mph — 74.9
AVERAGE SPEED : 54.2 TOTAL VEHICLES > 60 Mph — 3916 PERCENTAGE OF VEHICLES > 60 Mph — 50.7
MEDIAN SPEED : 63.0 TOTAL VEHICLES > 65 Mph — 1693 PERCENTAGE OF VEHICLES > 65 Mph — 21.9
85th PERCENTILE : 68.0 TOTAL VEHICLES > 70 Mph — 390 PERCENTAGE OF VEHICLES > 70 Mph — 5.0

Figure 8

DISTRIBUTION OF VEHICLE COUNTS BY HOUR OF DAY BY LANE

SITE NO : 005　　Location : INDIO - 010, R59.4　　Lane(s) : 1 2 3 4
DATE : 06/18/93　　County : RIV　　State-ID : CA　　Direction : E E W W

HOURLY SUMMARY　　VEHICLE COUNTS

HOUR	L1	L2	L3	L4	L5	L6	TOTALS
0- 1	190	71	50	155	0	0	466
1- 2	196	71	43	170	0	0	480
2- 3	161	50	27	184	0	0	422
3- 4	133	40	27	154	0	0	354
4- 5	139	50	42	0	0	0	231
5- 6	178	70	21	0	0	0	
QTR TOTALS	997	352	210	663	0	0	2222
6- 7	230	103	33	0	0	0	366
7- 8	348	143	44	0	0	0	535
8- 9	319	133	62	0	0	0	514
9-10	287	140	103	0	0	0	530
10-11	332	162	119	0	0	0	613
11-12	328	152	120	115	0	0	724
QTR TOTALS	[illegible]	[illegible]	[illegible]	115	0	0	3282
12-13	330	195	138	348	0	0	1011
13-14	338	213	111	297	0	0	959
14-15	369	228	139	331	0	0	1067
15-16	355	206	169	314	0	0	1044
16-17	368	232	109	293	0	0	1002
17-18	353	252	117	318	0	0	1040
QTR TOTALS	2113	1326	783	1901	0	0	6123
18-19	369	219	103	297	0	0	988
19-20	356	255	81	236	0	0	928
20-21	376	294	95	227	0	0	992
21-22	381	280	99	220	0	0	980
22-23	340	231	80	181	0	0	832
23-24	280	164	62	149	0	0	655
QTR TOTALS	2102	1443	520	1310	0	0	5375

Missing count data

Normal lane 3 data

DAILY SUMMARY　　VEHICLE COUNTS

	L1	L2	L3	L4	L5	L6	TOTALS
TOTAL	7056	3954	2003	3989	0	0	17002
PERCENT	41.5	23.3	11.8	23.5	0.0	0.0	100.0

Figure 9

DISTRIBUTION OF WEIGHT VIOLATIONS AND INVALID MEASUREMENTS FOR VEHICLES CLASSES 4-15

SITE NO : 001
DATE : 08/10/94

Location : LODI - 005, 43.7
County : SJ State-ID : CA

Lane(s) : 1 2 3 4
Direction : N N S S

		VEHICLES				******** NUMBER OF	WEIGHT VIOLATIONS		**********
CLASSIFICATION	TOTAL VEHICLE COUNTED	WITH INVALID MEASURE	TOTAL VEHICLES WEIGHED	TOTAL VEHICLES OVERWT.	PERCENT VEHICLES OVERWT.	AXLE	TANDEM	GROSS	BRIDGE
4	46	1	45	11	24	11	0	0	0
5	1146	42	[illegible]	[illegible]	[illegible]	25	0	0	0
6	246	22	[illegible]	[illegible]	[illegible]	30	12	0	12
7	0	0	0	0	0	0	0	0	0
8	698	28	670	21	3	19	2	0	3
9	5096	204	4891	1522	31	365	1326	747	1374
10	83	3	80	32	40	3	29	21	28
11	2963	[illegible]	[illegible]	[illegible]	[illegible]	451	0	434	461
12	226	[illegible]	[illegible]	[illegible]	[illegible]	5	0	13	13
13	12	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1
14	201	[illegible]	[illegible]	[illegible]	[illegible]	44	41	53	64
15	255	33	222	20	9	8	12	5	14
TOTALS	10971	442	10529	2378	23	962	1423	1274	1970

Probably exceptions

Approximately half are seasonal tomato haulers

Very high-questionable

NUMBER OF VEHICLES WITH DATA ERRORS : 9
SPEED : 8 WEIGHT : 1

"out of range" errors

PERCENT VEHICLES NOT CLASSFIED (CLASS 15) : 2.3

PERCENT VEHICLES WITH INVALID MEASUREMENTS : 4.0

Acceptable

Figure 10

DISTRIBUTION OF TRUCK RECORD DATA BY LANE

SITE NO : 001 Location : LODI - 005, 43.7 Lane(s) : 1 2 3 4
DATE : 08/10/94 County : SJ State-ID : CA Direction : N N S S

LANE NUMBER

CLASS	L1		L2		L3		L4		L5		L6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	5	0.1	7	0.8	11	1.5	20	0.4	0	0.0	0	0.0	43	0.4
3	130	2.6	124	15.0	91	12.6	165	3.4	0	0.0	0	0.0	510	4.4
4	12	0.2	8	1.	6	0.8	20	0.4	0	0.0	0	0.0	46	0.4
5	407	8.0	150	18.	144	20.0	445	9.1	0	0.0	0	0.0	1146	9.9
6	103	2.0	17	2.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	246	2.1
7	0	0.0	0	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0	0.0
8	328	6.4	33	4.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	698	6.1
9	2400	47.1	272	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	5095	44.2
10	45	0.9	5	0.6	2	0.3	31	0.6	0	0.0	0	0.0	83	0.7
11	1305	25.6	157	19.1	127	17.6	1374	28.1	0	0.0	0	0.0	2963	25.7
12	117	2.3	9	1.1	10	1.4	90	1.8	0	0.0	0	0.0	226	2.0
13	6	0.1	0	0.0	1	0.1	5	0.1	0	0.0	0	0.0	12	0.1
14	93	1.8	17	2.1	10	1.4	81	1.7	0	0.0	0	0.0	201	1.7
15	142	2.8	25	3.0	25	3.5	63	1.3	0	0.0	0	0.0	255	2.2
TOTAL	5093	100.0	824	100.0	720	100.0	4887	100.0	0	0.0	[illegible]	[illegible]	[illegible]	0.0

Vehicles with steer axles exceeding 3,500 pounds with short wheelbases not meeting class 4 thru 14 criteria.

Acceptable

LANE NUMBER

STATUS	L1		L2		L3		L4		L5		L6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
LEGAL	3804	74.7	660	80.1	484	67.2	3751	76.8	0	0.0	0	0.0	8699	75.5
OVERWT	1077	21.1	93	11.3	183	25.4	1025	21.0	0	0.0	0	0.0	2378	20.6
INVALID	212	4.2	71	8.6	53	7.4	111	2.3	0	0.0	0	0.0	447	3.9
TOTAL	5093	44.2	824		720		4887	42.4	0	0.0	0	0.0	11524	100.0

Typically higher percentage for "inside" lanes-acceptable

Figure 11

WIM MONTHLY SUMMARY SHEET

MONTH APRIL YEAR '93

SITE NO. 10 SITE NAME FRESNO

DATE	DAY	HOURLY PERIODS	NO. VEHICLES	NO. CL. 2	SPEED CHECK	NO. CL. 15	% 15	NOTES
1	TH							
2	FR							
3	SA	24						
4	SU							
5	MO							
DST ⑥	TU	-1						
7	WE				BAD			
8	TH		59 317	39 973	0^5 %	426	0^7	
9	FR	24						
10	SA							
11	SU							
12	MO							
13	TU	4/21	LANE 1		1^3 %	CL 15		
14	WE		LANE 6		2^5 %	CL 15		1200-1400
15	TH		✓. 6		1^2 %	< 5 MPH		✓
16	FR		✓ 6		1^6 %	< 30		✓
17	SA				BAD			
18	SU	24	43 768	33 913	0^3 %	193	0^4	
19	MO		54 766	36 727	0^5 %	401	0^7	
20	TU		54 490	36 175	0^5 %	408	0^7	
21	WE		53 720	35 335	0^2 %	628	1^2	1200-1400
22	TH		55 349	36 613	0^5 %	468	0^8	LANE 1: 1^5% < 45 0^5% < 5 mph
23	FR		62 092	42 869	0^4 %	413	0^7	
24	SA	24	42 521	32 135	0^4 %	257	0^6	
25	SU							
26	MO							
27	TU							
28	WE							
29	TH							
30	FR							
~~31~~								

LANES 1 & 6 SOME LOOP PROBLEMS

Figure 12

WIM MONTHLY SUMMARY SHEET

MONTH APRIL YEAR '93

SITE NO. 10 SITE NAME FRESNO

DATE	DAY	HOURLY PERIODS	NO. TRUCKS	% UNCLASS	% INVALID	% OVERWT.	NOTES
1	TH						
2	FR						
3	SA	24					
4	SU						
5	MO						
DST ⑥	TU	(-1)					
7	WE						
A ⑧	TH		11 029	3	3	16	
9	FR	24					
10	SA						
11	SU						
12	MO						
13	TU						
14	WE						
15	TH						
16	FR						
17	SA						
18	SU	24	3 719	4	3	16	
19	MO		10 203	3	3	15	
20	TU		10 767	3	3	15	
21	WE		10 770	4	3	16	
A 22)	TH		10 925	3	3	15	
23	FR		10 329	3	3	14	
24	SA	24	4 291	4	2	14	
25	SU						
26	MO						
27	TU						
28	WE						
29	TH						
30	FR						
~~31~~							

Figure 13

DISTRIBUTION OF GROSS WEIGHT BY LANE
SITE NO.27 - TRACY 7/20/94

**** CLASS 9 ****

LANE

	1		2		3		4		ALL	
Gross Wt Range	Count	%	Count	%	Count	%	Count	%	Count	%
< 20.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
20.0 TO 25.0	7	0.6	1	1.9	0	0.0	4	0.3	12	0.5
25.0 TO 30.0	81	6.9	7	13.5	1	1.8	48	3.7	137	5.3
30.0 TO 35.0	202	17.1	13	25.0	2	3.6	114	8.8	331	12.8
35.0 TO 40.0	84	7.1	4	7.7	6	10.7	95	7.3	189	7.3
40.0 TO 45.0	71	6.0	3	5.8	5	8.9	84	6.5	163	6.3
45.0 TO 50.0	58	4.9	2	3.8	5	8.9	85	6.6	150	5.8
50.0 TO 55.0	53	4.5	3	5.8	6	10.7	87	6.7	149	5.8
55.0 TO 60.0	71	6.0	1	1.9	4	7.1	81	6.3	157	6.1
60.0 TO 65.0	127	10.8	3	5.8	3	5.4	181	14.0	314	12.2
65.0 TO 70.0	179	15.2	3	5.8	8	14.3	177	13.7	367	14.2
70.0 TO 75.0	225	19.1	9	17.3	12	21.4	270	20.8	516	20.0
75.0 TO 80.0	20	1.7	3	5.8	4	7.1	64	4.9	91	3.5
> 80.0	1	0.1	0	0.0	0	0.0	5	0.4	6	0.2
All	1179	100.0	52	100.0	56	100.0	1295	100.0	2582	100.0
Avg Gross Wt	53.3	n/a	47.7	n/a	57.5	n/a	57.0	n/a	55.1	n/a
Standard Dev	16.5	n/a	18.0	n/a	14.1	n/a	15.1	n/a	15.9	n/a
Avg Axle 1 Wt	9.5	n/a	9.3	n/a	9.9	n/a	9.7	n/a	9.6	n/a
Standard Dev	1.0	n/a	1.1	n/a	0.9	n/a	1.0	n/a	1.0	n/a

Empty distribution

Loaded distribution

**** CLASS 11 ****

LANE

	1		2		3		4		ALL	
Gross Wt Range	Count	%	Count	%	Count	%	Count	%	Count	%
< 20.0	5	0.8	0	0.0	0	0.0	0	0.0	5	0.4
20.0 TO 25.0	236	38.8	11	39.3	0	0.0	10	1.6	257	20.2
25.0 TO 30.0	123	20.2	7	25.0	0	0.0	32	5.2	162	12.7
30.0 TO 35.0	11	1.8	2	7.1	0	0.0	14	2.3	27	2.1
35.0 TO 40.0	21	3.4	0	0.0	0	0.0	9	1.5	30	2.4
40.0 TO 45.0	24	3.9	0	0.0	1	4.0	13	2.1	38	3.0
45.0 TO 50.0	32	5.3	3	10.7	1	4.0	31	5.1	67	5.3
50.0 TO 55.0	24	3.9	2	7.1	1	4.0	41	6.7	68	5.3
55.0 TO 60.0	34	5.6	0	0.0	6	24.0	47	7.7	87	6.8
60.0 TO 65.0	22	3.6	1	3.6	2	8.0	62	10.2	87	6.8
65.0 TO 70.0	30	4.9	1	3.6	2	8.0	122	20.0	155	12.2
70.0 TO 75.0	46	7.6	1	3.6	6	24.0	205	33.6	258	20.3
75.0 TO 80.0	1	0.2	0	0.0	6	24.0	22	3.6	29	2.3
> 80.0	0	0.0	0	0.0	0	0.0	2	0.3	2	0.2
All	609	100.0	28	100.0	25	100.0	610	100.0	1272	100.0
Avg Gross Wt	37.1	n/a	33.8	n/a	66.2	n/a	61.7	n/a	49.4	n/a
Standard Dev	17.3	n/a	14.6	n/a	9.8	n/a	14.0	n/a	20.0	n/a
Avg Axle 1 Wt	7.7	n/a	7.7	n/a	8.7	n/a	8.1	n/a	7.9	n/a
Standard Dev	0.9	n/a	0.9	n/a	0.8	n/a	0.9	n/a	0.9	n/a

Empty distribution

Loaded distribution

Figure 14

DISTRIBUTION OF GROSS WEIGHT BY LANE
SITE NO.1 - LODI 8/10/94
**** CLASS 9 ****

	LANE									
	1		2		3		4		ALL	
Gross Wt Range	Count	%	Count	%	Count	%	Count	%	Count	%
< 20.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
20.0 TO 25.0	27	1.1	0	0.0	1	0.5	21	1.0	49	1.0
25.0 TO 30.0	173	7.4	5	2.0	16	7.3	203	9.5	397	8.0
30.0 TO 35.0	197	8.4	27	10.8	32	14.6	278	13.0	534	10.8
35.0 TO 40.0	127	5.4	26	10.4	10	4.6	140	6.6	303	6.1
40.0 TO 45.0	103	4.4	16	6.4	7	3.2	100	4.7	226	4.6
45.0 TO 50.0	128	5.4	12	4.8	9	4.1	82	3.8	231	4.7
50.0 TO 55.0	116	4.9	16	6.4	9	4.1	90	4.2	231	4.7
55.0 TO 60.0	116	4.9	13	5.2	9	4.1	63	3.0	201	4.1
60.0 TO 65.0	134	5.7	13	5.2	11	5.0	90	4.2	248	5.0
65.0 TO 70.0	163	6.9	11	4.4	8	3.7	121	5.7	303	6.1
70.0 TO 75.0	239	10.2	42	16.8	9	4.1	262	12.3	552	11.1
75.0 TO 80.0	413	17.6	49	19.6	33	15.1	439	20.6	934	18.8
> 80.0	416	17.7	20	8.0	65	29.7	246	11.5	747	15.1
All	2352	100.0	250	100.0	219	100.0	2135	100.0	4956	100.0
Avg Gross Wt	60.8	n/a	59.6	n/a	61.6	n/a	58.2	n/a	59.6	n/a
Standard Dev	19.5	n/a	17.9	n/a	21.5	n/a	20.4	n/a	19.9	n/a
Avg Axle 1 Wt	11.0	n/a	10.7	n/a	11.1	n/a	10.6	n/a	10.8	n/a
Standard Dev	1.3	n/a	1.3	n/a	1.3	n/a	1.3	n/a	1.3	n/a

Very high!

**** CLASS 11 ****

	LANE									
	1		2		3		4		ALL	
Gross Wt Range	Count	%	Count	%	Count	%	Count	%	Count	%
< 20.0	46	3.6	0	0.0	1	0.9	0	0.0	47	1.7
20.0 TO 25.0	435	34.3	0	0.0	3	2.8	43	3.3	481	17.0
25.0 TO 30.0	165	13.0	15	10.7	6	5.5	90	6.9	276	9.8
30.0 TO 35.0	89	7.0	51	36.4	3	2.8	59	4.5	202	7.2
35.0 TO 40.0	44	3.5	15	10.7	2	1.8	25	1.9	86	3.0
40.0 TO 45.0	24	1.9	6	4.3	0	0.0	27	2.1	57	2.0
45.0 TO 50.0	42	3.3	7	5.0	4	3.7	30	2.3	83	2.9
50.0 TO 55.0	40	3.1	7	5.0	1	0.9	43	3.3	91	3.2
55.0 TO 60.0	45	3.5	4	2.9	5	4.6	45	3.4	99	3.5
60.0 TO 65.0	51	4.0	4	2.9	6	5.5	63	4.8	124	4.4
65.0 TO 70.0	46	3.6	3	2.1	3	2.8	74	5.7	126	4.5
70.0 TO 75.0	48	3.8	9	6.4	2	1.8	217	16.6	276	9.8
75.0 TO 80.0	74	5.8	9	6.4	16	14.7	346	26.5	445	15.8
> 80.0	121	9.5	10	7.1	57	52.3	243	18.6	431	15.3
All	1270	100.0	140	100.0	109	100.0	1305	100.0	2824	100.0
Avg Gross Wt	41.7	n/a	46.3	n/a	71.9	n/a	65.5	n/a	54.1	n/a
Standard Dev	22.7	n/a	18.4	n/a	20.4	n/a	19.0	n/a	24.0	n/a
Avg Axle 1 Wt	8.7	n/a	8.7	n/a	9.4	n/a	9.0	n/a	8.9	n/a
Standard Dev	1.1	n/a	1.0	n/a	1.1	n/a	1.1	n/a	1.1	n/a

Very high!

Figure 15

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO.27 - TRACY 7/20/94

*** LANE NO.4 *** **** CLASS 9 ****

Speed Range	WEIGHTS Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Tractor Tandem Axles	Trailer Tandem Axles	Vehicle Gross	COUNTS All	Over Weight	Percent Over Weight	SPACINGS Tractor Tandem Axles	Trailer Tandem Axles
< 25.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0 TO 30.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0
30.0 TO 35.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0
35.0 TO 40.0	5.6	5.3	10.9	31.7	33.1	7	[illegible]	[illegible]	[illegible]	4.3	4.1
40.0 TO 45.0	0.0	0.0	0.0	0.0	0.0	[illegible]	0	0	0.0	0.0	0.0
45.0 TO 50.0	5.7	5.3	11.0	29.8	28.0	6.	8	4	50.0	4.4	4.0
50.0 TO 55.0	4.9	4.9	9.8	25.1	22.5	57.4	130	10	7.7	4.2	4.0
55.0 TO 60.0	4.9	4.9	9.7	24.6	22.4	56.7	607	13	2.1	4.3	4.3
60.0 TO 65.0	4.8	4.8	9.6	24.6	22.8	56.6	411	8	1.9	4.4	4.5
65.0 TO 70.0	4.9	4.8	9.6	25.8	22.8	58.2	116	2	1.7	4.5	4.7
70.0 TO 75.0	4.7	4.7	9.4	25.3	22.4	57.1	22	1	4.5	4.5	5.0
> 75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All	4.9	4.8	9.7	24.8	22.5	57.0	1295	38	2.9	4.3	4.4
Standard Dev	0.6	0.5	1.0	6.8	8.2	15.1	n/a	n/a	n/a	0	1.4

Consistent gross weights at different speed ranges.

Good balance

Indicates axle spacing good

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO.27 - TRACY 7/20/94

*** LANE NO.4 *** **** CLASS 11 ****

Speed Range	WEIGHTS Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Vehicle Gross	COUNTS All	Over Weight	Percent Over Weight	OVER ALL Vehicle Length	Wheel Base
< 25.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0 TO 30.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0 TO 35.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
35.0 TO 40.0	4.2	4.1	8.2	89.7	1	1	100.0	72.8	66.4
40.0 TO 45.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
45.0 TO 50.0	4.5	4.4	8.9	63.6	8	0	0.0	63.8	58.8
50.0 TO 55.0	4.1	4.2	8.3	64.2	84	1	1.2	65.0	59.7
55.0 TO 60.0	4.0	4.1	8.1	62.2	319	2	0.6	66.0	60.6
60.0 TO 65.0	3.9	4.0	7.9	59.3	167	0	0.0	67.1	61.6
65.0 TO 70.0	3.9	4.0	8.0	61.6	30	0	0.0	66.7	61.5
70.0 TO 75.0	4.3	4.5	8.8	54.8	1	0	0.0	67.8	61.6
> 75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All	4.0	4.1	8.1	61.7	610	4	0.7	66.1	60.8
Standard Dev	0.5	0.5	0.9	14.0	n/a	n/a	n/a	4.6	0

Indicates vehicle lengths good

Figure 16

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO.21 - MOJAVE 6/23/92
**** CLASS 9 ****

*** LANE NO.4 ***

	WEIGHTS						COUNTS			SPACINGS	
Speed Range	Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Tractor Tandem Axles	Trailer Tandem Axles	Vehicle Gross	All	Over Weight	Percent Over Weight	Tractor Tandem Axles	Trailer Tandem Axles
< 25.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0 TO 30.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0 TO 35.0	4.5	4.0	8.6	29.8	27.4	65.7	7	0	0.0	4.1	3.8
35.0 TO 40.0	5.0	4.5	9.5	29.4	28.3	67.2	31	1	3.2	4.1	4.8
40.0 TO	[illegible]	[illegible]	[illegible]	[illegible]	0	67.1	157	18	11.5	4.1	4.1
45.0 TO	[illegible]	[illegible]	[illegible]	[illegible]	25.5	62.3	286	51	17.8	4.2	4.2
50.0 TO	[illegible]	[illegible]	[illegible]	[illegible]	15.7	44.1	349	17	4.9	4.2	4.2
55.0 TO 60.0	4.5	4.6	9.1	16.5	12.9	38.5	173	1	0.6	4.2	4.2
60.0 TO 65.0	4.2	4.5	8.6	15.7	10.3	34.6	17	0	0.0	4.3	4.4
65.0 TO 70.0	3.9	4.5	8.4	12.0	6.5	26.8	5	0	0.0	4.4	4.2
70.0 TO 75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
> 75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All	4.7	4.6	9.3	22.9	20.2	52.4	1025	88	8.6	4.2	4.2
Standard Dev	0.6	0.5	1.0	8.5	10.3	18.7	n/a	n/a	n/a	[illegible]	1.3

Heavier trucks at lower speeds due to uphill grade

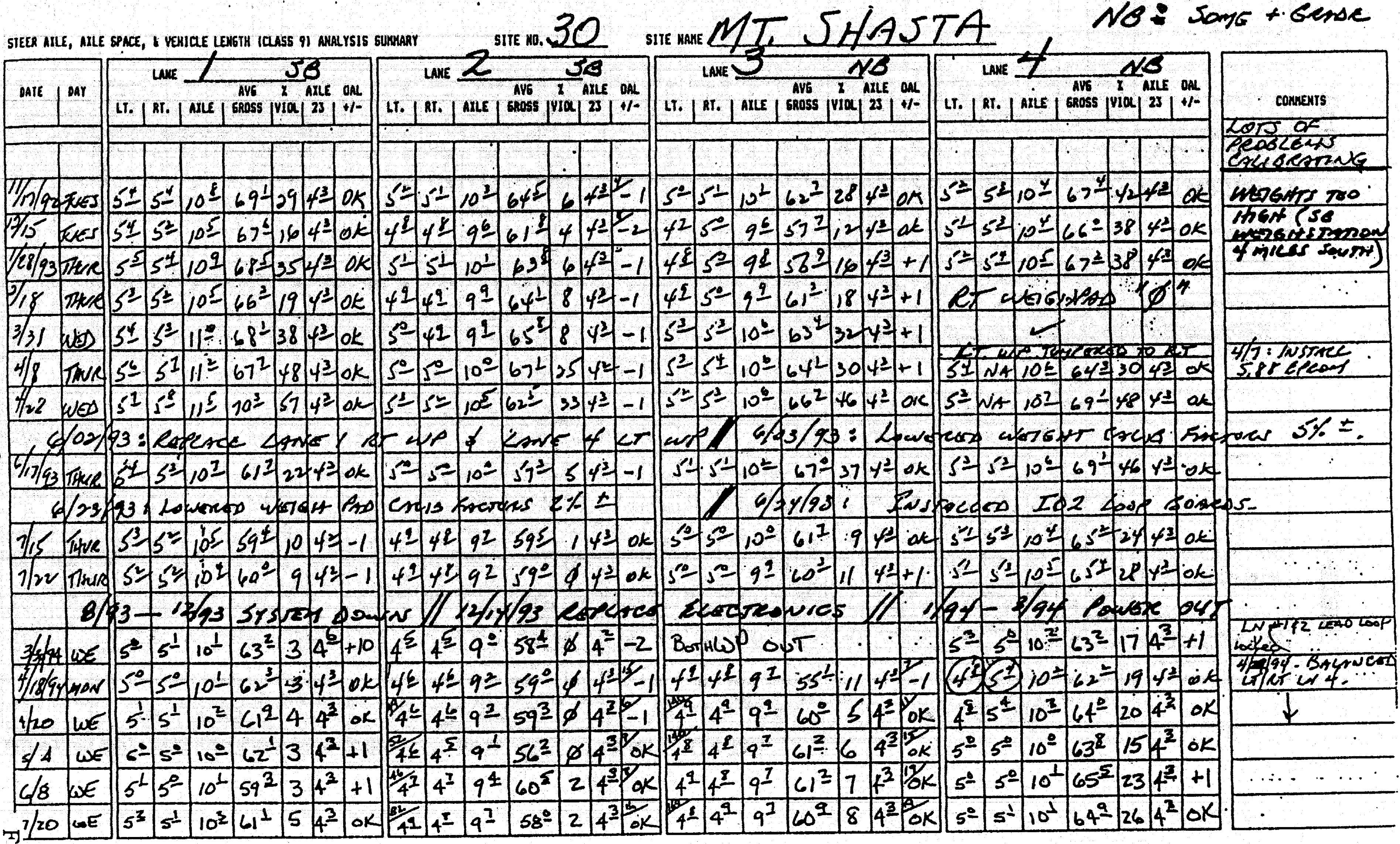
Should be 4.3

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO.21 - MOJAVE 6/23/92
**** CLASS 11 ****

*** LANE NO.4 ***

	WEIGHTS				COUNTS			OVER ALL	
Speed Range	Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Vehicle Gross	All	Over Weight	Percent Over Weight	Vehicle Length	Wheel Base
< 25.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0 TO 30.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0 TO 35.0	4.1	3.6	7.7	63.6	2	0	0.0	64.3	59.0
35.0 TO 40.0	4.1	3.8	7.8	65.0	31	2	6.5	66.0	60.2
40.0 TO 45.0	4.0	3.8	7.8	68.0	49	4	8.2	64.0	58.4
45.0 TO 50.0	4.2	4.0	8.2	61.9	74	7	9.5	65.2	59.5
50.0 TO 55.0	4.0	4.0	8.0	49.5	34	1	2.9	64.8	59.3
55.0 TO 60.0	3.7	3.9	7.6	30.2	15	0	0.0	64.8	59.3
60.0 TO 65.0	3.3	3.8	7.1	22.2	2	0	0.0	58.9	55.7
65.0 TO 70.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
70.0 TO 75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
> 75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All	4.1	3.9	8.0	59.1	207	14	6.8	64.9	59.3
Standard Dev	0.6	0.5	1.1	17.3	n/a	n/a	n/a	4.9	4.1

Figure 17



STEER AXLE, AXLE SPACE, & VEHICLE LENGTH (CLASS 9) ANALYSIS SUMMARY SITE NO. 30 SITE NAME MT. SHASTA NB: SONG + GRADE

DATE	DAY	LANE 1 SB							LANE 2 SB							LANE 3 NB							LANE 4 NB							COMMENTS
		LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	
																														LOTS OF PROBLEMS CALIBRATING
11/17/92	TUES	5^4	5^4	10^8	69^1	29	4^3	OK	5^2	5^1	10^3	64^5	6	4^3	4/ -1	5^0	5^1	10^2	62^7	28	4^3	OK	5^3	5^2	10^4	67^4	42	4^3	ok	WEIGHTS TOO HIGH (SB WEIGHSTATION 4 MILES SOUTH)
12/15	TUES	5^4	5^2	10^5	67^6	16	4^3	ok	4^8	4^8	9^6	61^8	4	4^3	5/ -2	4^2	5^0	9^6	57^7	12	4^3	ok	5^1	5^2	10^4	66^0	38	4^3	OK	
1/28/93	THUR	5^5	5^4	10^9	68^5	35	4^3	OK	5^1	5^1	10^1	63^8	6	4^3	-1	4^8	5^2	9^8	56^9	16	4^3	+1	5^2	5^4	10^5	67^3	38	4^3	ok	
2/18	THUR	5^3	5^2	10^5	66^3	19	4^3	OK	4^9	4^9	9^9	64^1	8	4^3	-1	4^8	5^0	9^9	61^3	18	4^3	+1	RT WEIGHPAD 4 0 4							
3/31	WED	5^4	5^3	11^0	68^1	38	4^3	ok	5^0	4^9	9^9	65^8	8	4^3	-1	5^3	5^3	10^6	63^4	32	4^3	+1			✓					
4/8	THUR	5^6	5^1	11^2	67^2	48	4^3	ok	5^0	5^0	10^0	67^2	25	4^3	-1	5^2	5^4	10^6	64^2	30	4^3	+1	LT WIP TRANSFERRED TO RT 5^1	NA	10^6	64^3	30	4^3	ok	4/7: INSTALL 5.88 EPROM
4/22	WED	5^1	5^8	11^5	70^3	57	4^3	ok	5^2	5^2	10^5	62^5	33	4^3	-1	5^2	5^3	10^6	66^2	46	4^3	OK	5^3	NA	10^7	69^1	48	4^3	ok	
6/02/93: REPLACE LANE 1 RT WIP & LANE 4 LT WIP // 6/23/93: LOWERED WEIGHT CALIB FACTORS 5% ±.																														
6/17/93	THUR	5^4	5^3	10^7	61^7	22	4^3	ok	5^0	5^0	10^0	57^3	5	4^3	-1	5^1	5^1	10^6	67^0	37	4^3	ok	5^3	5^3	10^6	69^1	46	4^3	ok	
6/23/93: LOWERED WEIGH PAD CALIB FACTORS 2% ± // 6/24/93: INSPECTED IO2 LOOP BOARDS.																														
7/15	THUR	5^3	5^2	10^5	59^4	10	4^3	-1	4^9	4^8	9^2	59^5	1	4^3	OK	5^0	5^0	10^0	61^7	9	4^3	ok	5^1	5^3	10^4	65^2	24	4^3	ok	
7/22	THUR	5^2	5^2	10^2	60^0	9	4^3	-1	4^9	4^9	9^2	59^0	0	4^3	ok	5^0	5^0	9^9	60^3	11	4^3	+1	5^1	5^1	10^5	65^4	28	4^3	ok	
8/93 — 12/93 SYSTEM DOWN // 12/14/93 REPLACED ELECTRONICS // 1/94 - 3/94 POWER OUT																														
3/24/94	WE	5^2	5^1	10^1	63^2	3	4^6	+10	4^5	4^5	9^0	58^4	0	4^2	-2	BOTH WIP OUT							5^3	5^0	10^2	63^2	17	4^3	+1	LN #1+2 LEAD LOOP locked
4/18/94	MON	5^0	5^0	10^1	62^3	3	4^3	ok	4^6	4^6	9^2	59^0	0	4^3	15/ -1	4^9	4^8	9^7	55^1	11	4^3	7/ -1	4^2	5^1	10^2	62^2	19	4^3	ok	4/[illegible]/94 - BALANCED LT/RT LN 4.
4/20	WE	5^1	5^1	10^2	61^2	4	4^3	ok	18/ 4^6	4^6	9^2	59^3	0	4^2	6/ -1	138/ 4^9	4^9	9^9	60^0	5	4^3	9/ OK	4^8	5^4	10^3	64^0	20	4^3	OK	↓
5/4	WE	6^0	5^0	10^0	62^1	3	4^3	+1	52/ 4^6	4^5	9^1	56^2	0	4^3	7/ OK	138/ 4^8	4^8	9^7	61^3	6	4^3	15/ OK	5^0	5^0	10^0	63^8	15	4^3	OK	
6/8	WE	5^1	5^0	10^1	59^3	3	4^3	+1	46/ 4^7	4^7	9^4	60^5	2	4^3	8/ OK	4^9	4^8	9^7	61^3	7	4^3	17/ OK	5^0	5^0	10^1	65^5	23	4^3	+1	
7/20	WE	5^3	5^1	10^3	61^1	5	4^3	OK	82/ 4^9	4^7	9^7	58^0	2	4^3	16/ OK	118/ 4^8	4^9	9^7	60^9	8	4^3	8/ OK	5^0	5^1	10^1	64^9	26	4^3	OK	

Figure 18

STEER AXLE, AXLE SPACE, & VEHICLE LENGTH (CLASS 9) ANALYSIS SUMMARY SITE NO. 01 SITE NAME LODI

DATE	DAY	LANE 1 NB							LANE 2 NB							LANE 3 SB							LANE 4 SB							COMMENTS
		LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	LT.	RT.	AXLE	AVG GROSS	% VIOL	AXLE 23	OAL +/-	
9/27/93	WE	5^2	5^5	10^8	59^7	26	4^3	④	5^1	5^2	10^3	58^5	12	4^0	+1	5^3	5^6	10^9	58^9	34	4^2	-3	5^2	5^2	10^5	57^9	25^2	4^3	+3	revised loops 7-23
9/28	TH	5^2	5^5	10^8	61^2	28^5	4^2	-1	5^4	5^4	10^8	61^8	23	4^5	+4	5^3	5^6	10^7	58^6	35	4^2	-1	5^2	5^3	10^5	58^9	27	4^3	OK	
10/1	FR	5^3	5^6	10^8	60^4	29	4^2	-1^5	5^3	5^3	10^6	60^8	27	4^5	+3	5^4	5^6	11^0	57^3	34	4^3	-1^5	5^1	5^1	10^2	55^1	21	4^3	OK	revise loop 10-4
10/5	TU	5^2	5^4	10^6	59^8	23	4^2	-1^5	5^2	5^3	10^6	60^0	20	4^4	+1	5^3	5^6	10^7	59^3	36	4^2	-1^3	5^1	5^1	10^2	57^4	19	4^3	$+0^4$	
10/26	TU	5^3	5^4	10^6	59^8	24	4^3	-0^3	5^2	5^3	10^5	60^3	18	4^3	$+0^2$	5^4	5^6	11^0	58^8	37	4^3	-1^4	5^1	5^2	10^3	57^5	21	4^2	-0^8	
11/10	WE	5^2	5^2	10^4	58^0	18	4^8	OK	5^2	5^2	10^3	59^1	12	4^2	-1	5^2	5^5	10^7	57^7	31	4^4	+1	5^0	5^1	10^1	56^1	15	4^2	OK	
12/15	WE	5^1	5^1	10^2	55^4	11	4^3	+1	5^0	5^1	10^1	56^4	8	4^3	+1	5^3	5^5	10^8	60^3	31	4^4	+1	5^0	5^2	10^2	57^1	14	4^2	OK	
1/13/94	TH	5^1	5^1	10^2	53^7	11	4^2	OK	6^0	5^0	10^0	55^4	5	4^3	+1	5^1	5^5	10^6	58^4	28	4^4	+1	5^0	5^2	10^2	56^7	15	4^2	OK	
2/15	TU	5^2	5^1	10^3	56^3	11	4^4	+3	5^2	5^1	10^1	57^0	11	4^4	+1	5^1	5^3	10^6	58^0	28	4^4	+2	5^0	5^2	10^2	56^8	13	4^2	-1	
3/8	TU	5^3	5^2	10^6	58^5	21	4^3	+1	5^2	5^2	10^2	57^4	16	4^3	OK	5^2	5^5	10^7	58^7	35	4^4	+2	5^2	5^2	10^4	58^8	23	4^2	-2	4/5: ADJ. LOOPS.
3/24	TH	5^3	5^3	10^5	58^1	20	4^3	+1	5^3	5^4	10^7	58^2	16	4^2	OK	5^2	5^7	10^9	59^9	43	4^4	+2	5^0	5^2	10^2	56^1	18	4^2	-1	4/5: BALANCE LT/RT
4/9	SA	5^2	5^5	10^8	63^1	23	4^4	+3	5^2	5^5	10^7	62^3	22	4^5	+3	5^4	5^4	10^8	61^3	37	4^2	-1	5^3	5^2	10^4	58^1	25	4^3	OK	
4/13	WE	5^3	5^5	10^8	59^9	28	4^4	+2	5^2	5^3	10^4	60^6	17	4^3	OK	5^5	5^4	10^8	58^7	38	4^3	OK	5^3	5^2	10^5	57^3	25	4^3	OK	
5/11	WE	5^3	5^6	10^9	62^2	31	4^4	+2	5^2	5^3	10^6	60^0	22	4^3	OK	5^5	5^4	10^9	55^6	32	4^3	+1	5^2	5^2	10^5	58^3	25	4^3	OK	
6/8	WE	5^4	5^6	10^9	62^1	31	4^4	+2	5^3	5^3	10^5	58^6	21	4^3	OK	5^5	5^4	11^0	57^6	37	4^2	OK	5^4	5^2	10^6	56^1	24	4^3	OK	6/20: ADJ. LOOP
6/22	WE	5^3	5^1	11^0	62^7	36	4^2	OK	5^3	5^4	10^6	62^8	23	4^3	OK	5^5	5^4	10^9	56^8	28	4^3	OK	5^4	5^2	10^6	56^8	26	4^3	OK	ADJ. IMBALANCE +300 6-27-94
7/20	WE	5^2	5^7	11^0	60^9	33	4^3	OK	5^2	5^4	10^6	59^9	26	4^3	OK	5^5	5^4	10^9	57^5	37	4^3	OK	5^4	5^1	10^5	57^1	25	4^3	OK	
8/10	WE	5^3	5^7	11^0	60^8	34	4^2	-1	5^3	5^4	10^7	59^6	26	4^4	+1	5^6	5^5	11^1	61^6	43	4^3	OK	5^3	5^2	10^6	58^2	27	4^3	OK	

Figure 19

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PANEL DISCUSSION - WIM DATA QUALITY ASSURANCE

Mr. Mark E. Hallenbeck
Washington State Transportation Center

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National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

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WIM DATA QUALITY ASSURANCE

Mark E. Hallenbeck, Washington State Transportation Center

SHRP is an interesting organization. It no longer exists as an organization, although most of us still think of it as SHRP, rather than as LTPP. SHRP made some decisions upwards of 7, 8, 10 years ago about weigh-in-motion and vehicle classification equipment, and data collection. At the time those decisions were made, a series of assumptions had to be made. Some of those assumptions turned out to be quite correct and some turned out to be painfully wrong. Among them was that $5,000 weigh-in-motion systems would be readily available, and accurate; that we would be able to put them just about anywhere we needed information; and, that all states would willingly install them. These were not good assumptions. As a result of some of those decisions, LTPP has been put in a position where we have had to make up for lost ground. One of the things we are making up for right now has to do with quality control; the quality of the data being supplied.

Historically, people tended to manipulate traffic data because they did not like the way it looked. This had to do more with traffic volume information than weight or class, because, with a few exceptions, nobody collected weight or class data ten or 15 years ago. SHRP was very concerned about this issue at the time data collection plans were being developed. They said, "what we do not want for this major multi-million-dollar research project is for somebody to take a look at a pavement deteriorating and say 'those numbers must be wrong; we must have more trucks out there. They must weigh a lot more because our state's pavement cannot fall apart faster than their state's pavement. Let's twist that factor up a little bit.'" So a decision was made that SHRP did not want people to adjust or edit their data based on professional judgment. However, it was all right if people looked at their equipment and the data that came in, and said "this scale is not working. We are not going to send in the data."

When SHRP said "do not edit your data," it was not that there was no intention to review data, to throw out data that was bad, or to be able to adjust data who's calibration was out. What they did not want was to have that happen both arbitrarily and differentially; one state adjusting up because they liked it that way; another state deciding not to adjust it. The data are meant to be comparable from site to site. Based on all those historical decisions and assumptions, it does not change the basic need of LTPP or SHRP, which is to obtain consistent and accurate data.

We also have come to the obvious conclusion that the data collection equipment does not work, in many cases, as well as we would like it to for a variety of reasons. The reasons have been well documented in a lot of papers written by a lot of very bright people. The result is that SHRP is trying as hard as it can to create a quality-assurance process, which can be applied consistently across the nation, so that the data available to pavement researchers over the next 40 or 50 years will be of the best and most consistent quality possible.

I am a data person. That is what I do for my living. One of my old college professors had a series of laws about data and the use of data. The one I liked the best was that the quality of data varies inversely from the time it was collected and the distance from which it was collected. If you collect survey data, and it has all kinds of problems, by the time that data gets to be an 'old national database,' it is perfect. If you look back at the AASHO Road Test and you study the real AASHO Road Test history, there are all kinds of ugly data problems in that information. But there are a lot of Ph.D.

dissertations being written on that information, even now, 40 years later. And believe me, they do not know all the nasty holes and blemishes in that information. The same thing is going to happen with SHRP data. So we would like that database to be as good as it possibly can.

As we look at the weigh-in-motion data, knowing that this is going to be used 40 years from now, one of the things we do not know is, how is it going to be used 40 years from now? And that is why we have collected an awful lot of data, that some people look at and say "why are you collecting all this information?" And the answer is, "because you only get one chance to collect it." There is only one March 1994. If something happens in March 1994 to that pavement and if you have loading data to compare against it, you might be able to determine why it happened. If you do not get it in March 1994, you do not get it, period. So we store a lot of information. But storing that volume of information makes it very difficult to review. So the QA process is intended to be done as quickly, as easily, in as automated a process as possible while insuring that the data is accurate. We hope, and believe me this is item number one on all of the work that LTPP is doing right now, that as soon as we have the process, we will make it available to every state and provincial highway agency, as a piece of paper if you want to write it. Or if you write it in dBase, or in Nexpert, here is the process. And at the same time, we will give you a disk copy of whatever particular program we will have written in order for you to do it yourself.

It is best if a state or a provincial agency collects information, runs it through the program, looks at it the day after or the week after it is collected, and says "this scale or classifier has a problem. We better go fix it." That is far better than for it to end up at LTPP's region two months after it was collected, sit there another month until they have a chance to process it, and then have them come back and tell you there is a site problem. Meanwhile, three months of inappropriate numbers have been collected and transmitted over your phone lines. So in the end, we hope to provide you with the same information so that you can use it to your benefit, as much as for LTPP's.

My assumption is that the tools we give you will be a benefit. But if history and the Far Side teach me anything, it is that the benefit that I expect out of this may not be the best benefit that you find. I suspect there are a lot of things that people are going to turn around and teach me, using a tool that I gave them to do something else with. And I encourage you to do those things.

The quality assurance process that we are doing looks at two basic pieces of information--the calibration of the weigh-in-motion scale and the volumes that are being collected by vehicle class, by weigh-in-motion scales and classifiers. Our problem runs into one additional difficulty. We find that no two states and provinces do anything the same way. And all of those differences show up in the LTPP database. Some states give us weigh-in-motion data from the beginning of history to the current time; 4 lanes, 6 lanes, 8 lanes worth of data; individual vehicle records that fill up a multi-gigabyte hard disk. Other states give us a week of classifier data, and it is only for the LTPP test lane. The quality assurance process has to deal with those two extremes and everything in between. We have to deal with different traffic characteristics. There are 780 GPS test sections and many SPS test sections. Each one is different. There are all kinds of data collection equipment: weigh-in-motion scales; bending plates; piezo-electric cable; piezo film; and, bridge weigh-in-motion. There are different versions of software (1.0, 2.0, 3.0, etc.), each of which acts differently. The equipment is put in asphalt, in good concrete, in bad concrete, in you name it. Retrieval and storage--some people collect it all the time, some people collect it once a day, some people collect it once a year. Data submittal--sometimes we receive it once a month, sometimes it shows up at SHRP once a year.

We have found that every time we think we know what the trucks look like, they change. And the national database is going to have to know when they are right and when they are wrong. So the concept that we have acquired from everyone else is to make sure we can define what is expected at a particular site, lane or device, monitor those expected values, and report when we see something that we did not expect. If it is right, if it is unique to this site, change the expected values so that the next time we see it, we recognize the pattern. And if it is not, you can go out and check if there is a scale, sensor, or an electronics problem. If there is a problem, do not submit the data, or let us take it out and not use it. But if we do not really know, we will put it away and hold it carefully until we can make a decision. On the other hand, we want to provide as quickly and in as automated a fashion as possible the information necessary for the people who operate that site to go out and make a determination whether the information is real or not real. But, you have to realize that there are some very unusual vehicles out there. These vehicles do exist.

As we have progressed into the analyses we have come to a series of conclusions. 1) Our expected values are not just site-specific, they are lane specific. We will have to create from the information you give us what I call a history file. And that history file will give us expected values. Our history, in this case for weigh-in-motion, is initially going to be based on class 9 vehicles. We stole this concept from Minnesota. It seems to work very well. And it has to do with loaded, unloaded peaking characteristics. In every state in the United States, and possibly the Canadian provinces, the 3S2 truck, the 5-axle, 18-wheel semi runs at 80,000 pounds. It is the maximum legal limit all over. And that is a great known value. We do not really know what ground truth is. But for 3S2s we have a pretty good feel for what it is.

Figure 1 is for a Missouri site where we have chosen to plot the number of trucks by 4,000 pound weight categories. We like number of vehicles plotted as opposed to percentage of vehicles if only because that gives us one more key in how many vehicles are out there. If there are not many trucks, that helps explain some of the erratic areas that you find in some of the graphs. We have done graphs for a week of data containing eight trucks, and we think when you look at percentage, that is a pretty erratic scale. And then you see there are only four trucks here, one there, and two there. No wonder it looks erratic! Then you find out it is a low volume SHRP site. But if it is an interstate, and it has only eight trucks, you know the scale has a problem. I do not know of too many interstate sites that get eight trucks in a week of data. Also, in Figure 1 you can see not only the change in peaking characteristics from one month to another, but changes in volume.

The double-humped peak of Figure 1 does not always show up. Figure 2 is for an Arizona site. There is no unloaded peak. Is it a legitimate value? In our opinion, yes. We went down and spoke to some of the people who deal with Arizona. This particular site happens to be just past the New Mexico border on an interstate. Apparently nobody drives an unloaded truck to that part of the country because you cannot stay in business. They are all loaded. So our history file, our comparison has to be smart enough or have a flag that shows this is a site where there is no unloaded peak.

Figure 3 is the same Missouri site as in Figure 1, except this is lane two. Figure 1 is for lane one. This is a site we have real concerns about. Is it wrong? I cannot tell you that, but I can call up Missouri and let them know we have concerns about this site. Figure 4 is for a Kentucky site. I think this one is underkept rated. I could be wrong. There are sites where the loaded peak is not 80,000 pounds. In Silicon Valley, a lot of semi-trailers run with computer chips surrounded by styrofoam. They cube out. They do not bulk out. They do not weigh 80,000 pounds. But in Figure 4 the unloaded peaks are light. I suspect this site is uncalibrated. It is too low.

Figure 5 is one where we are starting to see some shifts. Is it good or is it bad? This is one of the sites that started to cause us to change from percentage to number of vehicles. It turns out there are not a whole lot of vehicles in here. It is possible that the change from June to July is simply a matter of random chance; just because there are not that many vehicles associated with it. This was done with a portable counter over a period of a week, and the week happened to straddle the month between June and July.

Figure 6 is another site. We think this one is a counter that is not working correctly. There is another site in Washington that looks a lot like this one, and we were experimenting with it. We learned that the Washington site is out in the middle of rural, eastern Washington. There is not an enforcement scale within two counties, and there is a food processing plant just down the road. We thought that they could run 104,000 pounds out there on 3S2s if there is no enforcement. Raw vegetables going in, or canned vegetables coming out; both are possible. But the more we thought about it, when you start to add up the percentages of overweight vehicles, 25% overweight vehicles is a large number and probably not correct; particularly when you look at the even distribution out there. Based on that, we have come to the conclusion that this is probably scale chowder more than it is true vehicles.

Vehicle classification in some ways is more difficult because you do not have class 9 vehicles at 80,000 pounds or between 28 and 32, depending on whether they are flatbeds or whether they are a reefer, that do not have anything in them. So for vehicle classification, we have gone to comparing the data for reasonability. Essentially, we are looking at things like percent of volume by class, but that really changes from one site to another. So we have to have an initial measurement of what is expected and a flag when it is outside of those expected boundaries. We need someone who knows something about that site to confirm it; to determine if it is realistic, or it is a scale problem. We have to go out and deal with that. We have looked at weekday/weekend differences. We looked at lane-to-lane comparisons, directional comparisons, zero-volume records, and the number of unclassified vehicles. It becomes a little more difficult in the LTPP database, however, when some states give us all directions of data; some states do not. Some states give us all lanes. Some states give us only the LTPP test lane. But we are going to build the software to do the best it can with what is available.

For vehicle class, as we build the history, the expected value tables are really based on the various data you give us. If you have given us 1990 and 1991 data, we are going to look at it. In one particular site, a particular state's data, in 1990 there are roughly 1,700 vehicles a day in 3S2s by themselves. In 1991 they changed equipment. There were then five 3S2s a day. One of these two is not correct. We do not know which one is really correct, although I have my speculations. You would be surprised what you can learn when somebody changes equipment. We may come back and provide some material--a graph, a table, a chart--and ask, "which one you think is correct, or are they both correct?" And that will then serve as the history; remembering that sometimes you will get things that you do not expect.

At one point I came to the conclusion that you have high weekend sites, and you have low weekend sites. Figure 7 is for a Nebraska site. This is a month of data, but the trend goes on for 365 days, and I am totally convinced that this site is working beautifully (with the occasional day off for good time;

it goes to Florida for the day). But if you look at this site, you see an extreme variation in 3S2 volumes, FHWA class 9. The highest peak out there is Saturday. And on every Sunday the volume goes down, and it goes down farther on Monday. It dutifully comes up on Tuesday and reaches a secondary peak on Wednesday. But then it drops on Thursday, climbs slightly on Friday, and comes back to a new high on Saturday. This occurs week after week. It is not a high weekend or a low weekend. It is a Saturday/Wednesday peak. Why? I do not know. But it is legitimate data, and we have to account for it.

Initial vehicle class tests compare data sets from different submittals--1990 versus 1991, lane 1 against lane 2. Whatever you have given us, we will compare them. If there is something that jumps out, we will ask you about it. If not, it will become the history.

One of the other things we do is compare four cards to seven cards. Most states submit both data if they collect weigh-in-motion data. This is a great measure of scale health. Normally there are more vehicles counted--four cards, than there are weighed--7 cards. This can be seen in Figure 8. If that difference is high, something is wrong with that site; something is causing you to not weigh vehicles. You should go out and figure out why that is going on. It does not mean necessarily that there is a problem, but you need to be aware of it.

At the same time, as soon as I thought this was always a constant, i.e., the four cards greater than seven cards, I got another state with a site where there are more vehicles in the seven-card records than there are in the four-card records (see Figure 9). Why? They used two different pieces of data-collection equipment--a capacitance pad for portable weigh-in-motion and a different vehicle classifier. They have different estimates, different measures of how many 3S2s there are. We are going to come back to them and ask "you tell us which is the control total; we do not know." The simple fact that it raises a question, and in the end, the answer, will raise the quality of the LTPP database.

In conclusion, if we are off the beaten path, tell us why. We might be right. We might be wrong. But hopefully we will build you tools, so it will allow you to do your own quality assurance. And in the end, we will make the charts and quality assurance much better.

Figure 1

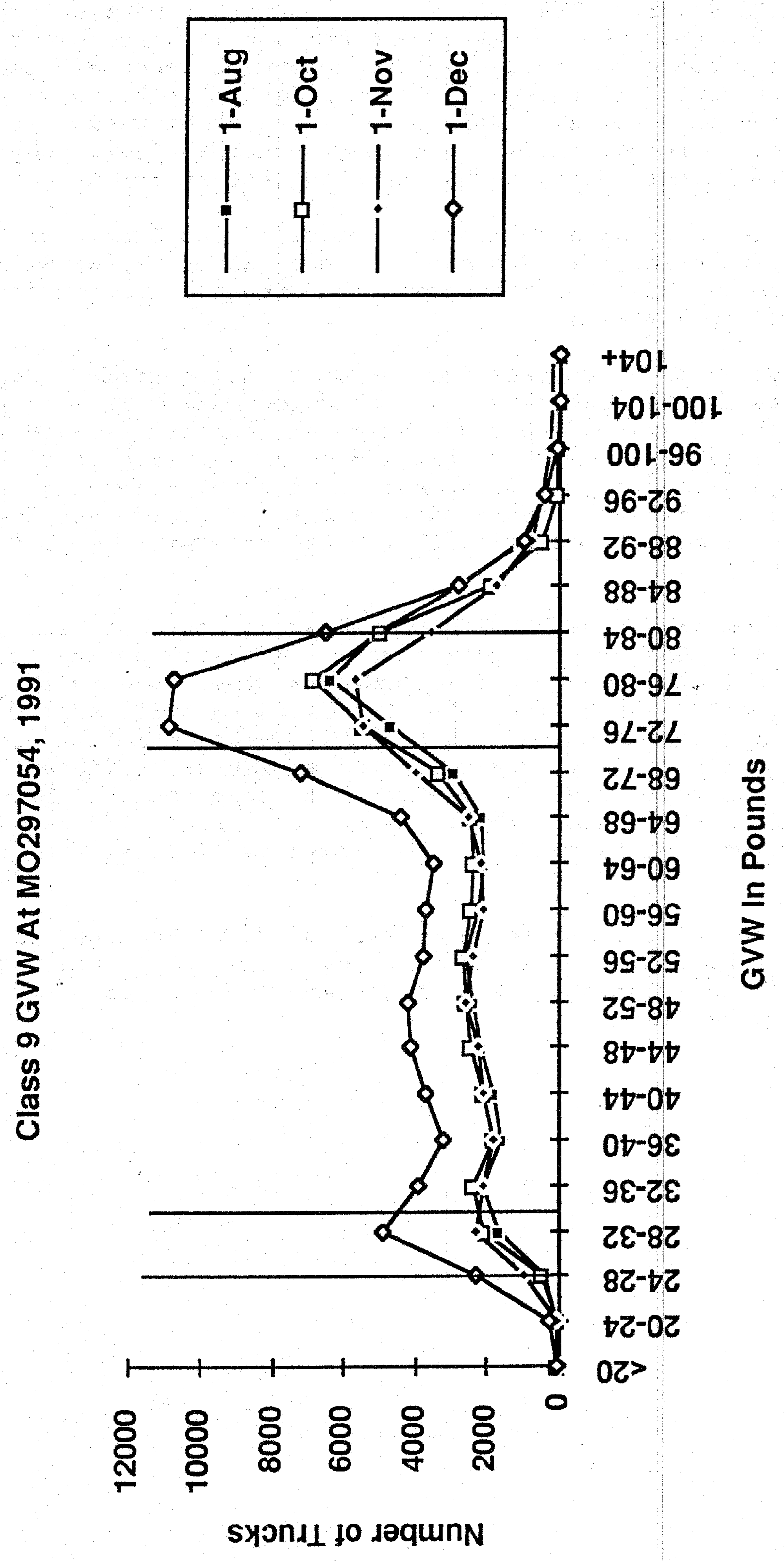

Class 9 GVW At MO297054, 1991
1-Aug
1-Oct
1-Nov
1-Dec
Number of Trucks
0
2000
4000
6000
8000
10000
12000
GVW In Pounds
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104
104+

Figure 2

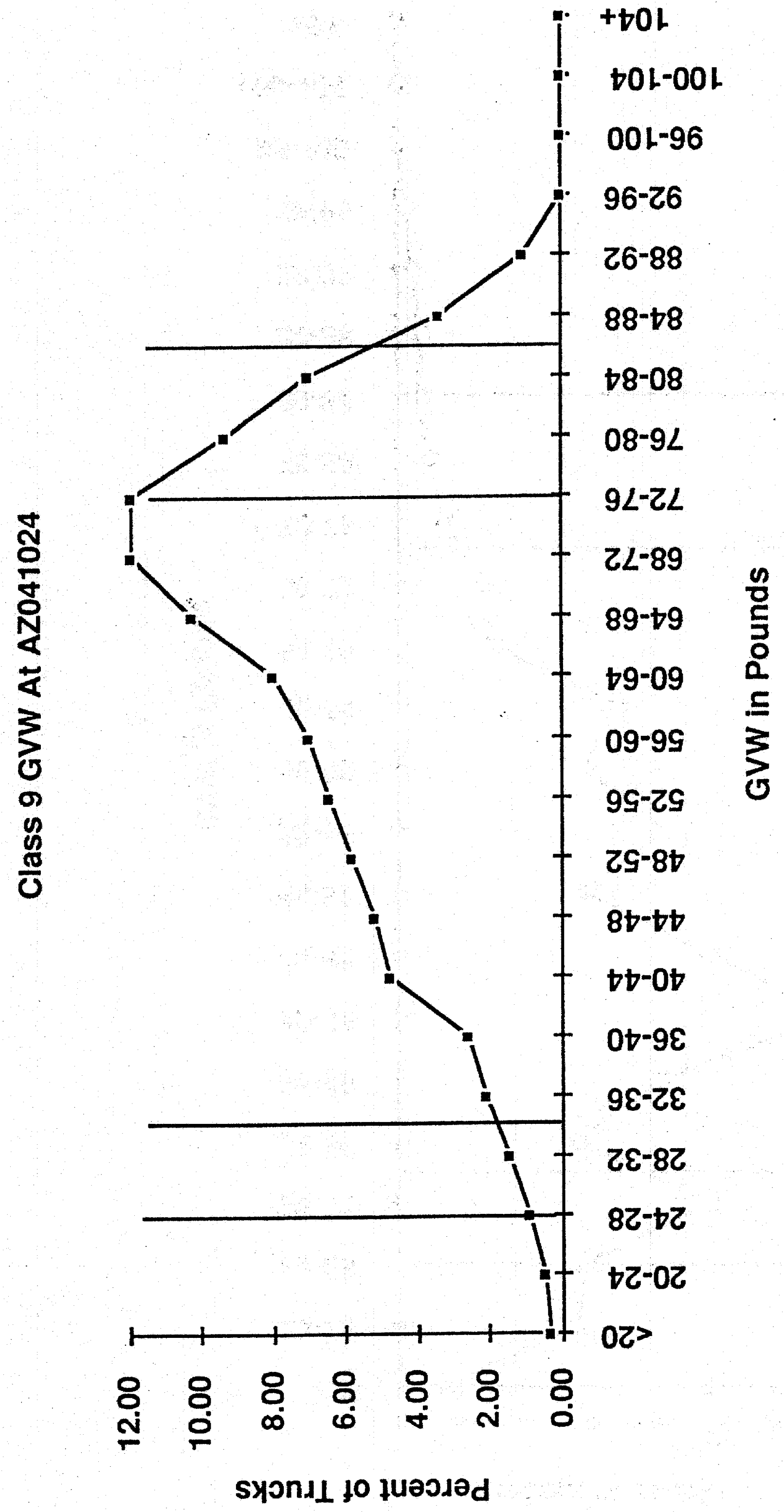

Class 9 GVW At AZ041024
Percent of Trucks
12.00
10.00
8.00
6.00
4.00
2.00
0.00
GVW in Pounds
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104
104+

Figure 3

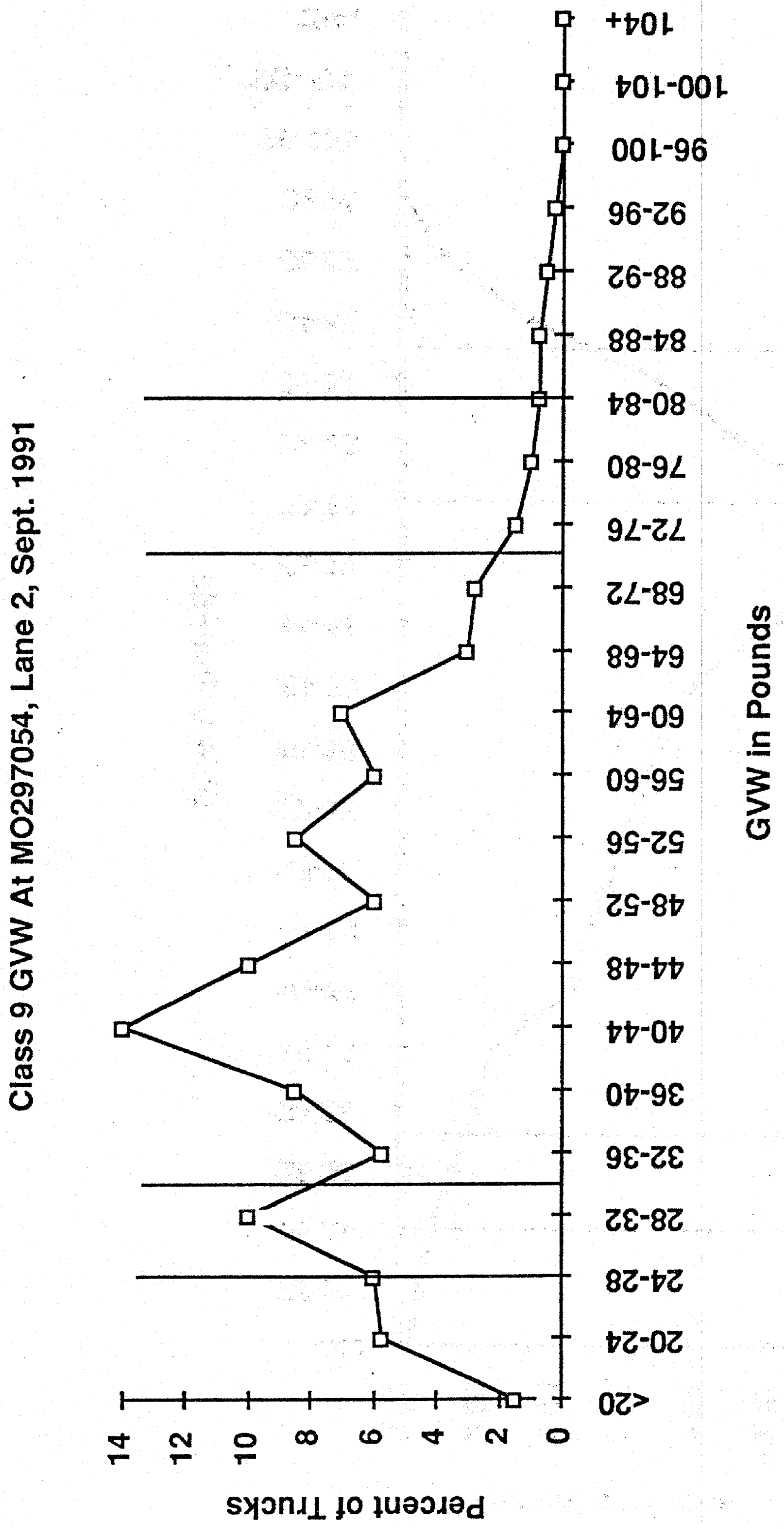

Class 9 GVW At MO297054, Lane 2, Sept. 1991
Percent of Trucks
0
2
4
6
8
10
12
14
GVW in Pounds
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104
104+

Figure 4

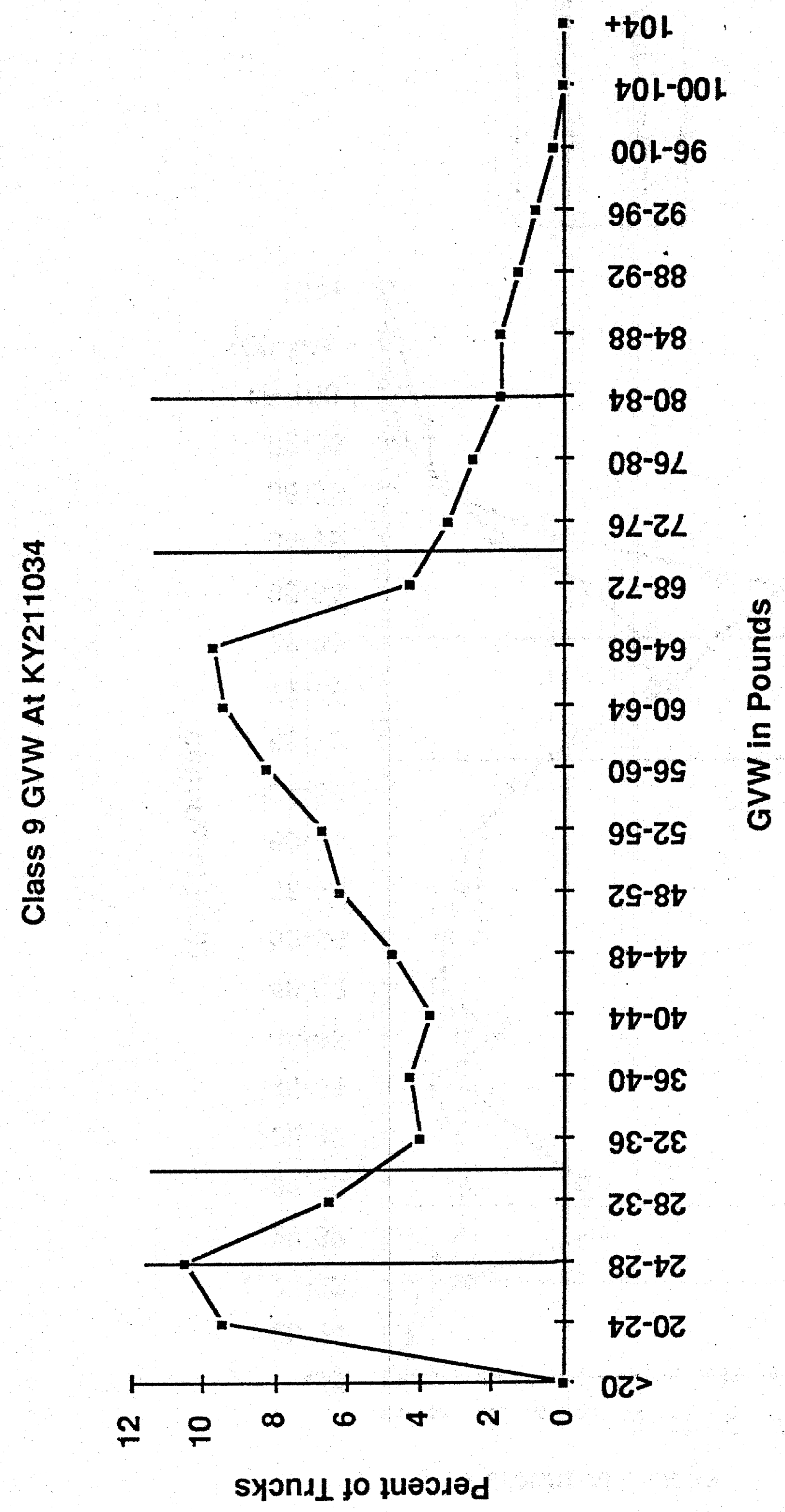

Class 9 GVW At KY211034
Percent of Trucks
0
2
4
6
8
10
12
GVW in Pounds
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104
104+

Figure 5

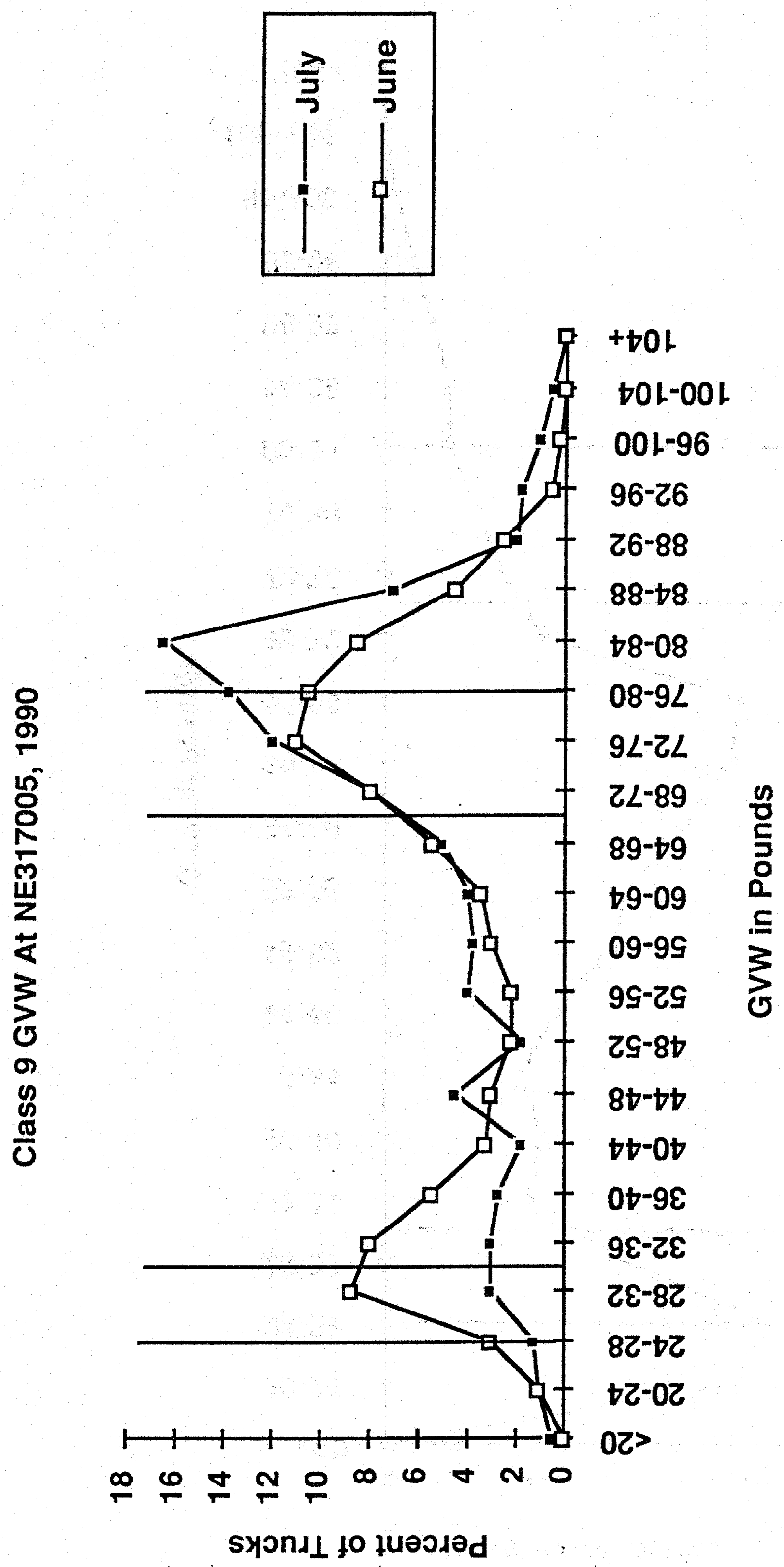

Class 9 GVW At NE317005, 1990
July
June
Percent of Trucks
0
2
4
6
8
10
12
14
16
18
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104
104+
GVW in Pounds

Figure 6

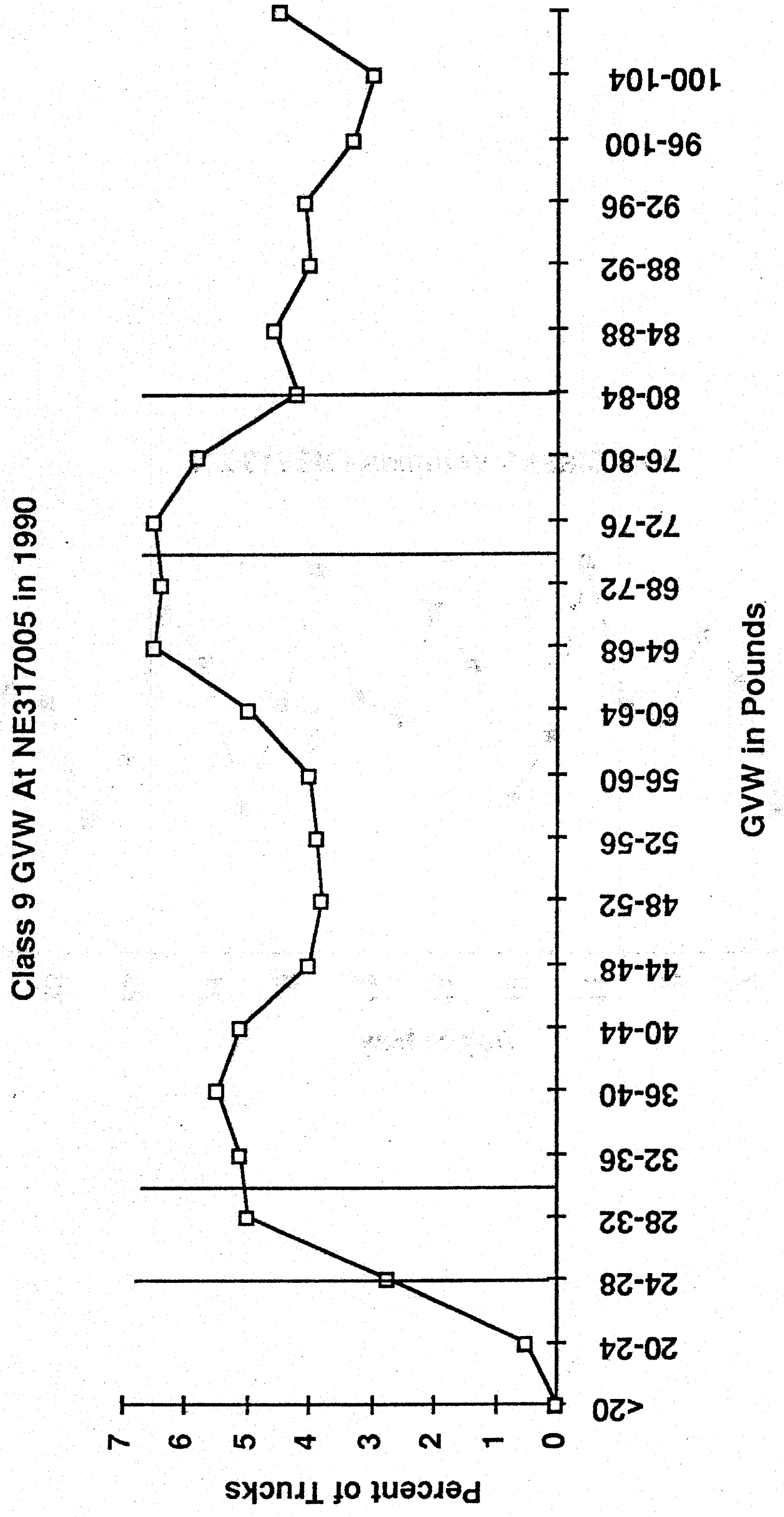

Class 9 GVW At NE317005 in 1990
Percent of Trucks
0
1
2
3
4
5
6
7
GVW in Pounds
<20
20-24
24-28
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
84-88
88-92
92-96
96-100
100-104

Figure 7

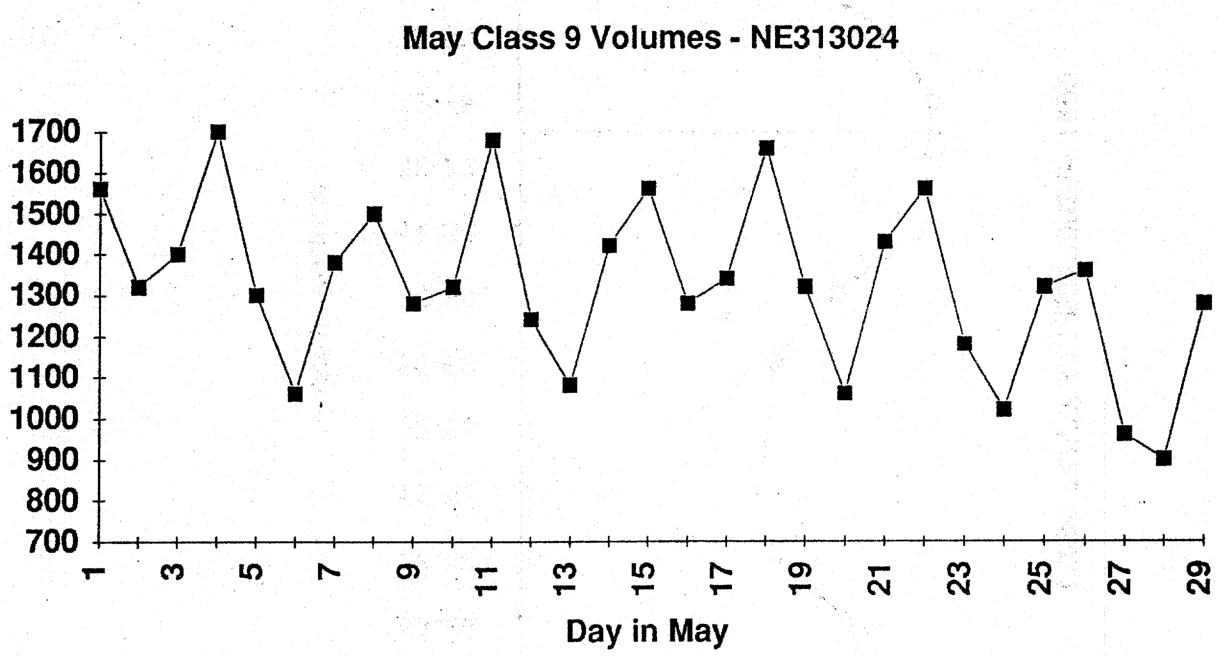

May Class 9 Volumes - NE313024
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Day in May

Figure 8

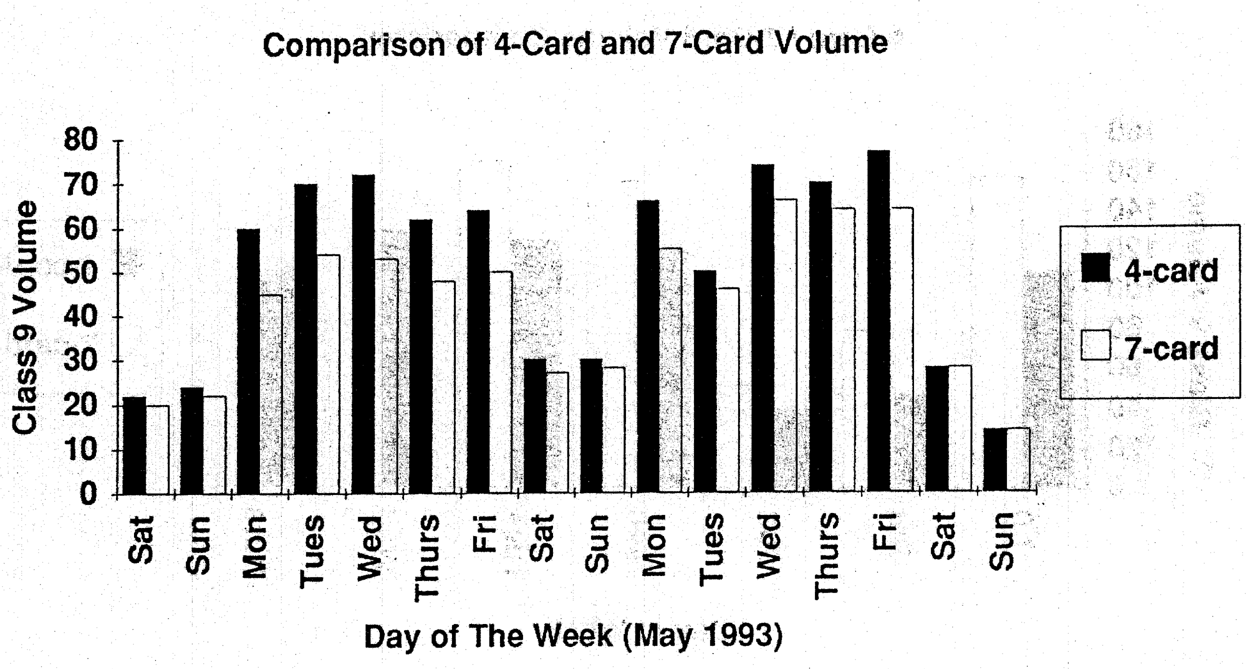
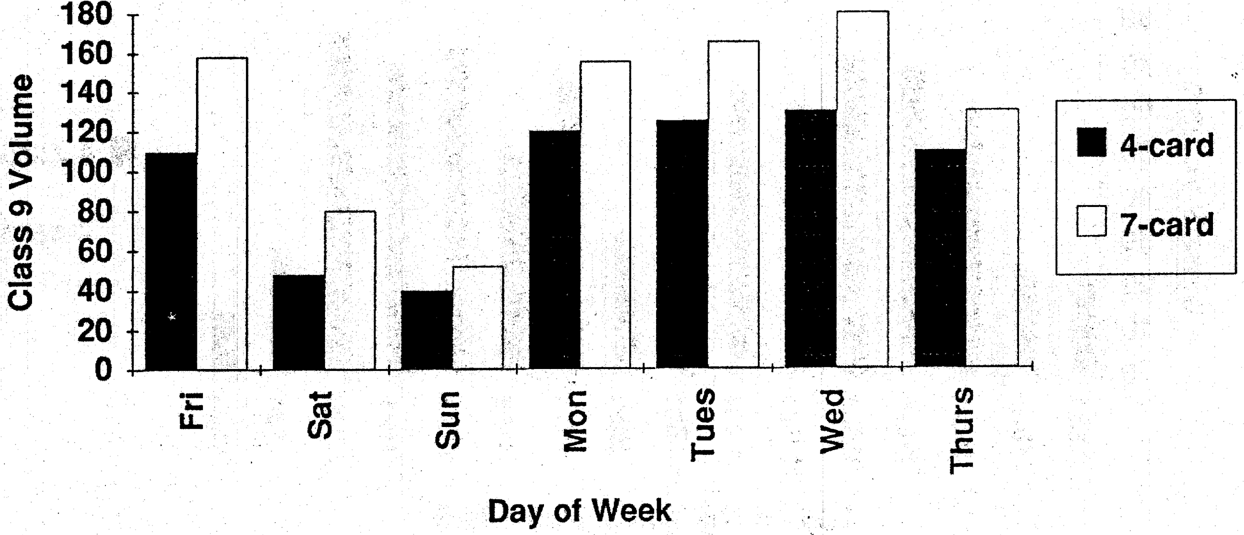

Comparison of 4-Card and 7-Card Volume
Class 9 Volume
0
10
20
30
40
50
60
70
80
Sat
Sun
Mon
Tues
Wed
Thurs
Fri
Sat
Sun
Mon
Tues
Wed
Thurs
Fri
Sat
Sun
Day of The Week (May 1993)
4-card
7-card

Figure 9

4-Card / 7-Card Volume Comparison



CONCURRENT SESSION, NEEDS AND USES OF TRAFFIC DATA

National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

SUMMATION: CONCURRENT SESSION, NEEDS AND USES OF TRAFFIC DATA

Mr. Clyde E. Lee
University of Texas at Austin

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

SUMMATION: CONCURRENT SESSION, NEEDS AND USES OF TRAFFIC DATA

Clyde E. Lee, University of Texas at Austin

This session dealt with the needs for and the uses of traffic data. We had eleven presentations and two of these dealt with the traffic monitoring at some test roads. [Mark Flinner described the Minnesota DOT project.] Minnesota DOT has developed a unique test road in that they built a three-mile road parallel to I-94. Traffic was diverted to this pavement test road in July 1994. They have a WIM system upstream of the fourteen asphalt and nine concrete pavement test sections, each 500 feet long. This test road is subjecting the pavements to actual interstate traffic. The plan is to run for five to ten years; the pavement is designed for a five- to ten-year life. This test road also includes a loop road of gravel and thin surfaced pavements in which a test truck is running repeated loads to simulate farm traffic. The objective of this project is to correlate traffic loading directly with the performance of the pavement test sections. Particular attention will be paid to the spring break-up time, which is important in the northern climates.

Another paper on test roads was given by [Joseph] Garner from the University of Texas at Austin. He described test sections that are on US 59. There are five concrete and five asphalt pavement test sections; each 1,000 ft long. [The sections] are monitored by a weigh-in-motion system, which is supplemented by some infrared lightbeam sensors that are directed just above the pavement surface to measure the lateral position of the wheel loads in the lane and to tell whether the vehicle has single or dual tires. The monitoring has been going on for two years now and will continue. The objective of this project is to develop a rehabilitation plan for an existing road that is about 140 miles long, and use as much in-place materials, as feasible, in the rehabilitation program to build a pavement design that will last for 20 years or more.

Mark Hallenbeck, from Washington State Transportation Center, described the analysis of some data from Washington State and from Florida. He analyzed the development of factors to factor short samples of traffic volume data to represent annual patterns of traffic. He gave some cautions about variability, the analysis of variability, accounting for hourly, daily, monthly and seasonal variations in traffic and in developing the factors so that they are representative of the true conditions.

Richard Margiotta [who is from] System Applications International Corporation [(SAIC)] told us about some procedures that are being developed to analyze the LTPP data that are coming in and gave us some examples from the North Central Region in 1991. Of course, this mass of data that is coming is going to require a lot of specific analysis, and his firm is working closely to develop some of those procedures so that we do get consistent data and that we analyze it in an appropriate way.

Mike Bruff, from North Carolina DOT, told us how North Carolina is attempting to use existing data, as much as feasible, to come up with the kinds of requirements for the congestion management system under ISTEA. In effect, they have done some inventories of existing data that are in the various databases and are going to try to utilize, as much as feasible, the existing data and then supplement that with special studies, where necessary, to come up with the data to describe the congestion management plan that is under development.

Shawn Turner from Texas Transportation Institute (TTI) in Texas, gave us a presentation about the data collection methods that can be used to define congestion. Of course, the definition of congestion is a variable and so he is recommending the development of some indices to smooth out the data and give a uniform description of congestion at various levels and on various systems. He [also] described such methods as floating car techniques and license plate matching and described their strengths and weaknesses.

Tom Wholley, with Vanasse, Hangen & Brustlin, talked about some guidelines for obtaining traffic data that relate specifically to mobile source emissions. He pointed out [that] in urban areas, frequently, the mobile source emissions account for up to 50 percent of the emissions of concern. They are developing some guidelines that can be used for collecting appropriate data. They are also analyzing some of the sensitivity of the various models that are used to predict the mobile source emissions.

[William] Youngblood, from Georgia Tech, described a project that is underway in Georgia that involved Georgia Tech, the Georgia DOT and the Atlanta Regional Planning Commission. They have done an extensive survey to identify the various sources of data that are out there in terms of both planning data and operational data. [It is] particularly critical, I think, in the areas of operations of traffic signal systems, and so on, that relate directly to our planning process and our operational process, to have all the data that we can. So they are looking at a procedure now, [after having] done the inventory, to bring that data into a common database. He pointed out that there are nineteen weigh-in-motion stations on the interstate system in Georgia, and the data are collected and thrown away. So that is a rich source of data that has been identified and can be brought into the analysis. That plan is under development to use a relational database, bring all the data together in a common place and [to look] at the possibilities of using a GIS to integrate that database and make it more appropriate.

Richard Gaulin, with Connecticut DOT, described a unique method of trying to estimate the vehicle occupancy rates. This methodology uses accident data as a basis for occupancy rates. I thought this sounds kind of far out to use accidents to give vehicle occupancy rates, but he pointed out that in Connecticut, in 1992, there were 112,000 accidents that involved 160,000 people. So he has checked this technique where they query all the various accident databases and analyze the data, use some serious judgment in what is appropriate data to use and then they check this against some field observations. By and large, it appears [to] give a very reliable estimate of vehicle occupancy. That technique, when used appropriately, can yield some good data so long as you do not try to get down to very small sections and microscopic samples.

Tai Liu, with the Volpe National Transportation Systems Laboratory, spoke about urban travel time surveys and the various techniques that have been used. They have an extensive study [in which] they have used a lot of data and various techniques, including video image matching of license plates and manual matching of license plates, floating car techniques and automatic vehicle identification techniques for determining travel time in urban areas. This methodology is quite varied. You could use different techniques. Tai [Liu] gave some cost estimates for using the various types of techniques and discussed some of the reliability that has been found in the various methods. Then, he pointed out that the data format and the data [collection] plan are very important. The costs can be quite high for that data. He pointed out that there is no perfect method, and it is important to have a good data plan and an objective. The objective of this project is to develop, for the nation, a uniform method of collecting the travel time information so that there can be comparisons made among states.

Paul Shuldiner, from the University of Massachusetts, followed up with a detailed discussion and presented some actual video images of the license plate survey technique. [He] pointed out how the reliability of this method can be quite high if the data are analyzed specifically. He has worked his students pretty hard looking at hours and hours of video images to check the reliability. And the license plate matching from video images can be a good technique.

So, in general, this session was devoted to data collection, and defining some of the needs of data and then matching the techniques with those data needs. We had eleven presentations that gave us a lot of good information.

TRAFFIC APPLICATIONS ON THE MINNESOTA ROAD RESEARCH PROJECT (MN/ROAD)

Speaker: Mr. Mark S. Flinner
Minnesota DOT

Author: Mr. Curtis Dahlin
Minnesota DOT

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

September 18-22, 1994

ABSTRACT

Mn/ROAD is a pavement research project in Minnesota. The 3 mile, 2-lane test road has been built parallel to inplace I-94 northwest of Minneapolis/St. Paul. Westbound traffic flows from inplace I-94 onto the test road and back again with no interruption. This traffic provides the loadings necessary for pavement research. The road has 14 asphalt and 9 concrete test sections each 500 feet long. The sections are designed for a service life of 5 or 10 years. The roadway opened to traffic in July 1994.

A Weigh-in-Motion (WIM) system is located in the inplace section of I-94 immediately upstream from the test road. This system continuously collects vehicle classification, speed, axle spacing, vehicle length and axle weights by wheelpath.

Some of the standard applications will consist of monitoring Equivalent Single Axle Loads (ESAL's) applied to the pavement over time. Pavement deterioration will be compared to ESAL application. Particular attention will be focused on the loadings and pavement performance in the spring when the roads are in a weakened state due to the frost coming out of the ground.

An effort will be made to determine whether the relationship of the equivalency factors currently being used for various weight single axles, tandems, tridems and quadrums is proper for this location. Another application will be to compare the weights of selected axles or axle groups as recorded by the WIM with the deflections, strains and stresses measured by the numerous sensors buried in the test pavements.

Weights applied to each lane will also be studied. There is a significant difference in traffic loading by lane. This will enable an analysis to be made of how the individual lanes perform based on the traffic they experience.

Wheelpath weights will also be monitored by the WIM. The impact of a strong cross-wind on the distribution of weight by side of the truck will be studied by using data from the weather station located at the site.

This road provides the pavement and traffic communities with the opportunity to study the relationship between the two elements. This research is all taking place in a setting with realistic pavement designs and actual traffic stream vehicles. It should provide valuable insights which can be used for future pavement designs.

INTRODUCTION

The idea for the Minnesota Road Research Project (Mn/ROAD) was formulated in the early 1980's. Its basic purpose is to test various pavement designs subjected to actual traffic loadings in combination with the effects of the environment. The site selected for the 3 mile 2-lane test road is on westbound I-94 northwest of Minneapolis/St. Paul. The test section, which was opened to traffic in July 1994, was built parallel to the inplace roadway. Traffic makes a smooth transition from the original roadway to the test section and then back to the original roadway.

The road has 14 asphalt and 9 concrete test sections each 500 feet long. There are coring and transition zones of 50 to 165 feet separating the test sections. Some sections have 5 year designs while others have 10 year designs. The use of actual traffic to provide the Equivalent Single Axle Loads (ESAL's) has several advantages. First, the vehicles and their drivers are provided at no cost to the project and at no additional cost to those driving the vehicles. Second, there is a wide variety of trucks, axle groups, and weights of those axles. This provides a good cross section of loadings to the pavements. This is very important to the project.

INSTRUMENTATION

The traffic traversing the test section are monitored by a Weigh-in-Motion (WIM) system located in the original roadway just prior to the transition to the test section. The WIM, located in both lanes, is an International Road Dynamics (IRD) hydraulic load cell. It was installed in 1987 in concrete pavement. It collects all of the standard data for a system of this type including vehicle classification, speed, axle spacing and vehicle length. It is different from some WIM systems in that it collects wheelpath weights and not just axle weights. The system operates automatically and continuously. At this time, data are automatically polled once a week.

There is also a weather station located at the site. Its purpose is to provide solid environmental data such as temperature and precipitation which will be used in evaluating the performance of the pavements. There are also thousands of sensors buried at various depths in the pavement. Some of the readings taken by them include measuring pavement response to axle loads, moisture, and depth of the frost.

DATA ANALYSIS

The broad purpose of the project is to determine the number of

ESAL's which will be applied to each test section in order for them to fail. As stated earlier, there are 5 and 10 year designs, but they will probably not all last those respective 5 and 10 years. Some will likely fail sooner and others later. Environmental factors, notably the sun, amount of water in the roadway and the freeze-thaw cycle, play a role in the deterioration of some pavements. The role they play in deterioration will be considered along with traffic loadings.

Specific analysis will be conducted on the relationship between axle or axle groups of varying weights with the pavement response to those axles. This pavement response will be measured by the thousands of sensors in the roadway. An effort will be made to match up the weights of selected axles or groups of axles as recorded by the WIM with the responses noted by the pavement sensors. This vehicle comparison will be useful in determining the relationship between weight and pavement damage. It can also make tentative judgments on the validity of the AASHTO ESAL equations currently being used.

The AASHO road tests were conducted in Illinois in the late 1950's. The results from that study has provided the basis for ESAL's for the past 20 or more years. Now with the opening of the Mn/ROAD test facility, the research community will have the opportunity to monitor the performance of pavements of various designs when axles and axle groups of various weights are applied to them. The AASHO road test studied only single and tandem axles. This current test will also study the impacts of tridem and quadrum axle groups. It will also be able to compare the impact of single axles with single tires of standard dimensions, single tires of wide dimensions, and single axles with dual tires. This latter test will require visual identification of these tires.

The comparison of WIM and sensor readings goes beyond a general study. That is because the WIM scales weigh vehicles with different axle configurations differently. For example, at this site, the system is properly calibrated to weigh loaded 5 axle semis correctly. However, one of the consequences of calibrating to them is that loaded 3 axle single unit trucks come in about 13 % high in the driving lane and about 8 % low in the passing lane. These differences are primarily attributed to the profile of the pavement leading up to and immediately downstream from the WIM scales and the interaction of that vehicle type with that pavement.

Differences in readings such as this have been observed at other WIM sites. Tests performed in May 1989 at the permanent WIM located on I-94 east of St. Paul showed that a loaded 3 axle single unit test trucks came in 11 % low while a loaded 2 axle single unit truck came in nearly 14 % high. A composite of traffic stream trucks had them coming in from 4% low to 6 % high.

That was with the system calibrated to 5 axle semis. (1)

Axle weights are constantly changing as they move down the road. The vehicles suspension system responds to the changing profile of the road. The interaction of various suspension systems with the road can be studied here. It would require visually identifying the suspension system and then matching up the WIM weights with the pavement response as recorded by the sensors in the pavement. In order to do this study, some roughness is needed in the pavement. The objective would be to record the WIM data and the sensor data at several locations downstream from the point of roughness. One could then see how quickly the axle(s) settled down after being excited.

Spring is the time of the year in Minnesota when the pavements are at their weakest. This is when the frost comes out of the ground, usually resulting in the ground being saturated with water. The load bearing capability of the road is then at its lowest. One of the prime studies will be to compare the ESAL's and pavement sensor responses in the spring with the other times of the year, particularly summer and fall. One of the specific areas of examination will be to determine if there is a point in the weight scale at which significantly more damage is done compared to the weights immediately below that point. This could be used to refine the current practice of setting springtime weight restrictions on roads that have limited weight-bearing capability. Obviously, some test sections will perform better than others during the spring as they are better able to distribute their loads over a larger area of the pavement.

A comparison of the traffic loadings in the side-by-side lanes will be an important part of the study. The ESAL's in the lanes is substantially different. The right lane has the vast majority of the ESAL's, as is typical of a rural facility with this level of traffic. The performance of each of the lanes will enable researchers to evaluate the relative impacts of traffic compared to the environment.

This project also provides the opportunity to study weights by wheelpath. Those weights as recorded by the WIM would then be matched up with and compared to the response of the pavement sensors. If there is a consistent difference in weights by wheelpath and a corresponding pavement response, the impact can be quantified. The wind speed and direction as recorded by the on-site weather station has to be noted while conducting this study. The study should be conducted for each of the basic conditions. They are no wind, strong cross-winds from both the right and left, strong head winds and strong tail winds. Presumably strong cross-winds will show the most differences in weight by wheelpath.

The designs and performance of low volume roads is also of concern. Consequently, a second test road has also been constructed next to the mainline test road. It is a continuous loop which has 17 test sections. The test sections are reflective of those which are or may be used on low volume roads. Some of these test sections are of flexible pavement and others are gravel. A 5 axle semi flatbed which was recently purchased specifically for Mn/ROAD will be used to provide the ESAL's. The weights will generally be at either the maximum legal load or over the legal load. The truck has been weighed both statically and by the WIM at the site. The response of the pavement sensors to the varying weights of this truck in the different seasons of the year will be studied.

There is the possibility of using a truck which has been instrumented to record the weight of the axles as it moves over the pavement. This would result in considerably more data being available which could be used in evaluating the loads applied to the pavement. This axle weight data would be coordinated with the weights recorded by the WIM. Presumably a relationship could be established which would result in an expansion and extension of the data collected by the WIM.

An evaluation of various rehabilitation techniques of pavements is also going to be a part of the study. Once the original pavements fail, they will be rehabilitated using different methods. The response of those different repairs to traffic will again be studied as it was with the original designs.

The studies discussed in this paper are not necessarily all being planned, but all are feasible given the features and capabilities of the Mn/ROAD facility. Some of these studies obviously have more value than others. Also, they are of interest to differing disciplines, and this may dictate which are done and which, if any, are not done. There are also other traffic applications such as safety questions and weight compliance issues which could be studied. However, they probably will not be studied as they do not directly relate to this project.

THE FUTURE

The life of the facility will likely extend to 20 years or more. It provides the research and traffic communities with the opportunity to greatly expand their knowledge of the relationship between traffic loadings and pavement performance. Mn/ROAD is the first major test of its kind which makes use of WIM to monitor traffic stream vehicles driving on such a heavily instrumented test facility. It has far-reaching implications for the future design of pavements.

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FACTORING OF VEHICLE CLASSIFICATION DATA

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FACTORING OF VEHICLE CLASSIFICATION DATA
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This paper describes the analysis of truck volume data collected by the Washington State Department of Transportation (WSDOT) over four and one half years, from 1988 through 1993. The primary objectives of this research were to: investigate the patterns in truck volumes at various locations in Washington State; determine whether seasonal factors can be developed and applied to short-duration truck volume measurements to better estimate average annual conditions; develop procedures for routinely calculating and applying these values in Washington; and develop an easy procedure that other states can use to create their own seasonal factoring process,

FINDINGS

Establish Truck Volume Patterns

Comparison Among Vehicle Classes

The project findings reveal that the four vehicle classes (roughly equivilent to cars, single unit trucks, tractor semi-trailer trucks, and tractor mutli-trailer combinations) collected by the permanent length classifying equipment have very different seasonal patterns, regardless of the volume or functional classification of the roadway or the geographic location of the site. In general, the longer truck categories show less seasonal variation (i.e., month-to-month changes in daily traffic volumes) than the short truck and automobile classifications. In addition, traffic volumes of Bin 2 vehicles (mostly larger, single unit trucks and RVs) tend to vary the most by season. This variance appears to be attributable to the recreational vehicles in this category. Figures 1 and 2 illustrate the differences in seasonal truck volume patterns among vehicle classes.

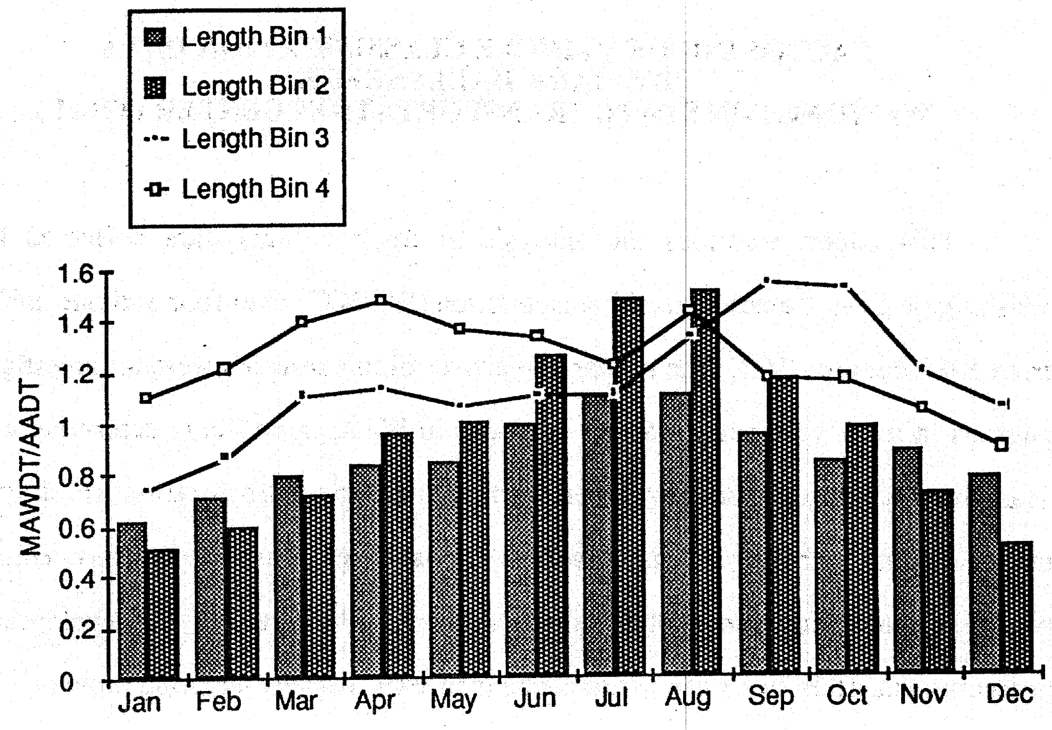

Figure 1. Average Monthly Weekday Volume /AADT Ratio for Site 61 in 1991

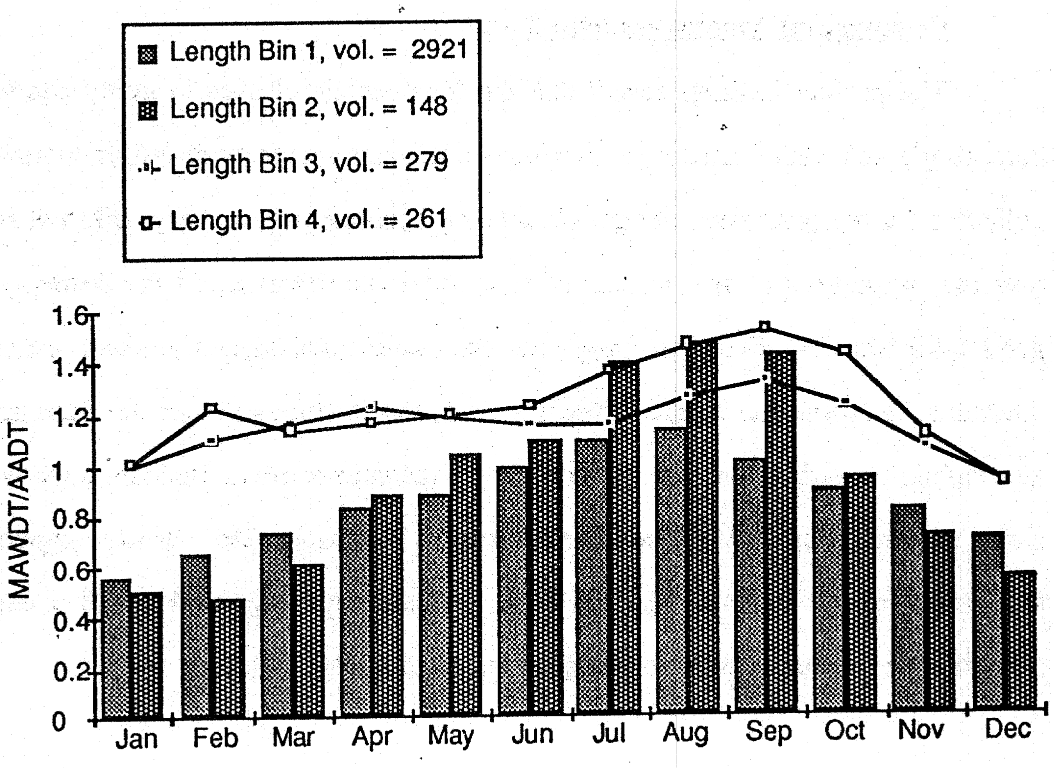

Figure 2. Average Monthly Weekday Volume / AADT, Site 41 - 1991

Geographic and Functional Roadway Distributions

As expected, the functional classification of the road and the location of each data collection site significantly influences the traffic patterns observed at that site. In general, the higher the functional classification of the road, the higher are the traffic volumes in all vehicle classes. The higher the traffic volumes, the more stable are the traffic volumes from month to month and from year to year. Conversely, the lower the road's functional classification, the lower is the traffic volume (particularly in the longer truck categories), and the more unstable is the traffic volume pattern, both from month to month and from year to year. While some low volume roads show reasonable stability in their traffic volume patterns, higher variation is often present on these facilities.

The impact of geographic location can also be seen in the traffic volume patterns observed in the data. In addition, the geographic influences change from one vehicle class to the next. For example, the recreational routes show increased automobile volumes (i.e., Bin 1) in the peak recreational periods; however, these increases are not as dramatic (in percentage terms) as those experienced by vehicles in Bin 2, which contains most of the recreational vehicles. Similarly, the two longer truck classes (Bins 3 and 4) are only minimally affected by the recreational peaks. In agricultural areas, the longer truck categories show traffic volume peaks that are not present (or at least not as noticeable) in other portions of the state. Figures 1 and 2 (presented earlier) show examples of these differences at two sites with fairly extreme seasonal variability.

When a site has a low traffic volume level like the site in Figure 3 (AADT for Bin 4 is 14 vehicles per day), relatively small changes in volume significantly affect the computed seasonal factors. Consequently, low volume sites often have highly variable seasonal factors even though the absolute volume changes from year to year are small. This high variability complicates the search for groups of roadway sections that have similar traffic volume patterns and reduces the accuracy of AADT estimates produced with short-duration counts and seasonal adjustment factors. This problem is accentuated

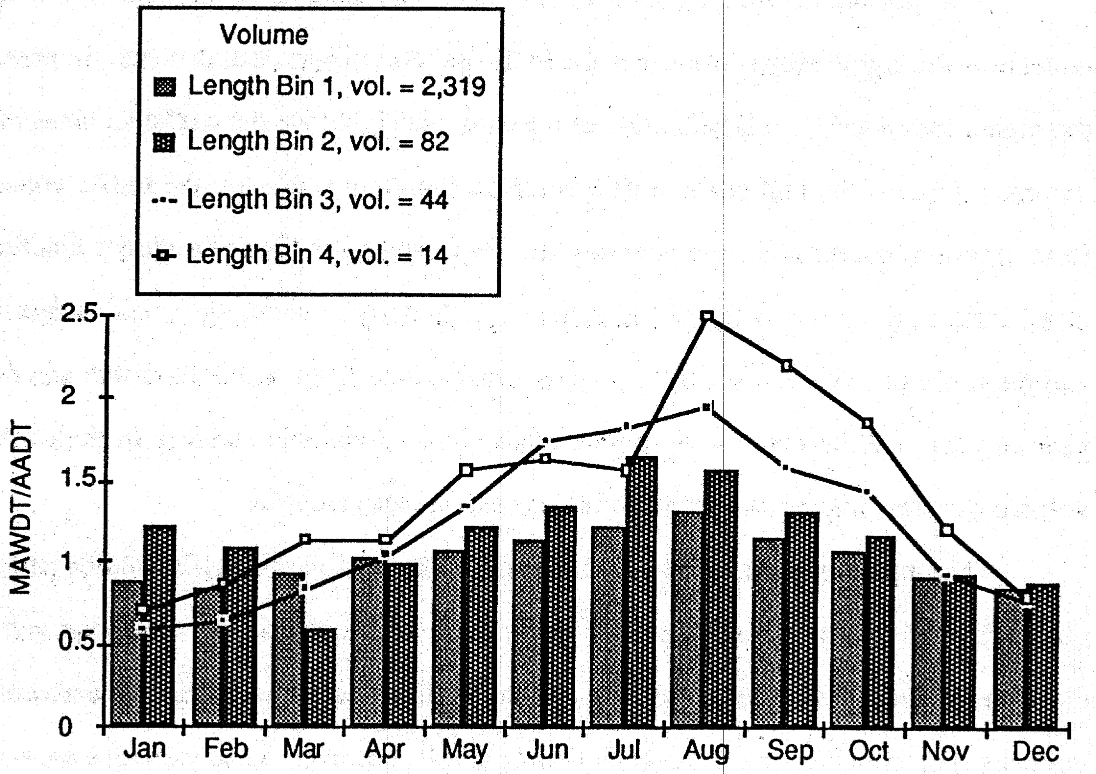

Figure 3. Average Monthly Weekday Volume / AADT, Site 820 - 1990

by more disaggregated classification schemes. That is, the FHWA 13-category classification scheme will produce a greater number of highly variable vehicle class seasonal factors than the four-length bin categories used in Washington. This increase occurs because the more disaggregated vehicle classification scheme causes more vehicle categories to have low volumes, which are, in turn, more unstable than the more aggregated vehicle categories.

13-Bin Versus 4-Bin Classification Schemes

When these disparate vehicle class patterns are combined into fewer categories (for example, the four Washington length classes), the individual peak traffic movements are "dampened." That is, the monthly volume patterns change less from month to month. The primary drawback to this dampening effect is that it masks the actual vehicle patterns that are occurring on the road. However, the dampening effect can prove advantageous. One of its advantages is that the seasonal factors for the larger vehicle categories tend to be more stable. Thus seasonal factors for more aggregated vehicle categories are more capable of predicting total traffic volume. These factors simply do not reflect the changes occurring in the vehicle mix within that volume with a high level of precision.

Stability Of Factors Over Time

The analysis of monthly to average annual traffic ratios over time showed that, in general, the greater the traffic volume is on a road (or within a classification), the more stable is the monthly ratio of weekday traffic to annual average condition. That is, on interstate and heavily traveled, principal arterials, the monthly traffic volume patterns are reasonably stable over time (from year to year). Traffic patterns on lower volume roads are often (but not always) unstable from one year to the next. While some low volume sites have stable monthly factors, others have factors that vary considerably from year to year.

While the actual monthly factors computed for low volume roads may change significantly from one year to another, the general volume patterns remain reasonably constant even for low-volume roads.

THE NORTH CAROLINA CONGESTION MANAGEMENT SYSTEM

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Presented at
National Traffic Data Acquisition Conference
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The North Carolina Congestion Management System

Meeting the Demands of ISTEA
with Existing Data Collection Activities

The Intermodal Surface Transportation Efficiency Act of 1991 required the development of six management systems. In North Carolina a joint State-MPO Task Force worked together to develop the Congestion Management System. ISTEA offers a great amount of flexibility as far as the development of the Congestion Management System goes, and it was the intent of the North Carolina Department of Transportation and the Task Force to pass this flexibility on to the individual MPO's, who are responsible for implementation. The CMS developed is responsive to the needs of the state and the urbanized areas, and meets the intent of ISTEA.

The North Carolina CMS allows the MPO's and the State to concentrate resources only on those elements with the greatest need, thereby obtaining a clearer picture of the deficiencies in the transportation system. The focus of the system is only directed toward the congested elements of the transportation system, rather than extensive data collection activities. In North Carolina the implementation of the CMS is not expected to create a great deal of extra work. With better documentation of the current process, and better analysis between the update years of the plan, the CMS is expected to be easily implemented.

INTRODUCTION

A key element of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 is the requirement that each state develop and maintain six management systems: Pavement, Bridge, Safety, Congestion, Public Transportation Facilities and Equipment, and Intermodal. In addition to the management systems, each state is also required to develop a Traffic Monitoring System for Highways.

In North Carolina, the Bridge Management, Pavement Management and the Safety Management Systems are already existing to some extent. Work is underway to develop the Public Transportation Facilities/Equipment and the Intermodal Management Systems. The purpose of this paper is to describe current congestion management activities within the State of North Carolina, as well as outline the State's Congestion Management System.

The Statewide Planning Branch is responsible for implementing the Congestion Management System (CMS) and the Traffic Monitoring System for Highways (TMS/H) and coordinating the activities of the other management systems with the metropolitan planning process. North Carolina has delegated the implementation of the CMS in the urbanized areas to the MPO's. The State and the seventeen Metropolitan Planning Organizations are in the process developing work plans and implementation schedules. The State will be responsible for combining the individual CMS's, and submitting them to the Federal Highway Administration (FHWA) for approval.

The North Carolina CMS will be implemented through the existing metropolitan planning process. Figure 1 shows how the CMS and the other five management systems will be merged into the existing planning process. In North Carolina, due to the strength and centralization of existing transportation planning activities, this integration is not expected to be overly difficult. The Statewide Planning Branch currently administers the 3-C (continuing, cooperative and comprehensive) transportation planning process for all seventeen urban areas in the state with populations over 50,000 as required by Section 134, Title 23, U.S. Code. It also provides assistance to all municipalities and counties in the development of transportation plans to adequately serve present and anticipated traffic and land development needs as required by North Carolina General Statutes. Transportation models for areas with populations over 5,000, including the urbanized areas, are also maintained at the state level.

Before the official development of the CMS, the basic building blocks for a CMS were already in place. North Carolina has a strong planning process that in fact fulfills

METROPOLITAN PLANNING PROCESS

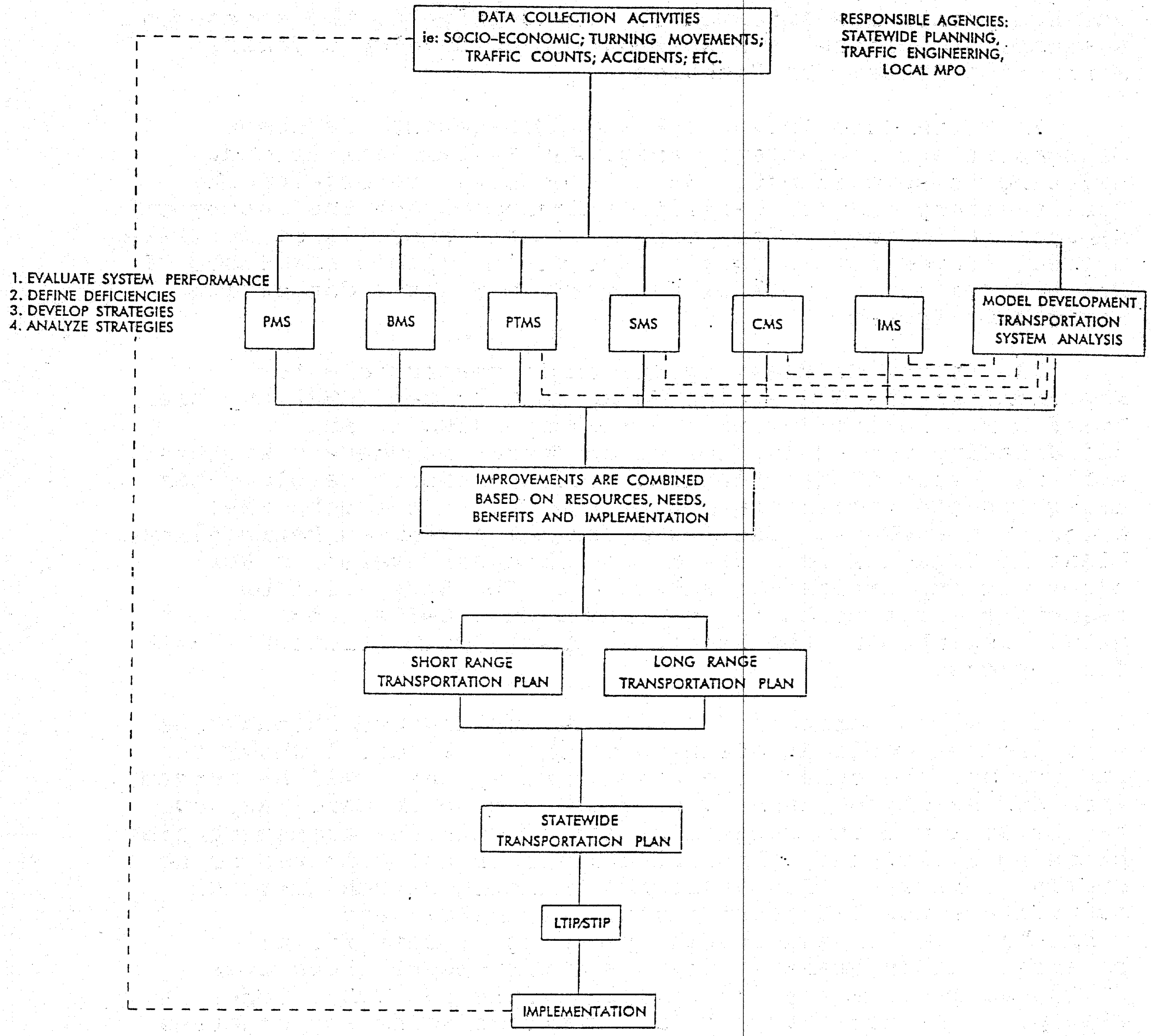

FIGURE 1

many of the requirements of the Congestion Management System. The transportation planning process includes, but is not limited to, (1) capacity analysis of the existing thoroughfare system, (2) projection of travel to a future design year, (3) evaluation of non-construction alternatives and alternate modes as a means of solving the transportation problems, (4) development of a major thoroughfare plan to adequately solve future travel needs, giving consideration to environmental and social factors and involving public participation, (5) cost estimates for proposed improvements, (6) development of recommendations for construction priorities, and (7) recommendations for plan implementation. Functional designs and more detailed traffic operations studies may also be done. In North Carolina's urban areas transportation plans are typically updated every 7-10 years. The CMS is expected to be beneficial because it will be flexible and more reactive to the changing nature of the transportation system.

EXISTING CONGESTION MANAGEMENT ACTIVITIES

There are several task forces established within NCDOT to address the needs and requirements of ISTEA. Among these are an incident management task force, a committee on ISTEA information management and finally, an NCDOT management steering committee whose job is to provide overall direction to the development of the management systems. A Congestion Management Task Force is being formed at the state level to coordinate the various congestion management activities and ensure that these activities are incorporated into key departmental functions.

These task forces have led to the implementation of the following types of congestion mitigation projects:

<u>Reversible Lanes</u> - Operating in Greensboro and Charlotte.

<u>Motorist Assistance Patrols (MAP)</u> - Operating in the Asheville, Charlotte, Gastonia, Winston-Salem, Greensboro, Durham and Raleigh areas. The MAP has become one of DOT's most popular programs, and several other areas have begun to request the service.

<u>Coordinated Traffic Signal Systems</u> - Being implemented in many areas.

<u>Freeway Management Systems</u> - The CARAT (Congestion Avoidance and Reduction for Automobiles and Trucks) project in Charlotte and IMPACT (Incident Management Program for Active Control of Traffic) in the Piedmont Triad Area combine several congestion management techniques.

Incident Management Programs - Being implemented in Mecklenburg, Gaston, Forsyth, Rowan, Guilford, Durham, Buncombe, McDowell, Dare and Curritick Counties.

Statewide Traffic Management Plan - Will identify nine traffic management zones that will be interconnected and able to intercommunicate across the state. When complete, the system will become a statewide traffic management system.

Variable Message Signs - Currently being installed at locations in the Charlotte, Greensboro and Winston-Salem areas.

In addition to these projects, several studies are also underway. They include: Study of Ramp Metering in the Greensboro area; IVHS Feasibility Studies in the Raleigh/Durham/Chapel Hill area and the Greensboro area; Adaptive Traffic Signal System Studies for Durham and Greensboro; Variable Message Signs in several coastal cities to alert motorists to delays and identify alternate routes; and various individual corridor level studies.

Many of these activities were initiated before the development of the "official" CMS in North Carolina. They are the result of burgeoning traffic growth on the central arteries throughout the state, and high growth rates in our larger cities. While ISTEA placed an increased awareness on these activities, their implementation was not necessarily related to the management system requirements.

DEVELOPMENT OF THE NORTH CAROLINA CONGESTION MANAGEMENT SYSTEM

In the Spring of 1993, the passage of ISTEA was almost two years old and the deadline for the CMS was approaching. NCDOT decided to form an interagency task force to develop the guidelines for the State's CMS. The State-MPO[1] Congestion Management Task Force was formed in April 1993 and consisted of Federal, State and Local MPO Staff. It met from June 1993 through January 1994 and produced a report detailing the guidelines to be used in the development of the North Carolina Congestion Management System. The objectives of the Task Force was twofold: to develop a CMS that met the intent of ISTEA; and to determine how best to integrate the CMS into the current State-MPO Metropolitan Planning Process.

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[1] The Metropolitan Planning Organization (MPO) is a forum for cooperative transportation decision making. Within each area's Metropolitan Area Boundary (MAB), federal, state and local agencies work together to ensure that the planning process is consistent with federal, state and local guidelines.

When the Task Force started work, very few other areas had even started. FHWA had still not released any final rules for the development of the CMS. The Task Force began by reviewing the Congestion Management Program from the San Diego Association of Governments and found it to be too detailed for the needs of North Carolina. The approach taken by the Lexington-Fayette Urban County Government (LFUCG) as presented at the Region 4 Congestion Management Technology Sharing Session in Lexington, Kentucky was also reviewed. The LFUCG program is much simpler and emphasizes the monitoring of congestion management corridors. While this approach seemed to be more in line with the needs of North Carolina, some modifications and tailoring were required.

The first work effort of the Task Force was to conduct a survey to determine the state of the practice for measuring and reporting congestion within the state. Specifically, the questionnaire asked local and state agencies to identify congested elements of the existing transportation system, to document how congestion is currently being measured, and to identify what type of congestion-related data is currently being collected.

The survey led to two important conclusions. The first being, that as a result of fairly robust and up to date travel models in all of our urbanized areas, either the Statewide Planning Branch or the local MPO's and urban areas have a good idea of the extent and breadth of congestion that is currently occurring. Secondly, though ISTEA has raised the amount of planning funds available, most of the MPO's agreed that they do not have the staff or the resources to undertake a great amount of new data collection activities. They felt the simpler the system, the better its chance of being implemented.

On the whole, it is not believed that congestion is a very extensive problem in North Carolina. Therefore, the Task Force did not think that it was necessary to develop a system that identified at what level of service every element of the transportation system was operating. In fact, in some ways, such a system would just be a duplication of the current transportation modelling process. By using existing data collection methods and basic congestion indicators, they believed it would be possible to identify those elements of the transportation system that are congested, or will become congested in the near future. With yearly reviews and the use of long term trends from the model, future congestion could also be predicted. This process would allow for the development of a CMS that would focus only on those congested elements of the transportation system.

Following the survey, the Task Force focused on two specific objectives: to develop a Congestion Management System that meets the intent of ISTEA and maximizes the current data being collected, and to minimize the amount of new data that would be required by the CMS to assess the level of congestion. The Task Force recognized that ISTEA offers a great amount of flexibility as far as the development of the CMS goes. It was the intent of the Task Force and the State as the implementing agency to pass as much of this flexibility along to the local MPO's.

By concentrating resources only on those elements with the greatest need, the deficiencies in the transportation system can be better analyzed. In addition, attention can be focused on the needed improvement strategies without spending scarce resources on extensive data collection activities.

NORTH CAROLINA CONGESTION MANAGEMENT SYSTEM

North Carolina's CMS was developed as a two tiered approach. For the first part, a defined transportation system would be monitored using existing data that is currently being collected on both the state and the local level: traffic counts, vehicle occupancy rates, accident data, turning movement counts, observation, public complaints, etc. This data is readily available either through the MPO process or the Traffic Monitoring System (TMS/H). From this data, a list of congested elements would be identified.

The second tier would be concerned only with those congested elements. More detailed data would be collected (detailed traffic counts, travel time studies and turning movement counts). Additional analyses would be done to assess the level of congestion and help identify needed improvement strategies.

The Federal Highway Administration guidelines for the Congestion Management System are included in 23 CFR 500. Work plans and identification of critical areas of congestion are due by January 1, 1995. Though the state has the responsibility for implementing and certifying the CMS, North Carolina has chosen to delegate the responsibility of the CMS in each urban area to the MPO's. The state will be the certifying agency for the CMS and will be responsible for the integration of the local CMS's into the Statewide CMS.

Schedule of Implementation

The schedule for the CMS is specifically laid out in 23 CFR 500.509:

(a) by October 1, 1994, the State shall develop a work plan that identifies major activities and responsibilities and includes a schedule that demonstrates full operation and use of the CMS in Transportation Management Areas (TMA) that are non-

> *attainment for ozone and/or carbon monoxide by October 1, 1995, and in all other areas by October 1, 1996. The most critical areas requiring analysis shall be identified and data collection activities shall be initiated.*
>
> (b) *By October 1, 1995, in TMA's that are non-attainment ..., the CMS shall be fully operational and shall provide projects and programs for consideration in developing metropolitan and statewide transportation plans and improvement projects.*
>
> (c) *By October 1, 1996, the CMS shall be fully operational in all areas and shall provide projects and programs for consideration in developing metropolitan and statewide transportation plans and improvement projects.*

North Carolina has three non-attainment TMA's: Charlotte, Durham and Raleigh. These areas must have a schedule in place that shows full implementation by October 1, 1995. This includes providing projects and programs for consideration in developing metropolitan and statewide transportation plans and improvement programs.

The other fourteen urban areas and the state are expected to have a schedule that shows full implementation by October 1, 1996 or earlier. The CMS shall also be providing programs and projects for consideration in developing metropolitan and statewide transportation plans and improvement programs.

Work Plans and Critical Areas of Congestion

To meet the first certification date of January 1, 1995, the State intends to submit the statewide schedule of implementation for each MPO as well as a listing of critically congested areas. To identify critical areas of congestion, each urbanized area and the state will review the June 1993 inventories of congested elements that were a part of the congestion management survey. If any other facilities are experiencing critical levels of congestion, they will also be identified.

In addition to the implementation schedules and the inventory of congested elements, each area's current data collection activities will also be critiqued. Any new data collection activities that need to take place to assess the level of congestion on the congested elements should be identified.

Major Activities of the Congestion Management System

The major activities associated with the North Carolina Congestion Management System are:

- Identify Transportation System Under Review
- Identify Congested Elements
- Establish System Monitoring Efforts
- Establish Performance Measures
- Identify Improvement Strategies
- Identify Funding and Implementation Procedures for Improvement Strategies
- Evaluate Effectiveness of Improvement Strategies
- Document Congestion Management System

A brief description of each of these tasks follows.

Identification of Transportation System Under Review

North Carolina has one of the largest state-maintained street networks in the nation. This system includes both rural roads and those inside municipal boundaries. As a result, the State has determined that it is necessary to identify a Statewide Transportation System (STS). The STS will focus on travel of a regional and statewide nature between and through population centers, as well as access to ports, airports, public transportation facilities, other intermodal transportation facilities and other major travel destinations. The street system may include those facilities functionally classified as freeways, other principal arterials and minor arterials within the urbanized areas; and principal arterials, minor arterials, and major collectors in the rural areas. As a minimum, it will include the National Highway System (NHS) and the State's Intrastate System. Within each urbanized area, the STS will be coordinated with each MPO.

Each MPO shall be responsible for identifying and quantifying congestion for that area that is within their Metropolitan Area Boundary (MAB). For the purpose of the CMS, the highway system under review shall be those facilities identified as major or minor thoroughfares on the mutually adopted Transportation Plan. During the process of developing transportation plans for an area, roads in the network are defined as major thoroughfares, minor thoroughfares and locals.

While several studies are underway, North Carolina's current urban transit systems only include buses. These transit systems typically operate as services, and contribute very little to commuting options. Only a few routes during the peak hours typically experience any type of congestion. While transit system issues were discussed by the Task Force, and congestion indices were developed, no one performance measure was decided on.

The urban transit system under review shall include all the elements of the existing bus system, including, but not limited to, existing routes, multi-modal terminals and any demand responsive systems in place. In addition, any carpool or vanpool program shall also be included. Much of the data to determine congestion on our urban transit systems are already being submitted through the State's Public Transportation and Rail Division.

Statewide, the transit system to be included shall include all modes of regional and statewide transit travel, including inter-city bus service, passenger rail and air travel.

In most urban areas, bikeways and sidewalks are not facing great amounts of congestion. The greatest problems occur in areas with extensive greenway systems. While several of these are experiencing congestion as a result of over capacity, and mixture of uses (bicycles, pedestrians and roller blades on the same path), it was the consensus of the task force that facilities not functioning as part of the integrated urban transportation system should not be included on the Congestion Management System.

Identification of Congested Elements

The purpose of the CMS is to identify those facilities that are congested or may become congested in the near future. By using the two tiered approached as described earlier, congested elements of the transportation system can be identified. For each of these congested elements, the MPO and state will be responsible for applying the measures of performance to their respective transportation systems as identified earlier. Both recurring and non-recurring congestion should be identified. Corridors or facilities determined to be congested, or having the potential to become congested in the near future (within the next 5 years), will be identified as congested elements. For these elements, a more detailed data collection effort may be necessary to determine the duration, severity and extent of congestion, and to assist in identifying solutions.

Establishment of System Monitoring Efforts

As part of developing the CMS, each area shall be responsible for identifying and coordinating the various data collection activities within their area. This inventory is expected to include all data collection activities currently underway at both the state and the local level (i.e. state and local ADT counts, turning movement counts, high accident locations, transit data, etc.).

As a minimum, detailed traffic counts, travel time studies and turning movement counts should be collected for each congested element. If other facilities that are not identified in earlier steps begin experiencing congestion, a separate analysis may be done. If it is determined that they are congested, these may be added to the list of congested elements and will be monitored more closely.

Establishment of Performance Measures

In order to properly identify and quantify the status of congestion in an area, performance measures must be defined. Performance measures are operational characteristics, physical conditions, or other appropriate parameters used as a benchmark to evaluate the adequacy of transportation facilities and estimate needed improvements. Such measures might be based on accident rates, delay, public complaints and volume/capacity ratios. Rather than list a specific measure of congestion, the Task Force chose to develop a menu of congestion measures to use. The guidelines for the CMS include an appendix that lists various measures of congestion that may be used to help the user define congestion. Based on these measures, the status of congestion in each area can be reported (i.e. miles of congested roadway, lane miles congested). The measure of congestion is expected to be consistent across the state. Each area will be responsible for establishing and setting their own performance measures for their respective transportation system based on the goals of the local area.

The State shall be responsible for establishing and setting acceptable performance measures for the Statewide Transportation System (STS). For those links on the STS that are within an urbanized area's MAB, the State, in coordination with the affected MPO, shall be responsible for establishing and setting the appropriate performance measures. Within urbanized areas, an MPO may establish more stringent standards on the STS.

Identification of Improvement Strategies

Once a congested element is identified, additional data will be collected. If this data identifies a problem, then additional analysis will be done to identify appropriate strategies to manage existing congestion, enhance mobility and avoid future congestion. For those facilities identified on the MPO's CMS, the MPO, in coordination with the NCDOT, shall take the lead in developing and analyzing improvement strategies. For those facilities that are on the Statewide CMS, the State, in coordination and cooperation with the MPO, shall be responsible for developing strategies to alleviate congestion.

The local MPO will have a role in helping to develop improvement strategies for the Statewide Transportation System. It is understood that, for those facilities that have a regional or statewide significance, the State, in consultation with the MPO, will address the improvement strategy which best mitigates the congestion problem and meets the performance standards necessary to maintain an adequate STS. Specific improvement strategies must be tailored to an individual area, therefore the Task Force chose to include an appendix that lists a menu of improvements that should be considered for a congested element.

Identification of Funding and Implementation Procedures for Improvement Strategies

Once the appropriate improvement strategies to alleviate congestion have been determined, the following shall be identified for each: the agency responsible for implementation, the time frame for implementation, and the probable funding source for the improvement.

Federal, state or local funds may be used to fund congestion reduction strategies. Federal funds that may be used are National Highway System Funds (NHS), Surface Transportation Program Funds (STP) and Federal Transit Administration Funds. In addition to these funding programs, ISTEA also recognizes the need for an additional program to deal specifically with congestion management projects in air quality non-attainment areas. The Congestion Mitigation and Air Quality (CMAQ) funds are available only to non-attainment areas. The State currently pays for improvements on an Intrastate Highway System. If a congestion problem exists on an Intrastate route then these funds may be used. Smaller pots of money are also available at the state level to fund small urban and spot safety projects.

Local areas also play an important role in the implementation of transportation improvements in their areas. They may fund improvements directly, or they may enact administrative controls that preserve future right-of-way. North Carolina has a strong long range transportation planning process that has a long history of implementing projects developed in the advance planning stages.

The Task Force recognized that there are a myriad of funding sources and project implementation techniques to implement improvement strategies, therefore the guidelines include an appendix of funding sources and implementation techniques that might be available to the user.

Each year, the North Carolina Board of Transportation holds public hearings to receive input on the State's Transportation Improvement Program (STIP). MPO's generally submit a Local Transportation Improvement Program (LTIP) request list at these meetings. This list will become the main vehicle by which those projects from the CMS are funded. Congestion relief projects will become the fifth major component of an MPO's LTIP request list. The other four components are highway, enhancement, public transportation and bicycle.

Evaluation of Effectiveness of Improvement Strategies

Once a congestion reduction strategy has been implemented, continuing monitoring efforts are necessary to assess whether the implemented strategy was effective in addressing the congested element. The objective will be to assess its effectiveness on both the specific congestion problem and the system as a whole. The Urban Area Travel Model and the Highway Performance Monitoring System (HPMS) will be important tools to assess an improvement strategy's success in reducing systemwide congestion. Based on the data collected, other tools may be used to determine an improvement strategy's success in relieving congestion at a specific site or along a corridor. Benefits may result from decreased delay, reduced travel time, reduction in accidents, etc.

Congestion Management System Documentation

Each area's Congestion Management System will be documented in a report that will be used to guide implementation of the CMS and will be used as the project selection document for the TIP. The Statewide Planning Branch of the NCDOT will be responsible for developing the Statewide CMS as well as integrating the individual MPO's Congestion Management Systems into the Statewide System. The detail and extent of this report will vary by area, but shall detail each element described above.

Coordination with other Management Systems

Of the six management systems mandated by ISTEA, the Congestion Management System is expected to be most interrelated with the Intermodal Management System (IMS) and the Safety Management System (SMS). The coordination between the CMS and the IMS will occur on the highway side, specifically where the congested links of the highway system correspond with the links in the intermodal elements. The coordination between the CMS and the SMS is expected to occur on the data collection side, where data collected in the SMS will be integrated into the CMS to help identify and analyze congested elements of the transportation system.

Coordination between the SMS and the CMS is an important part of the metropolitan planning process. In urbanized areas, the MPO shall become the lead agency for ensuring that the management systems are properly implemented.

Linkage to the Transportation Plan

The transportation plan is a long range document which evaluates system performance, identifies deficiencies and develops and analyzes strategies to provide for a more efficient future transportation system. The congestion management system is expected to be a process used to monitor, evaluate and develop strategies for dealing with the shorter term demands placed on the transportation system. The results of the congestion management system will also be evaluated within the development of the transportation plan. The model developed in association with the transportation plan update will be an important tool to help identify locations of future congestion.

SUMMARY

The Intermodal Surface Transportation Efficiency Act of 1991 required the development of six management systems. In North Carolina a joint State-MPO Task Force worked together to develop the Congestion Management System Guidelines. ISTEA offers a great amount of flexibility as far as the development of the Congestion Management System goes, and it was the intent of NCDOT and the Task Force to pass this flexibility on to the individual MPO's, who are responsible for implementation. The CMS developed is responsive to the needs of the state and the urbanized areas, and meets the intent of ISTEA.

The North Carolina CMS allows the MPO's and the State to concentrate resources only on those elements with the greatest need, thereby obtaining a clearer picture of the deficiencies in the transportation system. They are better able to focus attention on the needed improvement strategies, rather than extensive data collection activities. In North Carolina the implementation of the CMS is not expected to create a great deal of extra work. With better documentation of the current process, and better analysis between the update years of the plan, the CMS is expected to be easily implemented.

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CONGESTION MEASUREMENT - DATA COLLECTION METHODOLOGIES

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CONGESTION MEASUREMENT: DATA COLLECTION METHODOLOGIES

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ABSTRACT

Various congestion measurement techniques have been developed in the past to illustrate roadway congestion using available data. While this system has worked well, and will continue to function adequately for many analyses, there has been an increase in the breadth and type of information required in congestion and mobility studies. Roadway congestion studies are now oriented towards addressing person movement problems with a variety of construction, operation, and travel management programs designed to improve travel conditions and recognize limited financial resources and rights-of-way. Congestion measurement techniques must reflect these requirements, and convey information to a broad group of audiences, including transportation professionals, media, public, and elected officials.

Travel time-based measures appear to represent the quantities that are most easily communicated to the various audiences and satisfy the technical analysis needs. In order for travel time measures to be useful in the immediate future, however, there must be a link to the existing data collection and analysis procedures. This can be accomplished using estimation procedures based on relationships between generally available data and techniques, and travel time/speed-based measures. As advanced technologies are being integrated into many urban areas, travel time and speed information will become more readily available.

INTRODUCTION

The issue of congestion measures for transportation systems has become more important with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the requirement of management systems included in this Act. The following sections present a short discussion of some of the important factors that should be considered before a system of congestion measures is selected for congestion management systems.

The Importance of Context

It is essential that performance measures be consistent with the goals and objectives of the process in which they are being employed. Performance measures are key to controlling process outcome, whether the process is alternatives selection, congestion management, growth management or system optimization. For example, within congestion management, performance measures are used for problem identification and assessment, evaluation and comparison of alternative strategies, demonstration of effectiveness, and ongoing system monitoring.

Poor selection of measures has a high probability of leading to poor outcomes. In contrast, goals and objectives properly paired with performance measures provide the mechanism whereby decision makers can guide planners and engineers toward achieving desired ends, and can then check (using evaluation results) that the desired ends are in fact best served by the solutions offered (1).

A Proposed Framework for Analytical Techniques

A more flexible system of performance measures that focus on the key aspects of both trip making choices and plan evaluation can illustrate the effect of these potential solutions and a wide range of other solutions. The decision process used by travelers to select trip modes and routes is influenced by travel time, user cost, dependability, and access to alternative travel choices. The procedures used in plan evaluation consider travel time, capital and operating costs, and various societal and environmental impacts. Travel time is a common thread, both as a direct measure, and as an element of other indicators.

Research performed for a National Cooperative Highway Research Program project entitled "Quantifying Congestion" (2) suggests that a system of performance measurement techniques that use travel time-based measures to estimate the effects of improvements on person travel offers a better chance of satisfying the full range of potential analytical needs than the level-of-service measures that became conventional in the last four decades. This is not a suggestion that past technical procedures are fundamentally flawed or should be consigned to the dust bin. Until recently it was fairly easy to know what type of solution would be implemented because analyses were mode-specific, there was much less reliance on operation or management solutions, and funding categories dictated very little crossover between highway, transit and policy solutions.

Viewed in this perspective, calls for broader performance measurement systems are simply in reaction to changes in the need for information, rather than an indictment of technical procedures.

DEFINITIONS OF CONGESTION

Congestion measurement involves both adequacy and quality of transportation systems. Crucial aspects of adequacy are readily described using congestion measures couched in terms of deficiency and sufficiency. To describe quality, the complement of congestion must be quantified, namely, mobility or accessibility. The working definitions that follow draw upon the NCHRP "Quantifying Congestion" research (2).

Suggested Definition of Congestion

Any definition of congestion, and the transportation performance measures derived therefrom, should rely on concepts that are understood by the intended audience. The most widely understood measures involve travel time, speed and related quantities.

Past definitions of congestion tend to fall into two basic categories, those that focus on cause, and those which focus on effect. Performance measurement clearly requires a definition which addresses the effect, or symptoms, of congestion. A common theme permeates most definitions of congestion that focus on effect—congestion reflects an increase in travel time or delay beyond that acceptable to travelers.

Travel time and its derivatives are thus both widely understood and fundamentally useful in the definition and measurement of congestion. However, the congestion that is acceptable to travelers can vary by city size, location in the urban (or rural) area, and time of day or year. One method that may be used to resolve this issue is to define two quantities: congestion and acceptable congestion.

- Congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.

- Acceptable congestion is travel time or delay in excess of an agreed-upon norm.

The agreed-upon norm could reflect travel time or delay in a range from slightly to significantly above that incurred under light or free-flow travel conditions, and should be derived taking into account the expectation for each portion of the transportation system as influenced by community input and technical considerations. The amount of acceptable congestion may be varied by geographic location, time period, mode and facility type to reflect different expectations or objectives under different conditions.

With these congestion definitions, travel conditions may be compared for a variety of modes and system components on a more equal basis. However, it is still necessary to be aware that the role of congestion varies by mode. On most urban highways, congestion is a dominant factor in service quality. It is also caused by too many users. On transit systems, congestion also affects quality, but may be overshadowed in importance by other transit service characteristics such as frequency and route coverage, or lack thereof. Up to certain limits (typically encountered only in New York City or foreign countries), more users result in better service, because more frequency and coverage becomes practical. These differences suggest that congestion measures per se have limitations in cross-mode comparisons, even when using common measures such as travel time.

CONGESTION MEASURES

Development of a system of transportation performance measures should only be initiated after an examination of the uses, users and audiences, full consideration of program goals and objectives, and the nature of likely solutions. The measures offered here are presented to illustrate a system of congestion measurement techniques that use travel time-based measures to estimate the effects of improvements on persons. As previously discussed, there are a number of analyses that may not benefit from such a broad focus, but consideration of the context in which the measures are to be used should allow the user to identify the appropriate set of performance measures.

This section first provides a summary of the basic measures of congestion and mobility that can be calculated using travel time, traffic volume, person volume and basic roadway or transit system inventory data. The definition, calculation procedures and required data items are presented for each measure.

Definition of Data Items

Travel time is the time required to traverse a segment or complete a trip. Times may be measured directly using field studies, or can be estimated using empirical relationships with traffic volume and roadway characteristics, transit and highway computer network models, transit schedules or intended effect of improvements.

Desired travel time is the time deemed acceptable for door-to-door completion of a trip from origin to destination. The desired travel time should be differentiated by the purpose of travel, should reflect the expectation for each mode within the transportation system, and should be influenced by community input.

Segment or trip length is the distance associated with the travel time. Length can be measured directly with a vehicle odometer or scaled from accurate maps, but is typically an established item in a transit or roadway inventory database, and may be obtained from computer network representations.

Average speed for a segment can be used to calculate travel rate or travel times if field data are not readily available.

Actual travel rate is the rate, in minutes per mile or kilometer, at which a segment is traversed or a trip is completed. Travel rates may be determined directly using travel time field studies, or can be estimated using transit schedules or empirical relationships between traffic volume and roadway characteristics.

Desired travel rate is the maximum rate of travel (or lowest travel speed) at which a segment is traversed or a trip is completed without experiencing an unacceptable level of mobility. The desired travel rate should be based on technical factors that reflect the role and expectation of each portion of the transportation system, and should also be influenced by community input.

Vehicle volume is the number of vehicles traversing the segment that is associated with the travel time. Traffic volumes may be collected using field studies or estimated using standard procedures, but are typically an established item in a roadway inventory data base.

Person volume is the number of people traversing the segment being studied. The person volume can be collected for each travel mode, or estimated using average vehicle occupancy rates for types of vehicles.

Basic Mobility Measures

Travel time or difference in travel time can be a basic measure. It can be used to compare door-to-door travel times by different modes. A common use of comparison by travelers is for determining mode or route choice, or time of departure. Used in comparison with desired travel time or travel times for alternative transportation and land use configurations, it becomes a performance measure for both the transportation system and the arrangement of land uses, responsive to the trip length reduction afforded by allowing or encouraging mixtures of residential, commercial and office land uses.

The travel rate is the rate of motion, in minutes per mile, for a specified roadway segment, transit route segment, or trip. It is the inverse of speed (multiplied by a conversion factor) and is calculated by dividing segment travel time by the segment length. Values of travel rate are easier to use in statistical analyses than speed, and give the same comparison. Travel rate can be used with person volume to estimate corridor average speeds for persons traveling in different modes.

$$\begin{array}{c}\textit{Travel Rate}\\ \textit{(minutes per mile)}\end{array} = \frac{\textit{Travel Time (minutes)}}{\textit{Segment Length (miles)}} = \frac{60}{\textit{Average Speed (mph)}}$$

The delay rate is the rate of time loss for persons or vehicles operating in congested conditions, expressed in minutes per mile, for a specified roadway or transit route segment or trip. It is calculated as the difference between the actual travel rate and the desired travel rate, and illustrates the intensity of the congestion problem for travelers. The delay rate can also be calculated by dividing the difference (in minutes) between the actual travel time and the desired travel time by the segment length (in miles). The quantity can be used to estimate the difference between system performance and the expectations for those system elements, which can be used to prioritize alternative improvements.

$$\begin{matrix} \textit{Delay Rate} \\ \textit{(minutes per mile)} \end{matrix} = \begin{matrix} \textit{Actual Travel Rate} \\ \textit{(minutes per mile)} \end{matrix} - \begin{matrix} \textit{Desired Travel Rate} \\ \textit{(minutes per mile)} \end{matrix}$$

$$= \frac{\textit{Actual Travel Time} - \textit{Desired Travel Time}}{\textit{Trip or Segment Length (miles)}}$$

Total delay for a transit or roadway segment is the sum of time lost due to congestion, typically expressed in person- or vehicle-hours. Total delay in a corridor or an urban area is calculated as the sum of individual segment delays. This quantity is used as an estimate of the impact of improvements on transportation systems. The values can be used to illustrate the effect of major improvements to one portion of a corridor that affect several other elements of the corridor transportation system, either by improving travel rate or by drawing person travel away from portions of the system that do not perform well. The quantity is particularly useful in economic or benefit/cost analyses that require information on cost effectiveness.

$$\begin{matrix} \textit{Total Delay} \\ \textit{(person-hours)} \end{matrix} = \left[\begin{matrix} \textit{Actual} \\ \textit{Travel Time} \\ \textit{(minutes)} \end{matrix} - \begin{matrix} \textit{Desired} \\ \textit{Travel Time} \\ \textit{(minutes)} \end{matrix} \right] x \begin{matrix} \textit{Person Volume} \\ \textit{(people)} \end{matrix} x \frac{\textit{hours}}{60 \textit{ minutes}}$$

$$= \textit{Delay Rate } x \textit{ Person Volume } x \textit{ Segment Length}$$

The relative delay rate is a dimensionless measure that can be used to compare the relative congestion on facilities, modes, or systems in relation to different mobility standards for system elements such as freeways, arterial streets, and transit routes. It is calculated as the delay rate divided by the desired travel rate. The desired travel rate can reflect differences in operation between transit and roadway modes, allowing the relative delay rate to be used to compare different parts of the transportation system. The relative delay rate can illustrate that a delay rate of one minute per mile on a freeway (e.g., two minutes per mile vs. a desired rate of one minute per mile) is much more significant than a similar delay rate on a downtown street (e.g., five minutes per mile vs. a desired rate of four minutes per mile).

$$\begin{matrix} \textit{Relative} \\ \textit{Delay Rate} \end{matrix} = \frac{\textit{Delay Rate}}{\textit{Desired Travel Rate}} = \frac{\textit{Actual Travel Rate}}{\textit{Desired Travel Rate}} - 1$$

The delay ratio is a dimensionless measure that can be used to compare or combine the relative congestion levels on facilities with different operating characteristics like freeways, arterial streets, and transit routes. It is calculated as the delay rate divided by the actual travel rate. The delay ratio identifies the magnitude of the mobility problem in relation to actual conditions (as opposed to the relative delay rate which compares system operations to a standard).

$$Delay\ Ratio = \frac{Delay\ Rate}{Actual\ Travel\ Rate} = 1 - \frac{Desired\ Travel\ Rate}{Actual\ Travel\ Rate}$$

Speed of person movement is a measure of travel efficiency that could be used to compare the person movement effectiveness of various modes of transportation. The measure is calculated as the product of passenger volume and average speed for a particular route, and is typically expressed in terms of person-miles per hour. This quantity combines two desirable attributes for elements of the transportation system, speed of travel and the number of persons being moved. The value increases as either quantity increases. This measure can provide comparisons between alternative transportation improvements if a weighted average value of all corridor treatments is used. One problem with this value is that the size of the number is relatively large and difficult to compare to a standard or baseline value.

$$\underset{(person\text{-}mph)}{Person\text{-}Speed} = \underset{(persons)}{Passenger\ Volume} \times \underset{(mph)}{Average\ Travel\ Speed}$$

The corridor mobility index would consist of the speed of person movement value divided by some standard value, such as one freeway lane operating at capacity with a typical urban vehicle occupancy rate. This may be one method of addressing the magnitude and relativity problems with the speed of person movement. For instance, a freeway lane with a volume of 2,000 vehicles per hour at 35 mph and an occupancy rate of 1.2 persons per vehicle would yield a normalizing value of 84,000. The highest normalizing value may be obtained at speeds nearer to 45 to 50 mph and a volume of approximately 1,800 vehicles per hour, yielding a value between 100,000 and 110,000. The corridor mobility index, therefore, provides a relative value that can be used to compare alternative transportation improvements (e.g., high-occupancy vehicle treatments) to traditional improvements such as additional freeway lanes.

$$Corridor\ Mobility\ Index = Speed\ of\ Person\ Movement\ /\ Normalizing\ Value\ (e.g.,\ 100{,}000)$$

Accessibility at an individual location can be measured as average travel time to travel objectives or as the percentage of travel objectives reachable within a specified time. Travel objectives can be employment (all jobs in the region), housing, shopping, community services, or other destinations of interest. Weighted averages can be derived for a region. Most readily calculated using transportation planning computer networks and demographic data, accessibility has in the past been extensively used for assessing relative quality and equity in proposed or actual provision of transit service, but can be applied to any mode. It is also a performance measure particularly useful in examining the joint performance of the transportation and land use system.

Congested travel is the amount of travel (in vehicle-miles or person-miles) that occurs in congestion. It is calculated by multiplying the length of a congested segment by the vehicle traffic or person volume associated with the appropriate time period, then summing the congested travel over all segments.

$$\begin{matrix}\text{Congested Travel}\\ \text{(person-miles)}\end{matrix} = \sum \left[\begin{matrix}\text{Congested Segment}\\ \text{Length (miles)}\end{matrix} \times \begin{matrix}\text{Person Volume}\\ \text{(people)}\end{matrix} \right]$$

DATA COLLECTION METHODOLOGIES

There are several different data collection methodologies currently in use or being developed to measure travel time. The following sections discuss the various methodologies, examples of where each technique has been used, and the advantages and disadvantages of each technique. Some of the discussion has been adapted from a similar travel time methodology evaluation conducted by Hamm (3).

Floating Car

The floating car technique has been used since the early 1950's for speed and delay studies. The floating car technique is one of several variations on the "test vehicle" method in which the driver of the test vehicle attempts to "float" with traffic and pass as many vehicles as pass it. Other common variations include the "average car" method, in which the driver of the test vehicle attempts to travel at an average speed representative of all traffic, and the "maximum car" method, in which the driver of the test vehicle travels at a maximum safe speed that is consistent with traffic conditions and regulations.

In the 1950's, Berry and Green (4) and Berry (5) published results of studies conducted to determine the required number of runs for a given statistical confidence. The National Committee on Urban Transportation, a now-defunct organization, recommended between 6 and 12 individual test vehicle runs be performed to develop a representative estimate for a congested urban route (6). In more recent years, ITE's Manual of Transportation Engineering Studies provides minimum required travel time runs based on a range in travel speeds and permitted error (7). Most sample sizes range from 2 to approximately 14 individual test vehicle runs.

Travel times measured with the floating car technique are only as accurate as the driver's judgment of traffic conditions and the correct recording of times at checkpoints. No special equipment is required for floating car studies other than a vehicle, stop watch, and two data collection personnel. Stopped delay information can be collected at bottlenecks and signalized intersections, providing a better estimate of operating conditions at congested locations. The major disadvantage is the cost of labor in relation to the amount of data collected. The floating car technique is labor-intensive and is usually limited to a few measurements per day per staff member. The number of travel time runs during the peak period is also limited due to time constraints.

Floating Car with Electronic DMI

The integration of electronic technology into the floating car technique provides an easier, safer way for collecting more detailed travel time information. An electronic distance-measuring instrument (DMI) can be attached to the test vehicle's axle, and can provide instantaneous speeds up to every 1/10 second. This detailed travel time information is saved to a portable computer in an easy-to-use data format. An electronic DMI coupled with a portable computer allows travel time runs to be safely performed with only a driver. This technique also provides detailed travel times, particularly valuable for bottleneck identification and intersection evaluation.

Practically all urban districts of the California Department of Transportation (Caltrans) use this technique (called "tach runs" by Caltrans) to monitor congestion on the freeway system (8). The acceleration/deceleration characteristics of the test vehicle (and presumably the traffic stream) can be calculated with the detailed travel time data. These characteristics are potentially a valuable source of input data for fuel consumption and mobile source emissions analyses.

License Plate Matching

The license check or license matching method utilizes data collection personnel stationed at periodic intervals along the study route to observe the license plates of a sample or all of the vehicles that pass. The data collection personnel may record the plate number on paper, into a tape recorder, or into a portable computer. Although not commonly utilized, video could be used in conjunction with character recognition to automatically read and match license plates at pre-determined checkpoints. The matching of license plates and determination of travel time is typically performed later in the office. Only overall travel times (and not delay times) are available using this technique, because the data collection personnel are not positioned within the moving stream of traffic. The license matching method typically provides a large number of travel time observations for the study section.

Berry and Green (4) compared the license matching and floating car techniques and found travel times obtained from test vehicle runs to be comparable to travel times obtained concurrently by license matching. The study also found that the travel time variation was less for the test vehicle runs than the license matching observations. Rickman, Hallenbeck, and Schroeder (9) conducted a similar study on three arterial streets in Seattle, Washington. The results indicated that there was no significant difference in the mean travel times produced by the floating car and license matching techniques. The study did find that the variability of the license matching data was greater than that of the floating car travel times. The Seattle study also noted that the license matching data had a larger set of observations (ranging from 2 to 15 times the number of floating car runs).

Because stationary observers are able to record many license plates, the license matching technique can provide a larger data set and more representative estimates of travel time. This technique also provides travel times at small time intervals, giving a speed profile for the study section throughout the peak period. The license matching technique becomes labor intensive if portable computers are not available for collecting license plates. The technique also becomes less practical for high-speed facilities (difficulty of reading plates) or long study sections (low license matching percentage).

Inductance Loops

Inductance loops are becoming an important part of many traffic control systems and have the potential to provide information about travel speeds and times. Loop detectors collect traffic volumes and occupancy data, which can be converted to spot speeds. The spot speeds can be converted to travel times based on the assumption that the loop detector data collected at one location represents traffic conditions along the section of roadway to the next detector zone.

The Chicago area has installed an extensive loop detection system that is part of the Chicago Area Surveillance Network (10). The network consists of approximately 2,000 inductance loops along 130 freeway miles. Loop detectors are located almost every half-mile in the center lane, and loop detectors are located in every lane at three-mile intervals. Detector occupancies are sent to the Traffic Operations Center, where they are converted to speeds using a generalized speed-occupancy relationship. Travel times are then estimated for each half-mile section every 5 minutes.

Several other urban areas have a loop detectors in place but do not use it for travel time estimation. A recent study by the University of Washington evaluated the effectiveness of using loop detectors on a Seattle area freeway to estimate travel time (11,12). Other studies have examined the use of arterial street loop detectors for speed estimation.

There are several drawbacks that prevent loop detectors from being widely used for congestion and travel time estimates. The relationship between lane occupancy and speed in congested traffic conditions (greater than 30% occupancy) is not clearly defined. Inductance loops require frequent maintenance to ensure reliability of operation. Loop detectors only provide information about traffic conditions at a given point. If loop detectors are spaced at longer intervals (one to two miles), travel speeds may vary substantially between detectors in congested traffic conditions.

Loop detectors do have the ability to provide real-time traffic information, as is the case with the Chicago system. Loop detectors may already be a major component of an urban area's traffic control system, and could be easily utilized for speed estimation and monitoring.

Cellular Phone Reports

With the increasing use of cellular phones among motorists, their application for traffic monitoring has been largely unutilized. Some cities have a dedicated number for cellular phone users to report emergencies or accidents. Cellular phones could also be used by motorists to report their position at various checkpoints, allowing a traffic operations center to estimate travel times based on several cellular phone reports.

A demonstration test in North Houston utilized 200 commuters along three major freeway corridors to report at pre-determined checkpoints (13). When the commuters passed a pre-determined checkpoint, they called the operations center and reported something like "driver 25 at checkpoint 3." Travel times were then determined by monitoring successive calls by the same commuters. The participating commuters were chosen so that their trip along the corridor were distributed throughout the peak period. The checkpoints along the 3 corridors were spaced at 3- to 5-mile intervals. Changeable message signs were provided at several locations to provide real-time traffic information. Each day, approximately 1,500 calls were through the central communications center (14).

There were several problems noted with the demonstration test in Houston. Like the floating car technique, this methodology is subject to human error. Motorists must call immediately at the checkpoint, or risk connecting with the operator too early or too late. Some drivers would anticipate checkpoint locations and call early, whereas others may notice the checkpoint and make the call 1/4- mile later. Motorists sometimes completely missed calling at a checkpoint. Others would exit the freeway for gas or errands then re-enter and provide an erroneous travel time.

The initial set-up costs of the system were fairly high to install a communications center and provide cellular phones for participating commuters. However, operating costs were relatively low, and consisted of toll charges and minimal staff at the communications center. The cellular phone technique does allow near real-time traffic information to be collected. However, the most applicable use for cellular phone systems appears to be for reporting the occurrence and location of congestion-causing incidents.

Automatic Vehicle Identification

Automatic Vehicle Identification (AVI) is a technique that has emerged only recently in various traffic management and toll collection applications. An AVI system basically consists of an in-vehicle transponder, a roadside reading unit, and a central computer system. When a vehicle containing a transponder passes a roadside reading unit, the information on the transponder is read. This information can range from a simple identification number to toll account balances to trip information. For travel time purposes, the central computer monitors several consecutive reader units and matches tag identification numbers.

The Texas Department of Transportation (TxDOT) is currently developing a traffic monitoring system for the Houston area that uses AVI technology (15). Reader units are being placed at one- to 5-mile intervals along all the area's major freeways. A traffic control center will be used to collect and disseminate the travel time information. Several toll roads in the area have automated toll booths, thereby distributing thousands of AVI tags to motorists in the Houston area. TxDOT has also distributed additional tags free of charge to area commuters. Two of three phases of the system are complete, and the system is currently reading over 50,000 tags a day.

Several other areas are investigating the use of AVI for travel time monitoring. A study in the Seattle area investigated the use of commercial vehicles participating in the Crescent-HELP program for travel time estimates (16). The results indicated that there were not enough tagged commercial vehicles in the traffic stream to provide reliable real-time travel times. The TRANSCOM Electronic Toll and Traffic Management (ETTM) Operational Field Test is studying the feasibility of an incident detection system for the New Jersey to Staten Island corridor (17). The measurement of travel time using AVI technology is the proposed methodology for detecting incidents.

The AVI technology eliminates practically all of the human error associated with other travel time collection techniques. This technique permits real-time traffic information to be distributed from a traffic information center. There are substantial equipment costs for installing an AVI system, but operating costs are relatively low. The Houston system is being installed on a fast-track schedule with almost no interruption to the traffic stream. Because the AVI technology is being used in toll collection, fleet management, and other transportation applications, it is believed that AVI technology will become commonplace in many urban areas over the next decade.

Global Positioning Systems

Global positioning systems involve using satellites to continuously calculate a vehicle's location. Most GPS applications can pinpoint the accuracy of a vehicle to approximately 500 feet. The Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) project is utilizing approximately 5,000 vehicles in the northeastern Illinois suburbs near Chicago for real-time traffic information. The vehicles will be equipped with an navigation and route guidance system consisting of a video screen, a microcomputer, a data communication radio, and a GPS receiver. Traffic information will be gathered from and distributed to the test vehicles.

The in-vehicle equipment required for GPS currently ranges between $1,000 to $3,000. An additional communications medium would also be required to transmit or store the vehicle's location over time. Travel times can be calculated continuously with GPS, eliminating the need for close spacings of checkpoints. Adequate coverage could potentially be a problem for areas starting a GPS traffic monitoring system.

Video Imaging

The full use of video imaging has not been fully realized in traffic monitoring applications. There are several video-based systems being developed to measure speeds and travel times. These video systems capture vehicle images and attempt to match images from different camera locations.

Video can also be used in conjunction with character recognition to read and match license plates. The possibility of matching vehicle images captured by aerial survey video is also being investigated. The Washington Department of Transportation (WSDOT) is testing a video processor-based system at two locations in the Seattle area (18). The test utilizes video from cameras at two overpasses about 3/4-mile apart. Spot speeds within the field of view are calculated, and a tracking function estimates link travel time by matching vehicle images. No results are available yet from this test.

EMPIRICAL TRAVEL TIME RELATIONSHIPS

The previous sections presented different techniques for directly measuring travel times. However, many agencies may not have the resources to directly measure travel times for major roadway facilities in their region on a regular basis. The need also exists to predict travel times or speeds given future traffic volumes and roadway characteristics. In these cases, there is a need for empirical equations that permit travel times or speeds to be predicted given readily available data. The following sections discuss previous research of empirical travel time relationships, and provides a broad overview of the research being finalized for the NCHRP 7-13 project.

Previous Research

Travel speed is a traffic stream quality characteristic that can be used to quantify and evaluate congestion, and several studies have focused on developing relationships between travel time or speed and other traffic flow and roadway characteristics. Most of these studies have attempted to predict travel time or speed based upon limited information on local conditions like area and facility type, traffic volumes, and signal density.

Coleman (19) documents the effect of location and street type, heavy commercial vehicles, street width, signal coordination and density, and traffic volumes on the travel times along 15 test sections in five cities in Pennsylvania. Of all factors examined, Coleman found that travel rate (in minutes per mile) best correlated with signal density (signals per mile) when stratified by peak hour volume-to capacity (v/c) ratios for traffic flows less than critical density. For Coleman's relationships, the coefficients of correlation for the v/c ratio ranges varied from 0.75 to 1.0, indicating that between 56 and 100 percent of the travel time variability can be explained through the empirical equations. Area type, location, street type and width, percentage of heavy commercial vehicles, and signal coordination were found to have little to no correlation (coefficients of correlation ranging from 0.01 to 0.52) to travel times.

Treadway and Oppenlander (20) developed statistical models that could be used to estimate travel speeds and delays on high-volume highways. A multiple linear regression analysis was performed to gauge the effects of various traffic and roadway characteristics on travel speeds. The results of the study indicated that approximately 50 percent of the variation in speed on uninterrupted flow sections was explained by five variables, namely street intersections per mile, commercial establishments per mile, percent of sections where passing was not permitted, practical capacity, and traffic volume. Treadway and Oppenlander concluded that the most significant factors to consider in estimating travel speeds were the types of roadside development (e.g., commercial, urban, or rural) and the traffic stream friction (e.g., traffic volumes and practical capacity).

Guinn (21) conducted a similar evaluation on 77 street sections in New York State in 1967 to determine the relative effects of several parameters on travel times on urban streets. The study utilized the test vehicle method to collect travel times and other roadway and control characteristics, including number of lanes, speed limit, number of signals, percent green time of each signal, section length, link and area type, parking, and number of intersections, for each of the 77 sections. A multi-parameter analysis was performed to test the significance of each of the parameters.

Guinn concluded that neither a multiple-parameter nor a single parameter estimating equation could be developed that would explain the variation in travel times for urban streets. The empirical analysis did indicate, however, that signal density was the most important parameter affecting speeds on urban streets. The recommendations suggested that three parameters, namely signal density, traffic volume per lane, and speed limit, should be included in any further analytical studies of travel times on urban streets.

Civgin (22) considered the effects of posted speed limits, presence of a dividing median, v/c ratio, surface condition rating, number of lanes, traffic volume, parking, and practical capacity on travel times. The study used a multiple regression analysis. The coefficient of determination ($R^2=0.05$) indicated a weak linear correlation between average travel speed and the independent variables, with less than 5 percent of the travel time variation being explained by the independent variables. Civgin noted that posted speed limits and the v/c ratio had the greatest effect on average travel speeds, and other variables like surface condition rating and parking had little to no effect on average travel speed.

In the most recent attempt to estimate travel speeds using empirical equations, Ewing (23) suggested a simple linear model for average travel speed based on two independent variables: peak hour traffic volume and signal density. The model was based on 17 two-lane streets in Seminole County, Florida, and included data for the morning and evening peak hours in both directions (68 total observations). Ewing noted that although the explanatory power of this model was probably inadequate ($R^2=0.55$) for determining roadway levels of service, a better predictive model could be developed with more variables like the green ratio, arrival type, and percentage of turns from exclusive lanes.

$$\begin{matrix}\textit{Average}\\ \textit{Travel Speed}\end{matrix} = 44.7 - \left(0.0087 \times \begin{matrix}\textit{Peak Hour}\\ \textit{Traffic Volume}\end{matrix}\right) - \left(7.74 \times \begin{matrix}\textit{Signals}\\ \textit{Per Mile}\end{matrix}\right)$$

In summary, a number of attempts have been made to estimate travel speed or time based on traffic, roadway, or control characteristics. With the exception of Coleman's research (which was based on a limited data set), most of the models that have been developed to estimate travel speed account for less than 60 percent of the observed variability. There is a general consensus, however, about the independent variables most directly related to travel time and speed. These variables include traffic volumes and/or practical capacity (e.g., v/c ratio or volume per lane), signal density, and character of the roadway (e.g., roadside development, access, or speed limit). Practically all research of empirical relationships in the literature concentrated on arterial streets with little or no emphasis on freeways or uninterrupted flow.

NCHRP Research

Analyses currently being finalized for the NCHRP 7-13 project investigated various empirical relationships similar to the ones described earlier. These empirical relationships and equations being developed will allow the prediction of travel speeds and times for planning purposes. The equations were developed using travel time data submitted by nineteen different transportation agencies across the country. As such, the empirical equations predict travel speeds based on the input data from the nineteen different areas. Individual regions might consider developing similar empirical equations based on historical data from their region.

For arterial streets, the following variables were analyzed for inclusion in the empirical equations: ADT per lane, peak-hour volume per lane, traffic pressure (directional peak-hour lane volume divided by percent green), signal density, percent green, speed limit, and signal coordination. Preliminary analysis results indicate that separate equations are required for each arterial class (as defined by the 1985 Highway Capacity Manual). For the study data sets, signal density had the greatest correlation to travel speeds, and is considered to be a major component of any arterial speed prediction equation. The correlation of the other factors varied from one area to another, indicating that in some areas the factors were more important for speed prediction. Other variables that would most likely form a speed prediction equation include ADT per lane (or peak hour lane volume) and percent green.

For freeways, ADT per lane and access frequency (number of access points per mile) were examined for use in simple speed prediction equations. It was necessary in the analysis process to somehow account for the effects of bottlenecks on upstream freeway sections. Although these upstream sections may have less traffic (lower ADT per lane), queues from a downstream bottleneck can significantly lower the speeds on these sections upstream of a bottleneck. A methodology is being developed that weights the traffic volumes (ADT per lane) of sections upstream of a bottleneck according to the magnitude of traffic at the bottleneck and the distance from the bottleneck. The results of these analyses will be finalized in the next several months.

CONCLUSIONS

This paper presented proposed definitions of congestion and acceptable congestion based upon measured travel times and travel times considered to be acceptable. With these definitions, travel conditions can be prepared for a variety of modes and system components on a more equal basis. The amount of acceptable congestion can also be varied by geographic location, time period, mode and facility type to reflect different expectations or objectives under different conditions.

Travel time-related measures were presented that can be used in various situations and analyses. The consideration of users and audience are crucial in selecting the appropriate congestion measures. Some measure are also more appropriate on a small-scale, site basis, whereas other cumulative measures are more appropriate for measuring congestion on an area or regional basis.

Several travel time measurement techniques were presented that are applicable for collecting congestion information in urban and suburban areas. Each methodology has its advantages and disadvantages, and these must be weighed carefully against the objectives of the congestion measurement plan. Some methodologies are still in developmental and testing stages, and hold promise for more cost-effective data collection in the near future. Empirical relationships are being developed that will permit estimates of speed based on readily available data. These travel time estimation procedures should ease the data collection burden and allow the predictions of speed for various transportation improvement scenarios.

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The authors are indebted to the members of the study team for NCHRP Project 7-13, "Quantifying Congestion" for their thoughts. The method of presentation and expansion beyond the objectives of Project 7-13, however are their own. Gordon Shunk, Paul Bay, and G. Bruce Douglas have assisted in the development of the concepts included in this paper, as has the review panel for Study 7-13. The ideas presented in this paper should not be interpreted as official views of the project or the sponsors, the Transportation Research Board.

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IMPROVED TRAVEL DATA REQUIRED FOR MOBILE SOURCE EMISSION ESTIMATES, NCHRP 25-7

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Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

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IMPROVED TRAVEL DATA REQUIRED FOR MOBILE SOURCE EMISSION ESTIMATES, NCHRP 25-7

Tom F. Wholley, Vanasse, Hangen & Brustlin, Inc.

Throughout many of the presentations and the discussions over the past several days, we have heard a lot of references to air quality issues. I would like to ask you to step back from some of the detailed issues that we have been dealing with with respect to traffic and to think a little bit in a larger picture. I will talk about two general areas this morning. I will talk about the importance of traffic data to air quality with respect to the Clean Air Act requirements. And I will also talk about the status of a research project that I am involved with, NCHRP 25-7, that will apply some benefits to us down the line.

The Clean Air Act of 1990, the act that we are involved with responding to, at the time, really posed some significant challenges for the traffic and emission factor data being provided. Just to go a little bit back in history, the key document is a State Implementation Plan. Amendments from 1977 required the development of the 1982 State Implementation Plans. That was a document that the states prepared, which indicated how they would reduce their emissions such that the air quality standards would be attained by December 1987. However, December 1987 came and went, and air quality standards were not attained. The Clean Air Act Amendments of 1990 established new requirements and renewed the efforts to reduce emissions to get attainment. But unlike the documents of 1982, which had a focus on a time, 1987, to get to attainment, the State Implementation Plan requirements in the Clean Air Act of 1990 established a process. The 1990 Clean Air Act Amendments focus on developing a plan to reduce emissions over time until attainment is reached. Clearly there are milestones, requirements and achievement goals to be met. And it varies from area to area depending on the severity of the air quality guides.

One of the key components of this process was the requirement of the Clean Air Act to develop emission inventories. It focused on the year 1990 and was due in November 1992. The emission inventories are made up of three major components: traditional stationary sources, such as the large power plants; mobile sources, which is the area that we are involved with on road vehicles; and, area sources, which are small sources such as dry cleaning, evaporation of alcohol products. These area sources are small but numerous and could add up to a very large component. The development of the emission inventory for 1990 is extremely important because all future documents, plans and requirements that relate to the Clean Air Act are based on that emission inventory.

The next major document which was due in November of 1993 was the 15 percent Rate of Progress Plan. This I like to think of in terms of a leveling of the playing field. All the areas that had air quality that was above a certain level were required to develop the Rate of Progress Plan. This plan required states to take their 1990 levels and reduce them by 15 percent by the year 1996. Again, this plan was not focused on getting to attainment, except in certain areas that had air quality levels that were bordering on the standards. The pollutant that I am focusing on for discussion purposes is ozone. This plan was focused on developing a program that starts reducing emissions basically at the rate of 3 percent per year. After the states submitted their emission inventory, which documented what their emissions were, they were required to submit their Rate of Progress plan, which commits to certain measures to start getting emissions to be reduced. Then the focus went to attainment plans which were to be based on something called urban airshed modeling. The Environmental Protection Agency and various state air agencies were to do regional modeling, on generally 200 x 200 mile grids, so that they could take into account the effect of multiple metropolitan areas and the issue of transport. Urban airshed modeling was to be a modeling exercise that would then determine the bottom line of emissions reductions necessary so that the areas could come into attainment.

The Clean Air Act says that the amount of emission reduction cannot be any less than 24 percent in 1999. So major reduction of emissions is necessary to get to attainment. These emission reductions are going to be determined by the states in their plans, and they are broken up and divided into the key areas, (stationary sources, area sources and mobile sources). It is important to point out that since mobile sources can account for up to half of the emissions in that area, the role of mobile sources is going to be significant in coming to attainment.

What this really leads us to is the concept of mobile source budgets. As the states developed their Rate of Progress Plans, they set budgets for all those key areas (i.e., how much emissions can come from that sector?). And as they went and developed the attainment plans, they will lower those budgets appropriately to match the amount of emission reductions they need to get to attainment. So the mobile source sector becomes extremely important because we are constantly faced with increased growth, increased VMT in the mobile source sector, whereas possibly, the stationary source does not grow at that kind of a rate. The area sources may or may not grow, depending on population issues.

The single most important aspect of the Clean Air Act of 1990 as it relates to transportation is the concept of conformity. The State Implementation Plan focuses on how emissions are going to be reduced over time such that we come to attainment. Conformity is the process of evaluating the transportation network, the emissions from that over time and future-billed activities, activities that are related to the transportation plans and programs. Over time, the analysis should check in with the State Implementation Plan, and its various requirements that need to be met, to ensure that the transportation network will result in the appropriate emissions reductions so that the State Implementation Plan will not be jeopardized and will continue to result into attainment.

In order to accomplish this, you need to have a feel of the types of responsibility on the mobile source side, to appear in documents and analysis and to contribute to the overall State Implementation Plan. The National Cooperative Highway Research Program put together a proposal for the development of a method to evaluate the practices and create a document that will aid those people that have to do this kind of analysis. An example of why this document can be very important is that when people, whether they work for a State Air Agency, an MPO or a Department of Transportation, conduct their analyses it is important that they have an understanding of each side. Transportation people need to understand air quality issues and air quality people need to understand transportation issues. When they are working with traffic data, it is important that they know whether or not the data comes from a network model, whether they are based on the Highway Performance (HPMS) system or whether the traffic data has been adjusted to represent the appropriate season. This is so that when they are modeling for air quality and matching it up with the emission factors, there is some consistency; and that it gives you results that are appropriate. Various political decisions may be made based on those results to evaluate and implement programs, reduction strategies and activities.

Another area of importance is speeds for mobile source modeling. In one case there was an example where a State Air Agency asked a Department of Transportation for some speed data by functional class. The Department of Transportation went out, took speed guns and took instantaneous speeds on roads during an off-peak period and produced a table of vehicle speeds by functional class. The State Air Agency simply used that speed data. Because the data represented an optimum, i.e., the maximum speed that you will ever see on those roads, as opposed to average speeds, the State Air Agency model resulted in all the data being skewed. This potentially put into jeopardy some of the strategies and activities that the State Air Agency would be committing to. So it is extremely important that there is an understanding on both sides of what data is being provided and what data is needed.

The NCHRP report has an interesting theme, and I just would point out that the work is headed up by the University of Tennessee, my firm (Vanasse, Hangen & Brustlin), and Science Applications International Corporation. Also, transportation research at the University of North Carolina gives a broad background of people that provide interesting insights and, hopefully, will really improve the potential of the report. What is the real purpose of this? The purpose is to develop procedures to address the Clean Air Act requirements, whether for the State Implementation Plan itself, the emission inventories, the conformity analysis, or NEPA environmental state regulation documents.

The goals are to evaluate existing procedures and make some recommendations as to what are the best practices that we can do under today's conditions. Then, we are also going to try to identify the key parameters; whether we are talking about speed, hot and cold starts, or various other traffic components. What information is important? What information can we get away with by using default data or more general data?

It is divided into three tasks. The first task is to evaluate the current practices. The first step is to conduct a literature review. We want to build off of what exists, not recreate or redo work that has already been done. We are contacting key transportation and air quality staff to find out issues related to the policies or requirements. We are surveying various Departments of Transportation and MPO's. Some of the agencies were probably already contacted about this. Then we are going to review the State Implementation Plans, the transportation plans, and the TIPS to see the status and effectiveness of what has been done based on the procedures that were utilized.

For the most part, this task is pretty much done, and we found some interesting things in looking at this. There was a great deal of default information that was used. A lot of the simplified procedures were used throughout the country to come up with evaluations. The new criteria for conformity led to some significant concerns on how these results were to be evaluated. These procedures were how people did things over the past year. However, under various Clean Air Act requirements, there are new modeling requirements, e.g., the development of a statewide network model. We are expecting to see a transition. The more significant requirements of the Clean Air Act, as well as conformity requirements have just now become really established. The modeling procedures are lagging behind a little bit, and there needs to be a catch up for what is going to be happening into the future.

The second task in the NCHRP project is related to creating the document. This document will be used by people hopefully throughout the country. In all aspects, we want to create a foundation from background information so people understand what is going on with respect to the Clean Air Act Amendments and the ISTEA requirements, so they will understand the terminology and the issues being discussed, and then be able to more effectively apply the results of the document. Again, as I pointed out, conformity is one of the most important requirements. The discussion of conformity will be provided in there. The requirements are extremely important since traditionally transportation has not solved air quality problems. Traditionally, transportation has improved capacity through-flow. Improved speed could result in increased volumes. Emission reductions are achieved due to the improved flow, and therefore, exert a positive impact on air quality. But with the establishment of the new NOX criteria, NOX became uniquely different then the other key pollutant, which is the volatile organic compounds, or VOC's, with regards to speeding. Once you get above a certain limit, probably in the range of about 25 mph, as speed increases, the NOX emission factors tend to increase. So a roadway with an improvement from 10 to 15 mph, in terms of speed, would have a benefit on both pollutants. However, a roadway with an improvement from 30 to 35 mph, in terms of speed, could improve volatile organic compounds but have an adverse impact on NOX emissions.

Some other interesting issues come up as to how one might model it more accurately to try and determine what those impacts are, how severe they might be or how they may be mitigated. And throughout the document, we will discuss modeling procedures, some of the key components, how modeling is accomplished, transportation control measures and transportation demand measures. I was particularly pleased to see, yesterday, as we traveled around to all the various sites in a mass transit mode, how efficiently the buses went to all the sites. The only way I would have been more pleased is if we had been on an electric vehicle or a compressed natural gas vehicle. I will make that suggestion for the next time.

That is really what is underway at this point. We will be conducting some statistical analysis to look at the sensitivity and certainty of various components. For example, we will take the mobile model, which is the EPA's emission factor model for vehicles, and see how well it can reproduce internally; what kind of error, if any, might exist internally and some of the key parameters. We will then vary some of the input parameters that go into the model to help determine which parameters are significant, which parameters we need to get good, accurate information on and for which parameters we might be able to go ahead with default information.

The next aspect of this will be to look at traffic and emissions. We are going to take a network model and we will vary key components of that. We are going to look at time of day. We mentioned the NOX problem. If you do a 24-hour average, you may lose the sensitivity of looking at something from peak period versus an off-peak period. A roadway improvement or a roadway activity can have a different impact during peak periods. It may have its only impact during a peak period and have no impact during an off-peak period. As I previously mentioned about NOX and how it varies with speed, looking at speed during a peak period might be critical versus looking at a 24-hour average; you may loose the ability to really identify what the NOX increase or decrease may or may not be. We will also be looking at procedures, e.g., regional or urban versus rural, various parameters and approaches. Is it sufficient to do it as quick and dirty? What is a more detailed way? How much more accuracy or improvement can you get? Is it worth going to the next level? We will explore these kinds of issues.

Finally in this section, we will try to determine the significance of key variables. Again, we think this is critical. There is only so much time and resources. I have seen from the past days how much time and effort goes into gathering data. What data is available? There is going to be demands put on data collection to get good information. What we want is guidance on the importance and value of obtaining better information. It will significantly improve the results that you get. And the results you get are integral to the strategies and plans that may be implemented, whether it is an employee commuter option program or whether your inspection maintenance program needs to be made stricter. So a key part of this report will be to try to focus in on what values and parameters are important to improve air quality analysis.

A report on current practices is currently being developed. We are doing some final editing on that and we think that this is going to be an excellent reference document. Once this document is completed, you will be able to see what other areas are similar to yours, what kind of procedures they use, whether they use default information, what information that they have gathered and who the key contact people are. This will be a very valuable document once it is released.

The sensitivity analysis, as I mentioned, is just getting underway at this point. We are targeting February 1995 as the completion for that portion of the analysis. And then the report itself is going to be released in May 1995.

I have spent over 20 years dealing with transportation and air quality issues. One last point I would like to leave you with is that whether I have been involved in doing State Implementation Plan analysis, TIP analysis, Transportation Plan analysis, NEPA documents and so forth, it is the issue of coordination that I feel is extremely important. If you are trying to bring together the transportation plan and the air quality plan, both areas should have an understanding of what can be done. Imagine trying to determine how many cars will be on a particular roadway in 1999, what speed will they be operating at between 3:00 and 4:00 in the afternoon and what kind of vehicles they will be. The expectations sometimes do not match up to the reality of what kind of information can be provided. Both sides should know what the purpose of trying to determine future year information is, e.g., the level of accuracy required. That is an understanding that needs to be spread from the air quality people to the transportation people. These two sides must meet collectively as a group and prepare better analyses that lead the policy people to make the appropriate decisions.

INTEGRATION OF TRAFFIC OPERATIONS AND TRAFFIC DATA COLLECTION

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Presented at
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Rocky Hill, Connecticut

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Abstract of Paper Entitled:
Integration of Traffic Operations and Traffic Data Collection

The objectives of the project being reported are to identify and demonstrate methods by which traffic data "systems" can be optimally integrated for all transportation system management functions within and across jurisdictions. The study addresses the Georgia Department of Transportation, the Atlanta Regional Commission, and the City of Atlanta.

The methods and findings for Task A of the project are described, whose purpose was to identify the current and near-term future situation with respect to traffic data in the three subject jurisdictions. The methods and findings to date for Task B are reported, the goal of which is to develop the integrating concept and demonstration software.

Key findings from Task A are that:

- Most users' current needs are satisfied with the current data systems,
- Specific data were identified that are currently desired and/or needed in the future, but that are not currently available,
- Some of the desired/needed data are currently being collected by Operations but are not conveniently available to others, and
- The Atlanta Metropolitan Area's Advanced Transportation Management System (ATMS), now being developed, will provide an opportunity to make some very useful data available for nonoperational purposes.

Objectives established for Task B are to develop the integrating concept, and to investigate and select one of the following integration opportunities for demonstration:

- Make the ATMS data available for non-operational purposes,
- Integrate Operations, Planning and other data collection to the degree feasible, or
- Bring some or all of the Operations collected data on-line.

Tasks C, operational testing of the demonstration "system", and Task D, preparing a final report, are future activities.

INTEGRATION OF TRAFFIC OPERATIONS AND TRAFFIC DATA COLLECTION

Researchers:
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INTRODUCTION

This paper reports on an ongoing project within the Georgia Department of Transportation (GDOT) and the Georgia Institute of Technology (Georgia Tech), with the official title as shown above. The project's title does provide some clue to its fundamental objective, but could be better titled "Integration of Traffic Data Collection Efforts by Planning and Traffic Operations to Better Service the Needs of all Data Users."

This research project is sponsored by the Federal Highway Administration, with funding through GDOT. The efforts of the project are focused on the traffic data collectors and users within the GDOT, the Atlanta Regional Commission (ARC, The Metropolitan Planning Organization), and the City of Atlanta (COA).

The following sections will describe the project, report on the methods, findings and recommendations of the initial task (Task A), and outline the methods and findings to date of the second task (Task B). Task B is currently in progress, with two additional tasks to follow. Each of the tasks will be described in the following Section.

PROJECT DESCRIPTION

Objectives.

The research has the three following fundamental objectives:

1) To develop and demonstrate a model process for integrating the collection, storage and access of traffic data within the transportation agencies at all jurisdictional levels within the state of Georgia. The demonstration will be limited to the three agencies within the metropolitan Atlanta area - GDOT, ARC and COA.

2) To achieve the first objective in concert with the development of the Atlanta metropolitan area's Advanced Transportation Management System (ATMS). The ATMS is being developed with the latest technology to address all transportation management needs for the next few decades, with an immediate requirement to handle the traffic associated with the upcoming 1996 Olympic summer games. Statewide expansion of the ATMS is planned at a later date.

3) To use this opportunity to enhance the state's preparation for and implementation of the Intermodal Surface Transportation Efficiency Act (ISTEA) mandated Management Systems. In particular, this effort will assist in identifying user's traffic data needs, and in design of an overall data collection system (the Traffic Monitoring System for Highways (TMS/H) required to support the ISTEA Management Systems).

Tasks and Schedule.

The project is divided into four tasks. These tasks and a schedule for their accomplishment are shown in Figure 1. The purpose of the first task was to assess the current situation within the three participating agencies. Assessing the "current situation" required identifying existing data

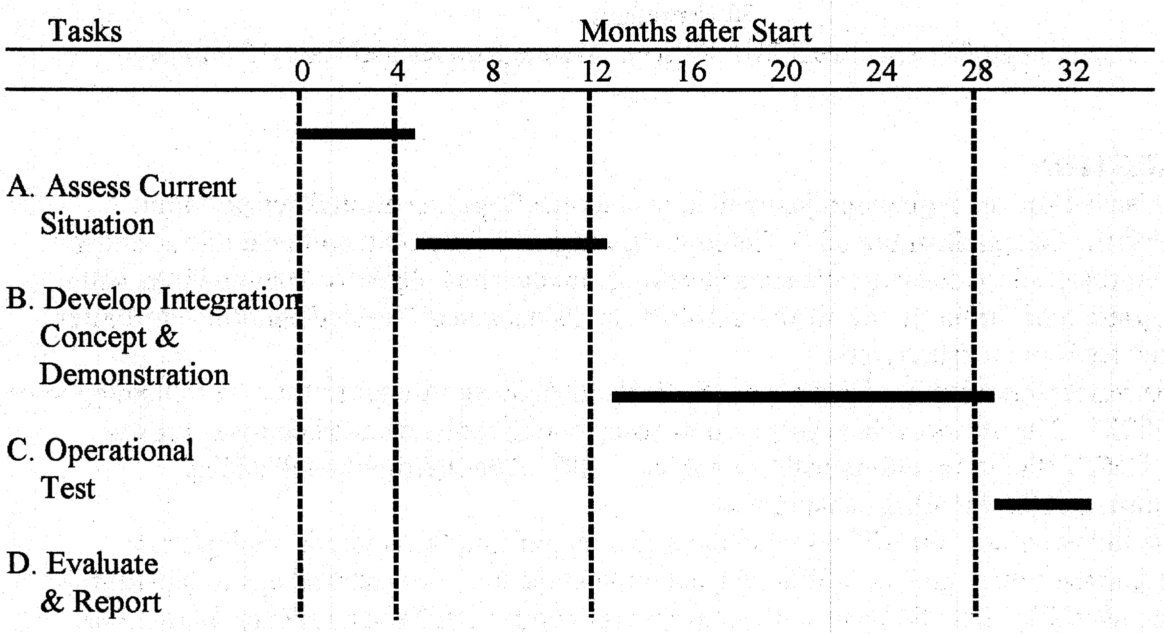

Figure 1. Tasks and Schedule

collection activities throughout the agencies, the uses to which collected data are applied, current data needs of all users, and the degree to which these needs are being satisfied. Although not implied in the task title, this task also required an assessment of the future data needs and the degree to which current data collection efforts would satisfy those needs. The purposes of Task B are to determine how to best satisfy user's data needs from current and planned collection efforts throughout the agencies, develop a data system concept that would achieve synergistic collection and optimum sharing of data, and then to develop a demonstration of the concept. Only a demonstration of the concept is possible given the resources available to the project.

The remaining tasks (C and D) are to conduct and document a one year test of the data integration demonstration, and finally to evaluate and report the benefits and lessons resulting from the demonstration.

TASK A METHODS

Methods.
The process used in achieving the Task A objectives consisted of the steps described in the next few paragraphs, with figures that illustrate the organizations involved and the tools employed.

Identification of Offices with Significant Traffic Data Involvement.
The first step involved identifying the offices within the three participating agencies that have significant involvement, either as a user, collector, generator, or processor of traffic data, or as an operator of a data system. These offices within the GDOT and COA are shown in Figures 2 and 3. The only office within the ARC involved is the Transportation Planning office within

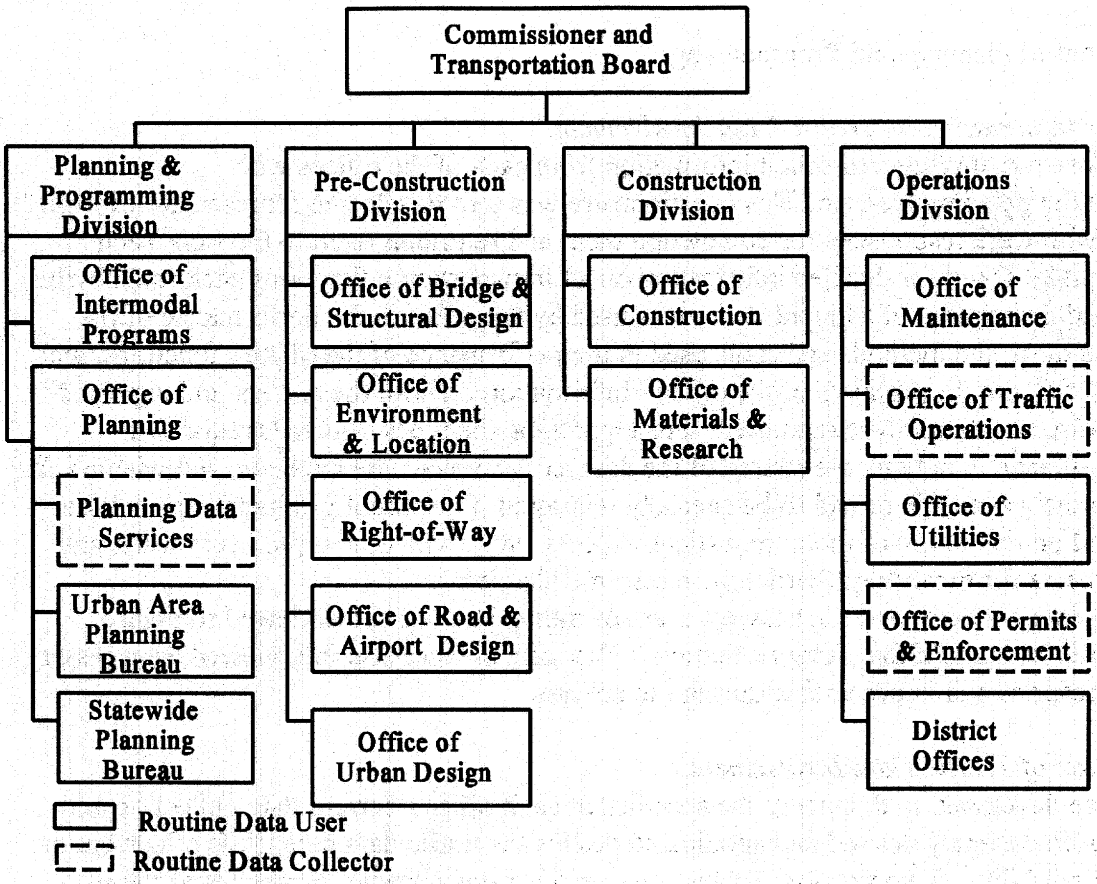

Figure 2. GDOT Offices that Collect or Use Traffic Data

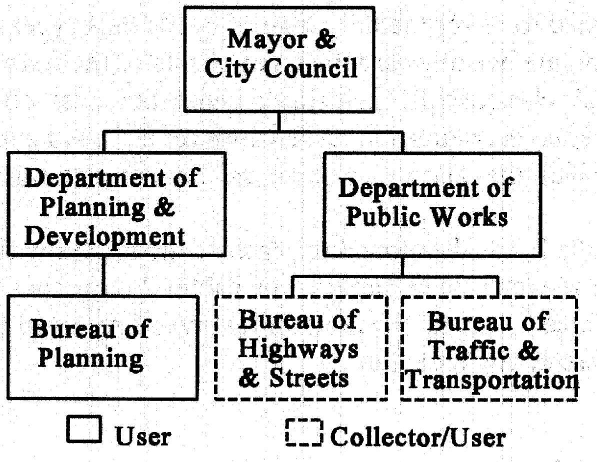

Figure 3. COA Offices that Collect or Use Traffic Data

the Department of Planning and Programming.

Collection of Information on Traffic Data Involvement.
A questionnaire was designed to solicit information from each of the offices with significant traffic data involvement. This questionnaire was sent to selected representatives from each office, who were responsible for completing them and returning them to Georgia Tech. The questionnaire asked for detailed information on all transportation functions performed bythe office, detailed description of all input data items used by the office in the performance of the identified functions, the methods and tools used in the performance of the office's functions, and descriptions of all output products of the office. Information on both the current and expected near-term future situations were requested. For input data, the types of details requested included the specific data type, the source of the data, collection/access methods, and whether the data was routinely available or had to be specially requested. For output products, information was requested on the nature of the output (data, reports, etc.), who the output users were, and the storage media for the output (hardcopy, electronic files, etc.).

Each data collector and the heaviest users of traffic data were interviewed to assure complete understanding of the current situation. Other offices were also interviewed as necessary to resolve questions and issues arising during the process.

Documentation of Traffic Data Involvement.
Methods were developed to document the specifics of each office's current data collection and use, and of both currently desired and anticipated desires for traffic data regardless of current or anticipated availability. Two types of Tables were used for this purpose. Examples of these tables are shown in Tables 1 and 2 for a specific office. Tables similar to Table 1 were developed for each of the major transportation functions (which corresponds to the GDOT organizational level called an "Division"). Each of the subordinate offices within the major transportation function, at several organization levels, has a single line in tables similar to this one. Note that the column headings were designed to cover the full range of traffic data types in a very organized way. The highest level of column headings are the components of the road system, the road map which documents their spatial relationships, their traffic generation characteristics, and traffic movement descriptors. Lower level columns in these tables reflect a systematic decomposition of these major headings in a fashion that allows a slot for any type of data relating to the road system.

A table similar to Table 2 was developed for each of the offices with traffic data involvement; i.e., one table for each row in Table 1. In Tables 2, note that each row addresses one data item identified in Table 1. Again the table format was developed to provide a place to record the relevant parameters of any data item.

TASK A FINDINGS
The findings of Task A are divided into several categories:
1) Data currently routinely collected by the planning function, is available on line, and used throughout the three agencies,

Table 1. GDOT Planning's Current Usage of Traffic Data

		Road System Components Data										Trip Gen Data						Traffic Movement Data																					
		Roadway								Vehi-cles		Users			Activity Centers			Sections											Intersections								Vehi-cles		
		Sections				Bridge												Basic			Derived								Basic		Derived Data								
Road System Management Function or Data Collector, Processor or User	Road System Map	Functional Class	Inventory	Project History	Condition	Bridge Inventory	Bridge Project History	Intersection Geometrics	Type of Control Device	Vehicle Classification	Vehicle Weight	Origins & Destinations	Vehicle Occupancy	Transit Ridership	Trip Generation/Volume	Trip Distribution	Path Assign/Select	Volume/Count	Speed	Projected Values	Section Capacity	Section Vol/Cap Ratio	AADT, ADT, etc.	AVMT, VMT, etc.	Average Speed	Vehicle Hours	Level of Service	Projected Values	Movement Volumes	Projected Values	Type of Control	Signal Timing	Capacity	Volume/Capacity Ratio	Level of Service	Projected Values	Link Travel Time/Speed	Intersection Stops/Delay	Accident Data
Planning Data Services																																							
-Transportation Data Collection										C	C	C	C	C				C											C		C						C		
-System Inventory	U		C					C	C																														
-Data Reporting	U		P	P			P	P		P	P	P		P				P					G	P															P
-Mapping & Graphics	G	U																																					
-Systems & Classification	U	G																U																					
Statewide Planning	U	U	U	U	U	U	U	U		U		U	U		U	U	U	U		G	G/U	G/U	U	G/U	G/U	G/U	G/U	G/U	E/U		U	E/U	E/U	E/U	E/U	A	G/U		U
Urban Planning	U	U	U	U	U	U	U	U		U		U	U		U	U	U	U		G	G/U	G/U	U	G/U	G/U	G/U	G/U	G/U	E/U		U	E/U	E/U	E/U	E/U	A	G/U		U
Atlanta Planning	U	U	U	U	U	U	U	U		U		U	U		U	U	U	U		G	G/U	G/U	U	G/U	G/U	G/U	G/U	G/U	E/U		U	E/U	E/U	E/U	E/U	A	G/U		U
Intermodal Programs																																							

A = All (Collector/Generator) C = Collector G = Generator E = Estimator P = Processor U = User

Table 2. Details of Current GDOT Data Usage, Planning (Incomplete Example)

Road System Management Function	Data Item	Use of Data	Required Update Frequency	Network Coverage	Temporal Coverage	Local Spatial Dimensions	Source of Data	Regular or Special Collection	Method for Accessing these Data	How Data are Processed for this Use	How Derived Data is Stored
Planning (All Three Units)	System Map	General Planning Activities	As Changes Occur	Statewide, All Systems, All Class	Current	All	Planning Data Services	Regularily Updated	Maps	Visually	Maps
Planning (All Three Units)	Road Functional Class	General Planning Activities	As Changes Occur	Statewide, All Systems, All Class	Current	All	Planning Data Services	Regularily Updated	Maps & Files	Visually & As Otherwise Appropriate	Maps & Files
Planning (All Three Units)	Section Inventory/ Geometrics	Various Planning Calculations	As Changes Occur	Statewide, All Systems, All Class	Current	All	Planning Data Services	Regularily Updated	On-Line from RC File	In Various Ways	In Various Forms
Planning (All Three Units)	Section Project History	Project Costs , Other	As Projects Occur	Statewide, All Systems, All Class	Current	All	Planning Data Services	Regularily Updated	System Under Development	Manually	Project Documentation, etc.
Planning (All Three Units)	Section Condition Information	Project Costs, Est. Capacity, etc	As Changes Occur	Statewide, All Systems, All Class	Current	All	Planning Data Services	Regularily Updated	On-Line from RC File	Manually	Project Documentation, etc.
Planning (All Three Units)	Bridge Inventory Information	Scheduling & Planning Projects	As Changes Occur	Statewide, All Bridges	Current	All	Maintenance	Regularily Updated	By Request	Manually	Project Documentation, etc.

2) Data that users expressed a desire for but that are not currently available to them,
3) Data currently routinely collected by traffic operations, and
4) Data that will be routinely collected in the future by the ATMS that is under development.

Data Currently Routinely Collected and Available On-Line.
The Planning Data Services Bureau within the Office of Planning collects a large amount of traffic and related data, which is the majority of data collected for non-operational purposes within GDOT. This data is placed in on-line computer files that can be accessed via the GDOT VAX computer system, or a hard copy can be obtained upon request. The data is used primarily for transportation planning, but is available for any legitimate purpose. Following is a description of the types and characteristics of this data.

System Inventory
Road system inventory/geometric data are routinely collected, processed and stored in the Road Characteristics (RC) file. The RC file consists of 52 specific items, including both physical and usage characteristics. The System Inventory Branch collects such data as the section beginning and ending locations, number of lanes, and the widths of lanes and shoulders. The RC file treats bridges as a road section with the appropriate data specified (such as length and width) and contains a bridge identification number that provides a link into Maintenance's bridge inventory file. Intersection traffic control devices are coded as one of three categories, one of which is a signal.

Continuous Collection Program
There are 85 continuous data collection stations in Georgia. Fifteen of the stations provide count information only. The remaining 70 stations provide count and vehicle classification information. These data are measured by Automatic Traffic Recorder (ATR) devices and collected daily by an automatic polling program that resides on the GDOT's mainframe VAX. The ATRs accumulate and record their data for one hour periods, and may be referred to as hourly accumulators.

The purpose of the continuous count program is to provide the data necessary to develop time of day, day of week, seasonal, and other adjustment factors used to interpret and adjust traffic data and derived parameters that are based on shorter time periods.

Coverage Program
Each of Georgia's 159 counties have designated collection sites for roads of all classifications, except local roads, for a total of about 22,000 collection sites. Data are collected at each of these sites once per year for a 24 hour period, except at those sites used for Highway Performance Monitoring System (HPMS) reporting. Count and classification data are collected using both hourly and daily count accumulator devices.

Local Road Sampling Program
Approximately 4,000 sites across Georgia are used for the local road sampling program. Traffic at each site is counted for a 24 hour period every year, using both hourly and daily count

accumulating devices.

Highway Performance Monitoring System (HPMS)

Approximately 2,400 sites in Georgia can be used for the HPMS program. The complete set of information (70 to 80 data items) required for the HPMS program is collected and reported for all of these sites. The data collected on these segments are also included in the coverage program as well.

Out of the 2400 total HPMS collection sites, 300 are used to provide vehicle classification and weight data on a three year cycle. All 300 of these collect count and vehicle classification data, and ninety of them collect weight data. One third of the sites, i.e., one hundred count/classification sites and thirty weight sites, are visited each year, and all are visited within a three year period. Each collection period is 48 hours, and all data are in hourly accumulation periods.

Strategic Highway Research Program (SHRP) Collection Stations

There are two permanent, continuous collection sites. There are sixteen non-permanent, quarterly collection sites. All of these sites collect volume, classification and weight data. Vehicle weights are measured with Weigh-In-Motion (WIM) devices. Data collection at the 16 non-permanent sites is for a seven day period each quarter.

Accident Data

The Georgia Department of Public Safety collects reports on all accidents within the state from the Highway Patrol and local jurisdictions. This accident data is entered into a digital file which is given to GDOT, along with the paper reports. GDOT Planning Data Services adds the mile-point location of the accident to the file and creates an accident database on the GDOT VAX system.

Desired Data That Is Currently Unavailable

There were several types of traffic related data that users expressed a desire for that are not routinely available. These data will be discussed hereafter by transportation function.

Planning (GDOT and ARC)

Both the GDOT and ARC planners clearly desired significantly more data, of several types, than is currently available to them. Both groups expressed a desire for both more extensive data and more current data. The types of data commonly desired were:

- Capacities, volume-to-capacity ratios and level-of-service values for both road sections and intersections. Planners currently must estimate these parameters themselves and obviously feet that the data would be more accurate in estimated in the field by traffic engineers,
- Intersection descriptions, including traffic control devices, signal timing, and movement volumes,
- Average speed or travel times for all significant roads,
- Extensive and current origin and destination data for the metropolitan areas, and

- Vehicle occupancy data for the major roadways, especially in the metropolitan areas.

Planning (ARC Only)
The metropolitan Atlanta MPO (ARC) also expressed a need for several types of data unique from the GDOT planners. These were:

- Peak volumes on the major roads in the metro area,
- Annual Average Daily Traffic (AADT) to a finer geographic grid, and
- Annual Vehicle Miles Traveled (AVMT) to a finer geographic grid.

The ARC will also be responsible for evaluating and reporting the effectiveness of the High Occupancy Vehicle (HOV) lanes to be established on the Atlanta area freeways, scheduled to begin operation about January 1, 1995. A plan has been developed identifying the data needed for this evaluation, but the methods and responsibility for collecting this data are not yet decided. The information needed includes volumes and occupancy data for vehicles in all lanes of the freeways during the hours of HOV operation.

GDOT Road Designers
The road designers clearly desired more extensive data on percent of trucks in the traffic stream, and more current data on the average weights of those trucks. The truck weight data currently being used to design roads is many years old. The available vehicle classification data rarely covers the specific roads being designed.

Multimodal Programs
The Office of Multimodal Programs indicated a future need for data on the flow of commodities between activity centers over the road system. This need will extend to other modes as well.

Data Currently Routinely Collected by Traffic Operations
Traffic Operations currently collects several types of data, but this data is generally not on line, and has not been asked for in the past. It is interesting to note that some of these data satisfy, at least partially, some of the expressed needs of others in GDOT and ARC. These data are:

Intersection Data
GDOT Traffic Operations is responsible for all traffic signals on the State Highway System, even though local governments are given direct control where possible. The Department currently checks each intersection with a traffic signal under its control about once per year. Although the data collected during these checks have long been maintained in the district offices, GDOT traffic engineers have recently begun to standardized the content of these data files. The plan is to record intersection diagrams, traffic movement data and signal timing information.

Section Speeds
To comply with federal speed monitoring requirements, GDOT collects speed data at about 48 sites statewide. This data is collected quarterly for 24 hours at each site. In FY95, the number

of sites are scheduled to be increased to 60. While this is not an extensive speed data set, it should be useful in estimating speed trends across the state.

Truck Weight
GDOT's Office of Permits and Enforcement is responsible for enforcing truck weight and size limitations on the State's roadways. In the process, they obviously collect a very extensive amount of truck weight data, such as that desired by the road designers. Currently this truck weight data is not being used external to the enforcement function, and is kept only for a limited time (a few days if at all). The weight data collected is from:

- 19 permanent weigh stations on the interstate highways, which weigh all passing trucks,
- 6 semi-permanent sites, which weigh all passing trucks for 8-16 hours per day,
- 9 teams with semi-portable scales, which operate daily for 4-8 hours at changing locations, and
- 42 roving teams with portable scales that weigh trucks suspected of being overweight.

Accident Analysis Results
The accident data received from the Georgia Department of Public Safety is analyzed to identify high accident locations. Investigations are conducted into the causes for the high accident rates, and fixes are developed for those locations on the State Highway System. Some of this data is on line and some is not.

Data That Will Be Routinely Collected in the Future by the ATMS

The Advanced Transportation Management System (ATMS) currently under development for the entire metropolitan Atlanta area will collect several types of data on all major area streets and highways for real-time traffic management purposes. This data will be very valuable for non-operational purposes as well. It will satisfy several of the expressed desires for more exhaustive data and for data to a finer geographic grid. The specific types of data that will be collected at numerous locations on all freeways and major arterials are:

- Continuous volumes,
- Speed,
- Density of traffic (calculated),
- Congestion indexes (calculated), and
- Video coverage of the freeways.

CONCLUSIONS AND RECOMMENDATIONS FROM TASK A

The general objective of this Task was to find ways to look for opportunities to make traffic data collection throughout the three agencies (GDOT, ARC, and COA) more effective by making it more synergistic. A question to be answered in the process was whether the data currently being collected, or already planned for collection, would satisfy all current and near-term future needs of users.

Conclusions

There is no doubt that data collection can be made more effective by simply making operations data (current and future collections) available to other users within the agencies. However, current data collection activities and planned expansions will probably not completely satisfy all needs of users. It is not clear whether the weight, speed and intersection data that operations does or will collect will be sufficient for other purposes. Not all needs are even known at this time; e.g., the data needs for the six ISTEA Management Systems are yet to be determined.

Regardless of questions about the adequacy (for other purposes) of the traffic data that operations is or will be collecting, it is obvious that the data is of value and should be made available for other uses. Later tasks in this project will assess the value of the data for these other uses.

Recommendations

The prioritized recommendations from Task A for "integrating traffic data collection and traffic operations" are to:

- make the Atlanta metro area ATMS data (volume, speed, density, congestion indexes, video) available for other uses,
- bring the statewide sampled speed data on-line,
- organize and place the Traffic Operations maintained intersection data in on-line files,
- capture and make Enforcement's truck weight data available on-line,
- place the HOV monitoring data on-line (must await decisions on responsibilities).

In the aggregate, these represent a potentially significant enhancement of the traffic database.

TASK B METHODS

As previously stated, the overall objectives of Task B are to:

- determine how to best satisfy user's data needs from current and planned collection efforts throughout the agencies,
- develop a data system concept that would achieve synergistic collection and optimum sharing of data, and
- develop a demonstration of the concept.

These objectives were pursued via the activities discussed in the following paragraphs.

Develop Traffic Data Integration Concept

The first required step of Task B was to develop a concept for how "the GDOT traffic data system" could be structured to accept operation's data and allow all users to access the data. This is essentially the "integrating concept" for integrating traffic data collection and traffic operations.

Review Available Integration Opportunities

Once an integrating concept is determined, the recommended opportunities for operation's data must be reviewed with both the collectors and the users. It is necessary to obtain the collector's agreement to provide the data, and the potential user's agreement that the data would at least be potentially useful.

Identify Integration Methods for Each Opportunity

For each of those opportunities approved by the collectors and potential users, the next necessary step is to identify the specific methods by which the opportunity can be realized. This generally involves determining how the data can be captured electronically, placed into a structured traffic database, and then made accessible to users.

Select Integration Demonstration Project

Since project resources are limited, and because of timing considerations on each of the recommended integration opportunities, it will not be possible to pursue all of the opportunities to completion (on this project). For these reasons, it will be necessary to select one or more of these opportunities for demonstrating the value of integrating traffic operations and traffic data collection.

Develop Demonstration Plan and Software

For the selected integration opportunity, the necessary methods, procedures and software will be developed and documented in a plan.

Coordinate Demonstration Plan

Prior to proceeding to Task C (Implementation and Operation of Demonstration), the plan will be coordinated with the GDOT, ARC and COA offices involved for approval. The locally approved plan will then be submitted to the FHWA for approval prior to proceeding.

TASK B RESULTS TO DATE

While Task B is still underway, substantial progress has been made on the first three subtasks. This progress is reported by these subtasks.

Develop Traffic Data Integration Concept

The overall integrating concept will be a standardized (between the agencies) traffic relational database. The structure of the database may be somewhat like that of Table 1, in that there will be a well defined hierarchy, relationship and place for any item of data. A road system map based Graphical User Interface (GUI) is envisioned, whereby any data can be accessed by geographical references (jurisdiction, road number, etc.). GDOT is already well on its way to developing the relational database and the Geographical Information System (GIS) based system map necessary for the GUI. The integrating concept shown in Figure 4 is a larger concept than necessary for this traffic integration project. The traffic data would be entered and accessed via the application programs shown in Figure 2. General access to traffic data would be via the System Data application.

Review Available Integration Opportunities

All of the recommended integration opportunities have been reviewed with the collectors and potential users of the data. All are in agreement that the opportunities are real, worthwhile, and something in which they would be willing to participate.

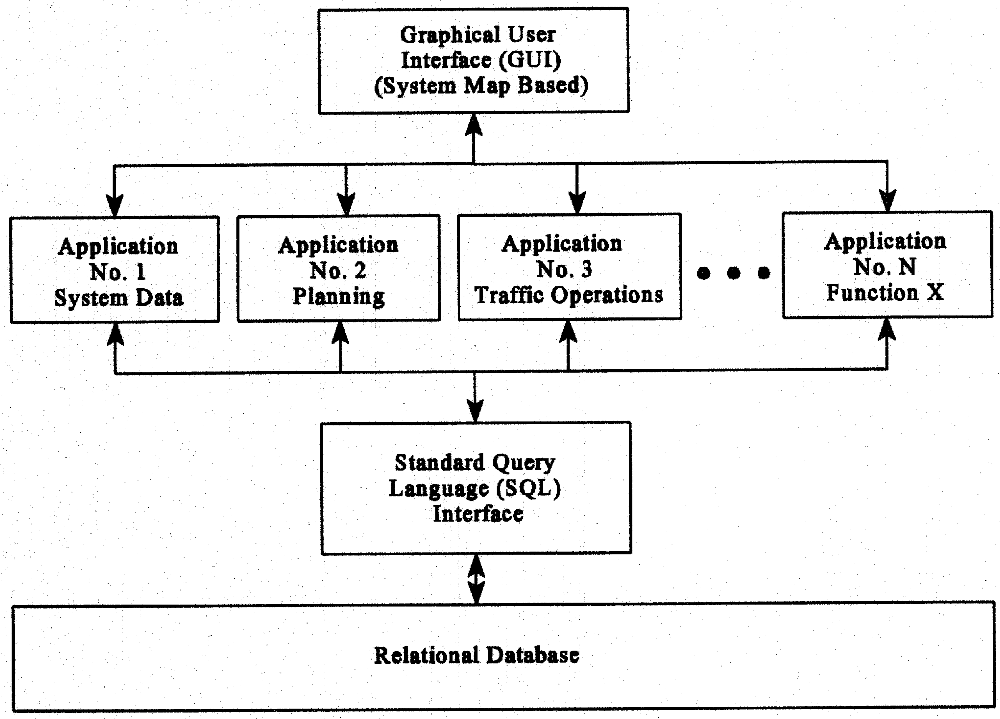

Figure 4. GDOT Traffic Data System Integrating Concept

Identify Integration Methods for Each Opportunity

Each of the integration opportunities have been investigated in some detail. Specific approaches have been worked out for each of them. All are achievable with sufficient time and expenditure of resources. However, the time constraints on many of them are incompatible with the period of this project as currently scheduled.

Select Integration Demonstration Project

As of the time of writing this paper, the time and resource requirements for demonstrating the integration opportunities and the time and resource constraints on this project have not been completely reconciled. The most achievable demonstrations involve the statewide sampled speed data and truck weight data from the permanent freeway weigh stations. These will likely be incorporated into the demonstration.

Other Task B Subtasks

No reportable results are available for the remaining Task B subtasks, although work is in progress.

A PROCEDURE TO CALCULATE VEHICLE OCCUPANCY RATES FROM TRAFFIC ACCIDENT DATA

Mr. Richard E. Gaulin
Connecticut DOT

Presented at
National Traffic Data Acquisition Conference
Rocky Hill, Connecticut

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A PROCEDURE TO CALCULATE VEHICLE OCCUPANCY RATES USING TRAFFIC ACCIDENT DATA

Richard E. Gaulin, Connecticut DOT

I. INTRODUCTION

A. Purpose

The purpose of this report is to document a procedure for calculating vehicle occupancy rates based on data extracted from a traffic accident database. The report will demonstrate how this new procedure can be easily initiated by any agency or organization that has access to a traffic accident database.

The report also examines traditional methods of calculating average vehicle occupancy rates. The results of these methods are compared against results from the new procedure thereby establishing a method for verification.

In addition, the report will investigate the notion of bias entering into the calculation of the occupancy rates. And finally, the report will determine the minimum number of observations (accidents) required to provide statistically sound occupancy rates from accident data.

B. Why Develop Vehicle Occupancy Rates?

Vehicle occupancy is an important measure for gauging efficiency in the use of transportation facilities, energy and other transportation resources. Among other things, occupancy rates are used to measure the success of ridesharing programs, and programs mandated to improve air quality and trend analysis.

Vehicle occupancy is critical in formulating transportation strategies. Occupancy rates are changing and are having significant impact on traffic congestion. Planning for the future is an important aspect of any transportation agency's strategy. Vehicle occupancy rates are necessary for formulating this strategy.

C. New Methods Required

The Federal Highway Administration has indicated that there is an urgent need in the transportation community for low cost techniques to produce up-to-date, facility-specific estimates of average vehicle occupancies. The technique documented in this report satisfies this demand and has the ability to produce bi-variate rates not easily produced on a regular basis.

Traditional methods for determining average vehicle occupancy rates are costly and thereby preclude rates being calculated on a regular basis. With costs rising even higher and budget and personnel cutbacks expected, it is likely that rates determined by the traditional method will be calculated on a less frequent basis.

D. Available Data

The Connecticut Department of Transportation (ConnDOT) presently maintains and uses a statewide traffic accident database. Motor vehicle traffic accidents are reported to the Connecticut Department of Motor Vehicles (DMV) on traffic accident reporting forms. These forms contain among other things location, number and types of vehicles involved, and the number of occupants in these vehicles. The data are then entered into the statewide database. This vehicle occupant data are exactly the type of information that is required to calculate vehicle occupancy rates.

Annually, Connecticut has an average of 120,000 motor vehicle traffic accidents in which approximately 250,000 vehicles are involved. By accessing the data on these vehicles and their occupants, ConnDOT has been able to develop a procedure to calculate average vehicle occupancy rates. Because of the nature of the information captured on the traffic accident reports (locational, environmental, etc.), occupancy rates can be facility-specific, time-of-day-specific and specific in many other ways.

This method of calculating vehicle occupancy rates has almost completely replaced the traditional method of field counting.

II. AVAILABLE VEHICLE OCCUPANCY RATES

Various methods have been used in the past to calculate vehicle occupancy rates. When vehicle occupancy rates are required, several options have been available. These options are: (1) to adopt rates used in other areas or recommended in nationally recognized publications; (2) develop local rates from available local data; (3) conduct new surveys to develop rates.

A. Rates from Nationally Recognized Publications

The 1977 Nationwide Personal Transportation Study (NPTS) describes occupancy characteristics of trips made by households in private motor vehicles. The NPTS was conducted by the Bureau of the Census under the joint sponsorship of the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration.

The study was based on a national probability sample of 24,466 households selected from each of the fifty states and the District of Columbia. The study calculated vehicle occupancy rates by trip purpose based on certain stratifications. Occupancy is generally calculated on either a "trip" basis (occupants per vehicle trip) or a "travel" basis (occupants per vehicle mile).

B. Rates from Household and Roadside Surveys

The 1965 Roadside Survey was conducted by stopping motorists at many locations throughout the state as well as at toll stations and eliciting responses to questions about their household and trip being made. These responses were tabulated and useful transportation characteristics were determined. Among the data were vehicle occupancy rates.

The 1976-1977 Household Survey was mailed to a 3% sample of Connecticut's occupied households. This consisted of 27,648 addresses. A total of 6,784 useable survey questionnaires were returned. As with the roadside survey, tabulations of the data were made and provided the information required to calculate vehicle occupancy rates.

The major problem with rates calculated using the above two sources is that the data are old. In addition, rates for only one point in time are available thereby precluding any trend analysis.

C. Rates from the Census Journey to Work

The Decennial census conducted by the Bureau of the Census captures information on person trips and the vehicles available in a household. This information is available for work trips only and on the basis of town-to-town, census tract to census tract or traffic analysis zone. By analyzing and manipulating these data, vehicle occupancy rates can be determined.

D. Local Rates

Local rates are specific to an area and in this case the area is the State of Connecticut. These rates are produced periodically by conducting field surveys. The procedure has consisted of selecting between twenty and seventy-five sites located in rural, small urban and urban locations. The sites are along roadways with the following functional classifications: interstate, principal arterial expressways, principal arterials non-expressways and minor arterials.

The surveys were conducted by observing and counting vehicles between 7:00 A.M. and 12:30 P.M. as the vehicles passed the survey sites. These time periods were selected to obtain the A.M. peak period and to cover both work and nonwork travel periods. Data were recorded by 30-minute increments.

These types of surveys were conducted every three years or so and provided the most up to date occupancy rates available. The rates obtained were used within the travel modeling process to validate current factors and as a primary source of non-work trip car occupancy.

III. NEW PROCEDURE

A. Introduction

The procedure for calculating vehicle occupancy rates based on data extracted from a traffic accident database is straight forward and easily implemented. Once the original concept was converted into a feasible procedure and occupancy rates developed, it was clear that these rates were consistent with rates developed from established methods. A statistical analysis was made to indicate the minimum sample size required to give sound results.

B. Methodology

ConnDOT maintains a traffic accident database which contains approximately 80 data items on each reported motor vehicle traffic accident occurring in the State of Connecticut. ConnDOT maintains a separate database for each calendar year with a total of the latest eight years available. The information in the databases includes data on the vehicles involved in the accidents and the occupants of these vehicles. The concept of the occupant rate procedure is to extract these vehicle and occupancy data and calculate occupancy rates. The method used to extract the data from the database and to develop occupancy rates can be customized by the user and would be based on the type of accident database, the computer system it resides on and the computer software available. Figure 1 illustrates the steps used by ConnDOT in its procedure.

The ConnDOT Traffic Accident Database resides on a UNISYS 1192 mainframe computer in a relational database system supported by the software product DB4. The database has a query language allowing users to extract data in various ways. This query language is used to extract the vehicle and occupant information. Appendix A contains a sample listing of the query language used in the extraction procedure.

The first step in the process is to determine the criteria for calculating the rates. Are the rates for a specific highway, roadway type, time period, etc.? Rates can be determined by any item contained in the database. Once this determination is made, a dataset containing only accidents meeting the criteria is extracted. Consider the example where rates are required for an interstate highway. Since the accident location contains route and cumulative mileage, it is an easy task to use the query language and extract only those accidents that occurred on interstate highways.

Calculating occupancy rates consists of obtaining the total number of occupants and dividing this by the total number of vehicles. The following formula is used to calculate the occupancy rates.

$$\text{OCCUPANCY RATES} = \frac{\sum \text{VEHICLE OCCUPANTS}}{\sum \text{VEHICLES}}$$

The next step in the process, therefore, is to extract the vehicle data from the dataset obtained above. Not all vehicle types are used in calculating occupancy rates. The vehicle types used by ConnDOT were: passenger cars, vans, station wagons, jeeps (blazers, broncos, etc.) and single tire trucks (pickups). The number of occupants in each vehicle is included with the vehicle data.

When the procedure was first proposed, ConnDOT determined that it would be necessary to calculate occupancy rates by hour of the day. This allowed hourly trends to be easily spotted with a resulting 24-hour or daily rate quickly calculated. The hourly rate process has shown to be very useful and has now become standard procedure. Work and non-work trip occupancy rates can be estimated by using factors and making certain assumptions about the time of day these trips are made.

The raw data extracted from the database is keyed into a spreadsheet application software package which is ideal for calculating the rates and presenting them in a neat and practical format. Table 1 is a sample of the finished product printed from the spreadsheet program.

Table 1 presents average hourly vehicle occupancy rates for a forty-five mile section of interstate route I-95 from the New York state line to the city of New Haven. The raw data extracted from the accident database using the query language is keyed into the

TABLE 1

The following vehicle and vehicle occupancy data was extracted from the 1988 Traffic Accident Database maintained by the Division of Planning Inventory & Data, Bureau of Planning. Only passenger cars, station wagons, vans, jeeps (broncos, blazers, etc.) and single tire trucks (pickups) are included. These data relate to accidents occurring on I-95 from the intersection with I-91 to the New York State line.

1988 VEHICLE OCCUPANCY RATES FOR I-95 (NEW HAVEN TO NY SL)

1 OCC /VEH	% OF TOT	2 OCC /VEH	% OF TOT	3 OCC /VEH	% OF TOT	4 OCC /VEH	% OF TOT	5 OCC /VEH	% OF TOT	6+ OCC /VEH	% OF TOT	HOUR BEGINNING	TOTAL VEHS	TOTAL OCCUP	OCCUPANCY COUNT
183	64.9%	66	23.4%	23	8.2%	6	2.1%	2	0.7%	2	0.7%	00:00	282	430	1.52
137	71.4%	36	18.8%	12	6.3%	3	1.6%	1	0.5%	3	1.6%	01:00	192	280	1.46
118	65.6%	45	25.0%	12	6.7%	3	1.7%	2	1.1%	0	0.0%	02:00	180	266	1.48
57	76.0%	15	20.0%	0	0.0%	2	2.7%	1	1.3%	0	0.0%	03:00	75	100	1.33
58	68.2%	12	14.1%	7	8.2%	4	4.7%	1	1.2%	3	3.5%	04:00	85	142	1.67
49	69.0%	13	18.3%	6	8.5%	1	1.4%	2	2.8%	0	0.0%	05:00	71	107	1.51
147	85.5%	17	9.9%	5	2.9%	2	1.2%	1	0.6%	0	0.0%	06:00	172	209	1.22
281	84.6%	34	10.2%	13	3.9%	2	0.6%	1	0.3%	1	0.3%	07:00	332	407	1.23
408	87.4%	41	8.8%	9	1.9%	6	1.3%	3	0.6%	0	0.0%	08:00	467	556	1.19
244	82.7%	38	12.9%	6	2.0%	5	1.7%	0	0.0%	2	0.7%	09:00	295	370	1.25
176	75.2%	34	14.5%	14	6.0%	6	2.6%	2	0.9%	2	0.9%	10:00	234	332	1.42
253	73.5%	66	19.2%	12	3.5%	10	2.9%	2	0.6%	1	0.3%	11:00	344	477	1.39
225	70.8%	62	19.5%	18	5.7%	7	2.2%	5	1.6%	1	0.3%	12:00	318	462	1.45
249	73.2%	54	15.9%	21	6.2%	11	3.2%	5	1.5%	0	0.0%	13:00	340	489	1.44
310	74.9%	62	15.0%	22	5.3%	13	3.1%	4	1.0%	3	0.7%	14:00	414	590	1.43
484	72.8%	104	15.6%	43	6.5%	23	3.5%	9	1.4%	2	0.3%	15:00	665	970	1.46
526	76.7%	111	16.2%	24	3.5%	23	3.4%	2	0.3%	0	0.0%	16:00	686	922	1.34
557	76.6%	114	15.7%	34	4.7%	12	1.7%	6	0.8%	4	0.6%	17:00	727	989	1.36
353	77.8%	63	13.9%	18	4.0%	12	2.6%	6	1.3%	2	0.4%	18:00	454	623	1.37
218	67.3%	64	19.8%	19	5.9%	19	5.9%	3	0.9%	1	0.3%	19:00	324	500	1.54
189	70.3%	45	16.7%	17	6.3%	11	4.1%	6	2.2%	1	0.4%	20:00	269	410	1.52
186	71.0%	46	17.6%	15	5.7%	10	3.8%	2	0.8%	3	1.1%	21:00	262	391	1.49
174	65.2%	61	22.8%	12	4.5%	12	4.5%	7	2.6%	1	0.4%	22:00	267	421	1.58
196	67.8%	57	19.7%	17	5.9%	13	4.5%	5	1.7%	1	0.3%	23:00	289	444	1.54
5778	74.6%	1260	16.3%	379	4.9%	216	2.8%	78	1.0%	33	0.4%		7744	10887	1.41

VEHICLE OCCUPANCY RATES FROM TRAFFIC ACCIDENT DATABASE

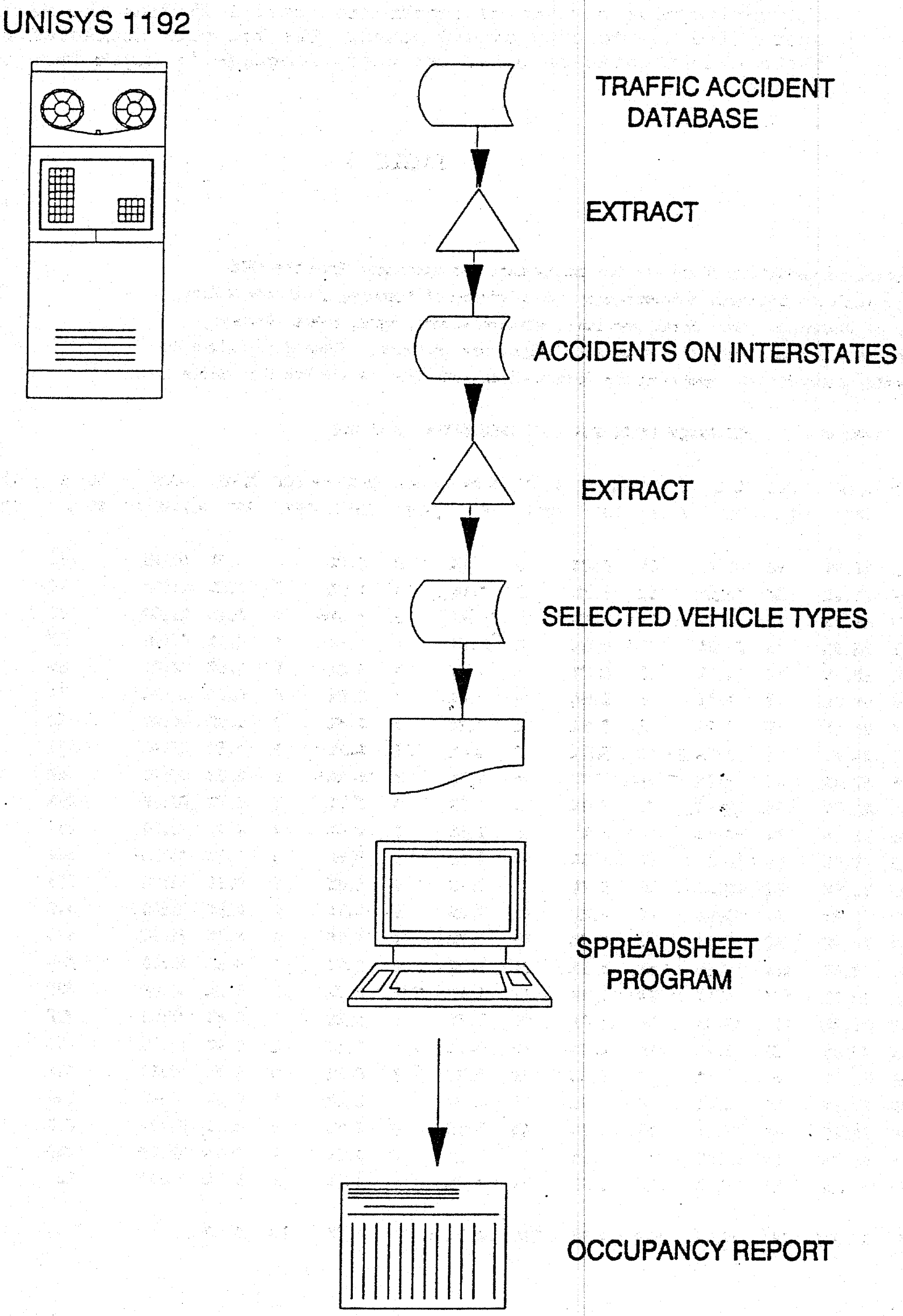

Figure 1

"OCC/VEH" columns. The database used for this particular table contained data on traffic accidents which occurred in 1988. The total number of vehicles and occupants involved is well over the minimum required to give statistically sound results.

The entire process beginning with extracting the accident data to producing the final results consisting of a table similar to Table 1 takes less than one day and can often be accomplished in as little time as three hours. Continual refinement of the process consisting of more efficient computer programming can reduce the time to about one hour for the entire process.

C. Advantages

ConnDOT's new procedure for calculating vehicle occupancy rates from the traffic accident database has shown to have several distinct and important advantages. These have convinced ConnDOT officials to adopt the new procedure.

First, and most importantly, is the time savings realized. As mentioned earlier in the report, ConnDOT had been using a field counting procedure to produce occupancy rates. This was done every two or three years and counts were taken at a very limited number of pre-selected sites. Planning and coordination for this effort often took months. The new procedure can be planned, executed and completed in less than one day. This also allows ConnDOT the option of calculating rates on a much more frequent basis. This is especially important when doing a trend analysis.

The procedure allows ConnDOT a tremendous amount of flexibility in determining rates. Frequency has increased from developing occupancy rates once every two or three years to as often as required. Rates can be determined by highway type, functional class, county, regional planning agency, statewide, day of week, time of day, month, etc. The possibilities are quite extensive. The following is a good example of how the rate procedure was used. The following analysis would not have been done using the traditional method. During a corridor analysis of the state's parkway, ConnDOT personnel were asked to determine if the addition of a High Occupancy Vehicle (HOV) lane was feasible. By using the traffic accident data for the portion of the parkway under study, ConnDOT was able to determine that vehicle occupancy was so low that adding the HOV was not warranted.

Another advantage to using the traffic accident database is the number of databases available. Presently ConnDOT maintains the latest eight years of accidents in the databases. This allows ConnDOT to go back in time to calculate rates which would otherwise be impossible to do after the fact. This is an important factor when doing trend analysis.

D. Cost Savings

Time savings naturally translate into money savings. ConnDOT has estimated that the new occupancy procedure can generate savings in the tens of thousands of dollars. These savings can be realized from only one field count study. Since the counts are conducted every two or three years, the actual savings could be considerably more.

The following are typical costs for the occupancy surveys that were calculated in the past:

Field Personnel	$11,500.
Data Preparation	$ 500.
Data Entry	$ 50.
Data Processing	$ 250.
Administration	$ 500.
Total Cost	$12,800.

These costs should be representative of a survey of 30 sites that were observed for 14 hours each. The cost to ConnDOT to duplicate this effort using accident data would be less than $250.00.

IV. COMPARISON OF OCCUPANCY RATES

One of the most important factors to be addressed when devising a new method to produce data is to establish a procedure for comparing results from both procedures. In this regard, ConnDOT personnel conducted a study to compare occupancy rates obtained from the traditional field survey method against rates obtained from the accident database method.

1982 and 1984 were the last years in which ConnDOT, with the help of regional planning agencies, conducted field surveys to calculate vehicle occupancy rates. As a result, these two years were used in the comparison study. Rates for both expressways and non-expressways were calculated from the field survey data. In order to make the traffic accident data comparable to the field survey data, only accidents occurring between 7:00 A.M. and 12:30 P.M., on Monday through Friday and during the months of April, May and June were extracted for 30-minute time periods. In effect, each traffic accident used is a random sample on either an expressway or non-expressway.

Table 2 depicts the occupancy rates calculated from both procedures. It should be noted that the % column is the change from the traffic accident rates.

V. CAUTIONS AND LIMITATIONS

A. Cautions

When the idea for this procedure was first developed, several factors were identified and had to be addressed as part of the verification process for the new rate procedure. One factor was the minimum sample size required to give statistically sound occupancy rates obtained from accident data. Another factor was bias. Was there some bias inherent to traffic accident data that would somehow affect the rates calculated? Another question that arose was that since traffic accident data were being used, was there certain groups of people excluded from the sample? Another point brought up was whether traffic accidents are truly random events? These are some of the factors identified in the initial investigation of this procedure. Each point is addressed below.

TABLE 2

COMPARISON OF VEHICLE OCCUPANCY RATES ACCIDENT DATABASE VERSUS FIELD SURVEY

1982

	EXPRESSWAYS			NON EXPRESSWAYS		
	ACCIDENT	FIELD	%	ACCIDENT	FIELD	%
PEAK 7:00-8:30	1.18	1.23	+4.2	1.16	1.20	+3.4
TOTAL 7:00-12:30	1.27	1.29	+1.6	1.25	1.22	-2.4

1984

	EXPRESSWAYS			NON EXPRESSWAYS		
	ACCIDENT	FIELD	%	ACCIDENT	FIELD	%
PEAK 7:00-8:30	1.12	1.22	+8.9	1.16	1.22	+5.2
TOTAL 7:00-12:30	1.23	1.22	-0.8	1.27	1.27	0.0

1. *Minimum Sample Size*

The minimum number of motor vehicle traffic accident records needed to determine car occupancy with a certain level of confidence can be calculated using the following formula:

$$n = \frac{(t^2 \text{ x } s^2)}{d^2}$$

where:

n = the number of observations needed
t = the value of Student's "t" statistic for a desired level of confidence
s = estimated standard deviation of occupancy rate
d = the acceptable error between the estimated occupancy rate and the true occupancy rate

The standard deviation for the entire accident database which includes data for 181,880 vehicles is 0.747.

The following table results by applying the above formula:

TABLE 3

OBSERVATIONS REQUIRED

TOLERANCE LEVEL	LEVEL OF CONFIDENCE (%)			
	80	90	95	99.5
±5%	88	204	337	831
±10%	22	51	84	207
±15%	9	22	37	92
±20%	5	12	21	51

For the peak hour where there is less variation in occupancy, i.e., a standard deviation of 0.48, the formula yields the following results:

OBSERVATIONS REQUIRED

TOLERANCE LEVEL	LEVEL OF CONFIDENCE (%)			
	80	90	95	99.5
±5%	48	112	186	457
±10%	12	28	46	114
±15%	5	12	20	50
±20%	3	7	11	28

How many traffic accidents with corresponding vehicles and occupants are required to calculate vehicle occupancy rates that are statistically sound? Considering the fact that ConnDOT has been using a database containing one year's accidents, the minimum number of accidents required has not been a problem. Problems with sample size can occur, however, when rates for very specific criteria would produce insufficient numbers of accidents.

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2. *Bias*

The presence of bias is a difficult concept to either prove or disprove. What type of bias could be present in traffic accident data? In order to answer this question, ConnDOT's Traffic Accident Facts book was consulted. Such factors as driver sex, weather or alcohol/drug involvement stood out as possible sources of bias. An investigation was made using accident data for the years 1982 and 1989. Vehicle occupancy rates were calculated for these two years. 1982 was used as the base year since field survey occupancy rates were calculated for this year. 1989 was used because it was the latest year available in the traffic accident database. Accidents occurring on Connecticut's interstate highways were used for this investigation. Accidents occurring on any day of the week during all months of the year were used. Only the vehicle types mentioned earlier in the report were used. The following tables show the results of this investigation for both A.M. peak (7-9) and P.M. peak (4-6).

a. Male vs Female Driver Traffic accident statistics indicate that 64% of all vehicles involved in traffic accidents are driven by males. To make a valid comparison, a breakdown of drivers using the interstates would have to be known. This is, however, not available. The table below shows rates calculated for all drivers, only male drivers and only female drivers.

TABLE 4

Vehicle Occupancy Rates - Male vs Female Drivers

A.M. PEAK

TIME (YR)	ALL DRIVERS	MALE DRIVERS	FEMALE DRIVERS
7-9 (82)	1.25	1.27	1.19
7-9 (89)	1.19	1.20	1.18

P.M. PEAK

4-6 (82)	1.44	1.46	1.41
4-6 (89)	1.35	1.37	1.33

b. Environment Since the field surveys were always conducted in clear weather, and weather was not accounted for when calculating the accident occupancy rates, the investigation looked at both good-weather and bad-weather accidents. Bad weather is defined as rain, snow, fog, hail, sleet, or cloudy. Good weather is defined as clear. 70% of all traffic accidents occur during good weather.

TABLE 5

Vehicle Occupancy Rates - Good Weather vs Bad Weather

A.M. PEAK

TIME (YR)	ALL WEATHER	GOOD WEATHER	BAD WEATHER
7-9 (82)	1.25	1.27	1.19
7-9 (89)	1.19	1.20	1.18

P.M. PEAK

4-6 (82)	1.44	1.46	1.41
4-6 (89)	1.35	1.37	1.33

c. **Alcohol/Drug Involvement** An investigation of alcohol/drug versus non-alcohol/non-drug accidents revealed several things. First the total number of alcohol/drug related accidents was not sufficient to produce meaningful occupancy rates. Also shown was that 65% of alcohol/drug related accidents occurred between 7:00 P.M. and 3:00 A.M.

TABLE 6

Vehicle Occupancy Rates - No Alcohol/Drugs Involved

A.M. PEAK

TIME (YR)	ALL ACCIDENTS	NO ALCOHOL OR DRUG ACCIDENTS
7-9 (82)	1.25	1.25
7-9 (89)	1.19	1.19

P.M. PEAK

4-6 (82)	1.44	1.44
4-6 (89)	1.35	1.35

B. Limitations

As far as limitations are concerned, occupancy rates generated from traffic accident data cannot be broken down by trip purpose. One possible solution to this might be the inclusion of trip purpose questions on the traffic accident form. Another limitation would be insufficient data required to calculate the rates.

VI. SUMMARY

The procedure for calculating vehicle occupancy rates from a traffic accident database is simple and can be easily implemented. The determining factors are the accident database itself, operating platform and software available. Rates calculated from the accident data are comparable to rates obtained in the conventional method and can be used with confidence. There are many advantages to calculating vehicle occupancy rates from accident data. Primarily, cost savings and flexibility are the main advantages.

DISCLAIMER

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration and the Connecticut Department of Transportation. The opinions, findings, conclusions and recommendations expressed in this publication are those of the author and do not necessarily reflect the official views or policies of the Connecticut Department of Transportation and/or the U.S. Department of Transportation.

TRAFFIC MONITORING FOR PAVEMENT TEST SECTIONS ON U.S. 59 IN TEXAS

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ABSTRACT

TRAFFIC MONITORING FOR PAVEMENT TEST SECTIONS ON U.S. 59 IN TEXAS

by

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U.S. 59 is an 885 km [550 mi] long principal arterial highway in east Texas that connects Laredo on the south, at the Mexico border, with Texarkana in the northeast, at the Texas/Arkansas state line. To aid in developing a long-range pavement rehabilitation plan for about 240 km [150 mi] of this highway north of Houston, a major ocean port city, a series of rigid and flexible pavement test sections were constructed in the two southbound lanes in 1992. At one test site, the existing pavements comprise Portland cement concrete slabs (rigid pavement) of various thicknesses and shapes that have been overlaid several times with asphalt concrete during the past 50 years, while at the other test site, the existing pavements are layered structures (flexible pavement) in which the cement is asphalt. Past practice has required the application of a thin asphalt concrete overlay (approximately 40 mm) [1.5 in.] about every 3 to 5 years in order to maintain the pavements in acceptable condition. The objective of the proposed rehabilitation is to use in-situ pavement materials whenever feasible to rebuild the existing pavement structures so that they will serve future traffic for at least 20 years without excessive maintenance.

In addition to frequent, periodic monitoring of the performance of the five 305 m [1000 ft] long, 2-lane pavement test sections (plus a similar control section) at each site, traffic loading in each lane, air temperature, and pavement temperature are being monitored continually. A bending plate weigh-in-motion (WIM) system, with the weighpads in each lane staggered 4.6 m [15 ft], detects and records vehicle speed, number and spacing of axles on each vehicle, and wheel loads. Additional data concerning traffic load applications to the pavement in each lane are obtained via a modulated infrared light beam that has its source in the center of the lane (at the downstream corner of the first weighpad) just above the road surface with its receiver located off the adjacent shoulder so that the light beam forms a 30-degree angle with the transverse axis of the weighpad. By measuring the time after a tire contacts the weighpad until the angled light beam is interrupted, the lateral position of the tire in the traffic lane can be calculated. The duration of the light beam interruption indicates whether the tire is single or dual, assuming that the front tires on every vehicle are single. This paper gives detailed descriptions of the traffic monitoring equipment and presents characteristic traffic loading and temperature patterns for a 12-month observation period in 1993.

TRAFFIC MONITORING FOR PAVEMENT TEST SECTIONS ON U.S. 59 IN TEXAS

by

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The University of Texas at Austin

U.S. 59 is an 885 kilometre [550 mile] long principal arterial highway in east Texas that connects Laredo on the south, at the Mexico border, with Texarkana in the northeast, at the Texas/Arkansas state line. In 1992, a series of rigid and flexible pavement test sections were constructed in the two southbound lanes at two locations near Lufkin, Texas about 160 kilometres [100 miles] north of Houston. The purpose of these test sections is to aid in developing a long-range pavement rehabilitation plan, using existing pavement materials whenever feasible. At one site, the existing pavements are Portland cement concrete slabs, all of which have been overlaid several times with asphalt concrete. At the other site, the existing pavements are layered structures containing asphalt cement. Maintenance practices have generally required thin asphalt overlays every three to five years to provide acceptable pavement serviceability.

In order to define the cause of damage to the test pavements, a weigh-in-motion (WIM) system was installed in a control section at each site. For each vehicle, including passenger cars, the WIM systems collect data about the time and lane of passage, wheel loads, speed, and distance between axles. An infrared light-beam sensor is used to collect tire-arrangement (single or dual) and lateral-position data for each vehicle. Thermocouples sense the air and pavement temperature, and the WIM system records these values hourly. To quantify the combined effect of traffic loading and volume-change-induced stresses, pavement-performance surveys are conducted periodically at each site.

EQUIPMENT DESCRIPTION

The WIM-system sensors include an inductance loop detector, a weighpad (tire-force transducer) in each wheel path, and an infrared light-beam sensor unit (source plus receiver) for each lane. The two weighpads in each lane are staggered 4.6 metres [15 feet] longitudinally, as shown in Figure 1, in order to establish a reference distance over which to measure the speed of each axle that travels in the lane. The infrared light-beam source is attached to the downstream corner of the leading weighpad frame in the middle of the lane. The bottom of the 15 mm [1/2 in.] diameter glass lens of the source is positioned about 3 mm [1/8 in.] above the pavement surface inside an angled hole in an aluminum block that is approximately the size and shape of a conventional, square raised pavement marker button. The source lead-in cable is routed underneath the weighpad frame in a conduit and to the roadside, along with the weighpad cable. The infrared receiver unit is positioned off the shoulder such that the modulated light beam from the source is directed just above the pavement surface to form a thirty-degree angle with the transverse, downstream edge of the weighpad, as shown in Figure 1. A two-metre-square [six-feet-square], six-turn inductance loop is located about 1 m [3 ft] in advance of the leading weighpad. Six turns of wire are used in an attempt to insure that tractors with log-hauling (pole) trailers and other high-bed trucks will be detected correctly. One thermocouple is located in the shoulder pavement about 1 m [3 ft] from the lane edge and approximately 20 mm [1 in.] deep and is sealed with caulk. Another thermocouple is suspended from the roadside WIM-system cabinet to measure ambient air temperature at the site.

The inductance loop in advance of the leading weighpad detects the presence of passing vehicles and alerts the roadside computer to record time and tire-force signals from the weighpads and time and beam-interrupt signals from the infrared light-beam sensors. The lane number (1 for right and 2 for left) and the time of arrival for each vehicle are recorded. The headway between successive vehicles can be calculated from these times. The speed of each axle is calculated by dividing the distance between the staggered weighpads by the time for each axle to travel between the two weighpads. The average speed of the vehicle can be determined by averaging the speed for each axle. If the speed of the vehicle is assumed to be constant, then only the speed of the first axle needs to be calculated. The spacing between successive axles is calculated by multiplying the average speed of two adjacent axles by the time taken for the two axles to cross a single weighpad. By using the average speed of adjacent axles, calculated axle spacing is correct even if the vehicle is accelerating or decelerating (at a constant rate). The axles on each vehicle are counted for as long as the loop detector is activated plus a time delay (adjustable) to allow the last axle to cross the downstream weighpad. Alternatively, axle counting for each vehicle continues after the loop detector is unoccupied until the downstream weighpad has counted the same number of wheels as the upstream weighpad.

Wheel load is measured by each weighpad. Axle load, axle-group load, and gross-vehicle weight can be calculated by summing the appropriate wheel loads. Axles more than about 2.4 m [8 ft] are considered to be single axles; axles closer together are called tandem or tridem axles. This criterion can be adjusted by the user of the WIM system. Equivalent Single Axle Loads (ESALs) are calculated from the axle-group loads, using the appropriate pavement depth or structural number and terminal serviceability index.

The lateral position of the right or left front wheel is calculated by measuring the time interval between its crossing the weighpad and breaking the angled infrared light beam. The position of the right wheel is measured in the right lane and the position of the left wheel is measured in the left lane. The time interval is multiplied by the vehicle speed and by the ratio of two sides of the triangle formed by the infrared light beam and weighpad. The duration of time that the infrared light beam is blocked can be used to indicate single or dual tires. The front tire is assumed to be single, and the blocked-time durations of the other tires are compared to the front tire blocked-time duration. If the other tires have blocked-time durations more than twenty percent greater than that for the first tire, the other tires are identified as dual tires.

The air and pavement temperatures are measured at each site by thermocouples located outside the instrument cabinet and in the shoulder pavement approximately 20 mm [1 in.] deep. The temperature is stored once an hour.

EQUIPMENT CALIBRATION

The WIM systems were calibrated in November 1992 to yield acceptable speed, axle-spacing, and wheel-load measurements by successively adjusting WIM-system parameters to approximate the values obtained from repetitive passes of a three-axle test truck with known wheel loads and axle spacings. These settings were confirmed in August 1993 using a five-axle test truck. Only minor adjustments were necessary.

A 6 m [20 ft] long straightedge with a 150 mm [6 in.] diameter x 3 mm [1/8 in] thick feeler plate was used to measure pavement roughness (deviations from the straightedge) both upstream and downstream of the weighpads. Initial measurements revealed very little roughness, but subsequent measurement after a year of traffic loading revealed some rutting in the wheel paths at both sites. Level-up patching was performed in one wheel path in advance of the weighpad prior to readjustment of the WIM-system parameters.

The lateral position measurements were calibrated by smearing oil on the painted (flat black) metal edge of the weighpad, measuring the location of tire tracks left in the oil by a passing vehicle, and correlating the observed locations with values calculated from tire travel time between the weighpad and the diagonal infrared light beam.

The thermocouples were calibrated by immersing them, along with a thermometer, in a container of ice water, which was gradually heated over a gas burner to about 60°C [140°F]. The temperature readings were also compared with local climatological data. (Ref1)

DATA PATTERNS

All data are stored by an on-site WIM-system microprocessor that is housed, along with a modem, in a cabinet, away from the roadside, near the right-of-way line. Real-time data may be viewed or downloaded at any time from a remote site over a telephone line.

Table 1 shows a sample screen display for a single 3-axle vehicle. A microcomputer housed at a local highway maintenance facility is programmed to connect to the modem in the roadside cabinet and download data files every two or three days, though it is possible to store data files on-site for more than two weeks. This avoids long-distance telephone expenses.

In the following portions of this section, some representative, observed traffic data patterns are summarized. The original data files were downloaded from the roadside to a computer in Austin and translated from a binary format into ASCII format. A spreadsheet program was written to sort vehicles by class and calculate ESAL and lateral-position data for each observed vehicle.

Volume and ESALs

The average annual daily traffic for 1993 for the southbound lanes was 7206, of which 20% were trucks. The right lane carried 75% of the total traffic volume. The right lane had 494,289 cumulative ESALs for 1993 which was 88% of the total ESALs. These ESAL calculations were based on a structural number of 4 (composite pavement) and a terminal serviceability index of 2.5. Five-axle vehicles accounted for 91% of the total ESALs in the right lane, but for only 18% of the volume. In the left lane, five-axle vehicles accounted for 86% of the ESALs and 7% of the volume. Two-axle vehicles accounted for only 2% of the ESALs in the right lane and 76% of the volume. In the left lane, the two-axle vehicles accounted for 4% of the ESALs and 89% of the volume.

Three-axle vehicles accounted for 3% of both ESALs and volume in the right lane. In the left lane, three-axle vehicles accounted for 5% of the ESALs and 2% of the volume. Four-axle vehicles accounted for 2% of both ESALs and volume in the right lane. In the left lane, four-axle vehicles accounted for 3% of the ESALs and 2% of the volume. Vehicles with six-or-more axles accounted for 2% of the ESALs in the right lane and 0.4% of the volume. In the left lane, six-plus-axle vehicles accounted for 2% of the ESALs and 0.2% of the volume. Six-plus-axle vehicles produced the highest number of ESALs per vehicle.

Weekly traffic volume trends are shown in Figure 2. The highest traffic volume by day of the week occurred on Fridays. The higher-volume days for passenger cars are Friday and Sunday. The lower-volume days for passenger cars are Tuesday and Wednesday. Saturday and Sunday are the lower-volume days for trucks. The day with the most ESALs is Monday, as shown in Figure 3. The days with fewer ESALs are Saturday and Sunday, the same days when truck volumes are lower.

Monthly ESAL trends are shown in Figure 4. The average daily ESAL total in the right lane was 1354. June had the highest daily ESAL average of 1599 and December had the lowest daily ESAL average of 1162. The five-axle average daily ESAL in the right lane was 1226. The highest average occurred in June with 1471 and the lowest average occurred in January with 1059. The summer months had higher ESALs, while the winter months had lower ESALs.

Lateral Position

Lateral position of each vehicle is measured as the distance from the respective outside pavement edge to the inside edge of the nearest front tire. The median value for lateral position of front tires on two-axle vehicles in the right lane was 1.3 m [4.2 ft], as shown in Figure 5. For five-axle vehicles in the right lane, this value was 1.0 m [3.2 ft]. In the left lane, the lateral position for two-axle vehicles was 0.9m [2.8 ft] and for five-axle vehicles, 0.5 m [1.5 ft], as shown in Figure 6. In the right lane the lateral position is measured from the right edge of the lane. Vehicles with the right front tire on the 3 m [10 ft] shoulder would, therefore, have a negative lateral position. If the right tire were on the stripe, the lateral position would be zero. If the right tire were in the center of the lane or further from the right edge, it would not block the infrared light beam, the time interval would be zero, and the lateral position would be calculated as 2 m [6.5 ft]. In the left lane, the lateral position measures the distance from the left front tire to the left edge of the lane. If the left tire were on the 1.2 m [4 ft] shoulder, the lateral position would be negative. Trucks are wider than passenger cars; therefore, they usually travel with their tires closer to the shoulder than cars.

Vehicles in the left lane generally traveled closer to the left shoulder than vehicles in the right lane travel to the right shoulder. This may be because vehicles tend to pass on the left and leave more clearance on their right side.

Temperature

Temperatures were recorded beginning in April, 1993. The hourly data for 23 June and 24 December 1993 are shown in Figure 7. The pavement temperature lags the air temperature by several hours and is higher than the air temperature except during the late morning and early afternoon hours. July was the hottest month with an average daily maximum of 43°C [110°F] for the air temperature and 49°C [119°F] for the pavement temperature. The average minimum temperatures for July were 23°C [74°F] for the air and 32°C [89°F] for the pavement. December was the coldest month with an average daily minimum of 5°C [41°F] for the air temperature and 11°C [51°F] for the pavement temperature. The average maximum temperatures for December were 21°C [70°F] for the air and 20°C [68°F] for the pavement. The average pavement minima and maxima were always higher than the corresponding air temperatures except for November and December when the air maxima were slightly higher. The air temperatures are somewhat high because the thermocouple for the air is only partially shaded.

CONCLUSION

Traffic at two pavement test sections on U.S. 59 in east Texas has been monitored continuously with specially-configured weigh-in-motion (WIM) systems since December 1992. Data for a virtually one-hundred-percent sample of vehicles has been collected for nearly two years at both sites. Daily, weekly, and monthly data trends have been calculated for 1993. The traffic loading data are being correlated with pavement performance data in order to develop a practicable pavement rehabilitation strategy for some 240 km [150 mi] of this principal arterial highway.

Staggered weighpads yield speed and axle spacing as well as wheel and axle loads. The infrared sensors, which are used to detect lateral position and identify arrangement of tires on each vehicle, have proven to be rugged, low-cost, and low-maintenance. The lateral position data can identify patterns of pavement-edge loading and off-scale vehicles. The indication of single or dual tires can be used to classify vehicles.

REFERENCE

1. "National Climatological Data, Texas," Vol. 98, 1993, National Climatic Center, National Oceanic and Atmospheric Administration, Asheville, NC.

TABLE AND FIGURE LIST

Table 1. WIM-Screen Display

Figure 1. WIM-System Layout
Figure 2. Daily Volume Trends
Figure 3. Daily ESAL Trends
Figure 4. Monthly ESAL Trends
Figure 5. Lateral Position, Right Lane
Figure 6. Lateral Position, Left Lane
Figure 7. Hourly Temperature

Table 1. WIM-Screen Display

Site: 2	Lane: 2	Time: 13:53:42	Date: 8-25-93	
Veh No: 3596		Speed(km/h):	106	
Gross Wt(Mg): 9.0		Wheelbase(m):	5.6	
Axle No		1	2	3
IR Time(ms)	3 2	1 4	1 9	1 9
R Wheel Load(Mg)		1.8	1.3	1.5
L Wheel Load(Mg)		1.7	1.2	1.5
Axle Load(Mg)		3.5	2.5	3.0
Axle Spacing(m)			4.2	1.4
Temp(°C)	Air: 35	Pavement:	43	

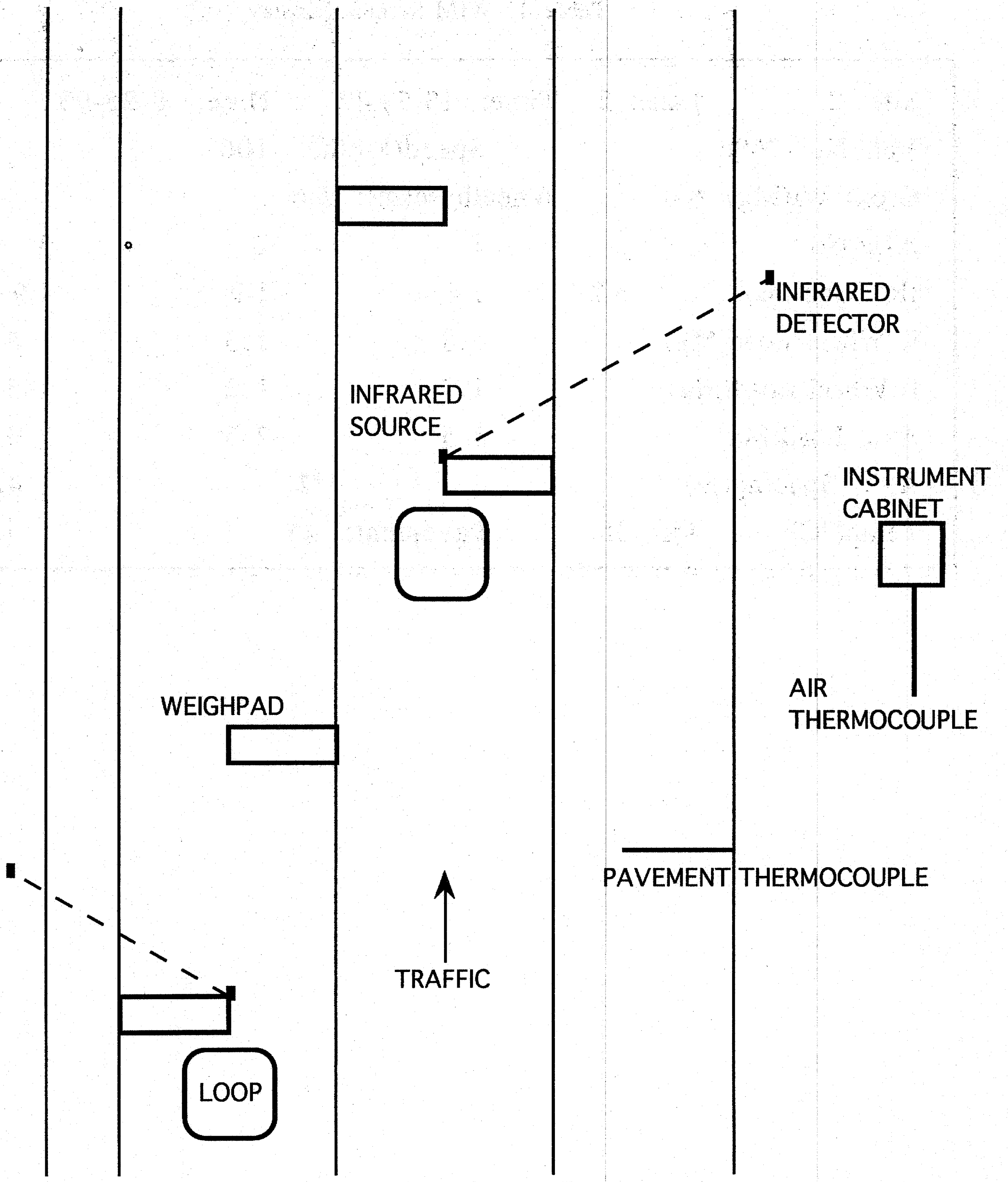

Figure 1. WIM-System Layout

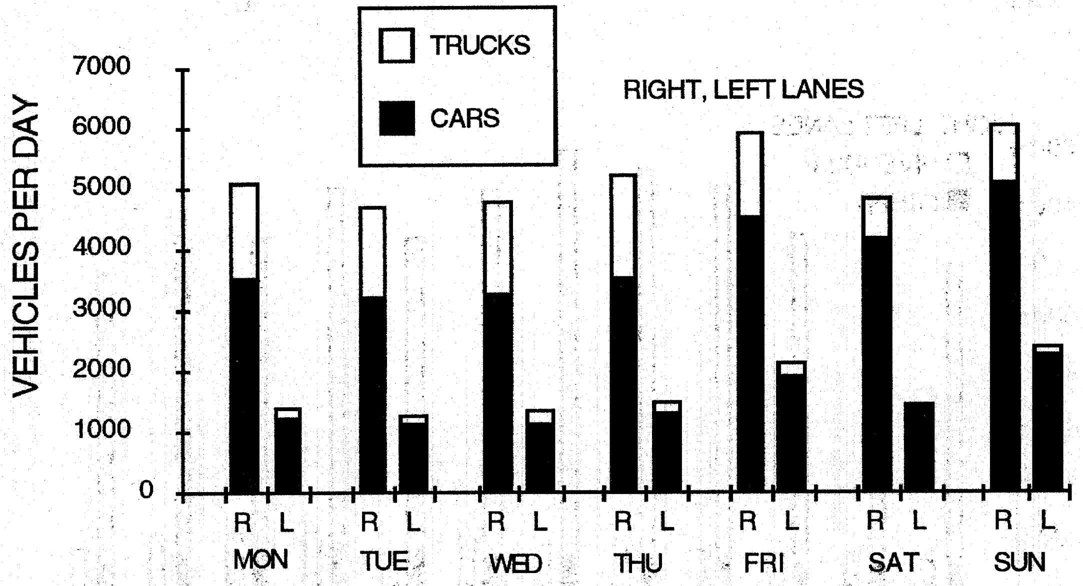

Figure 2. Daily Volume Trends

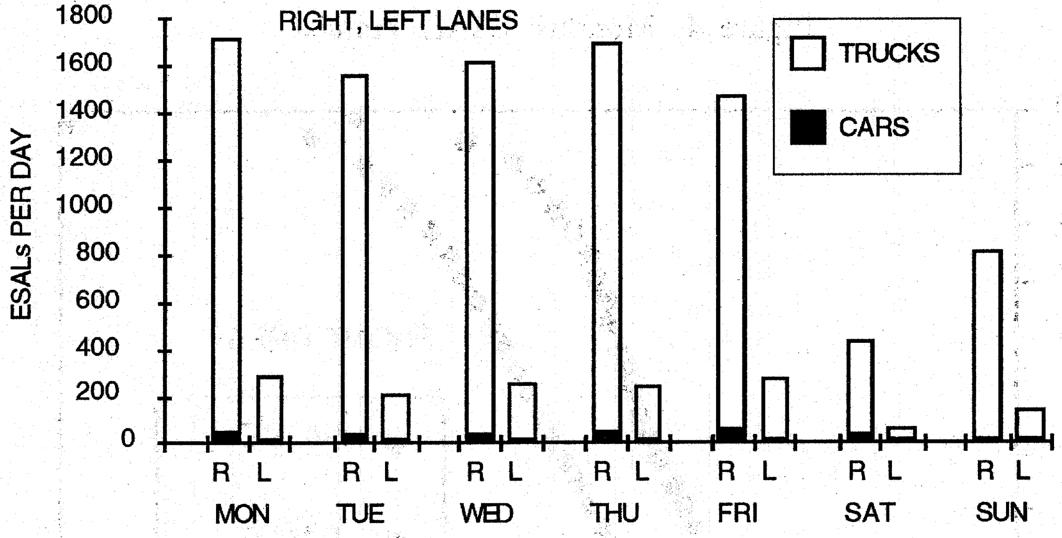

Figure 3. Daily ESAL Trends

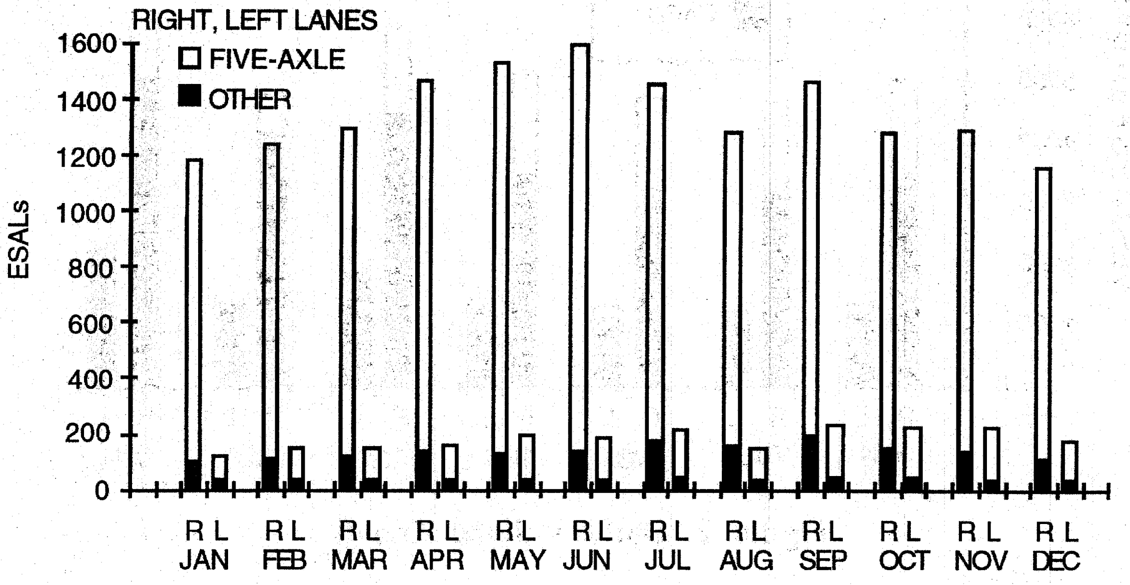

Figure 4. Monthly ESAL Trends

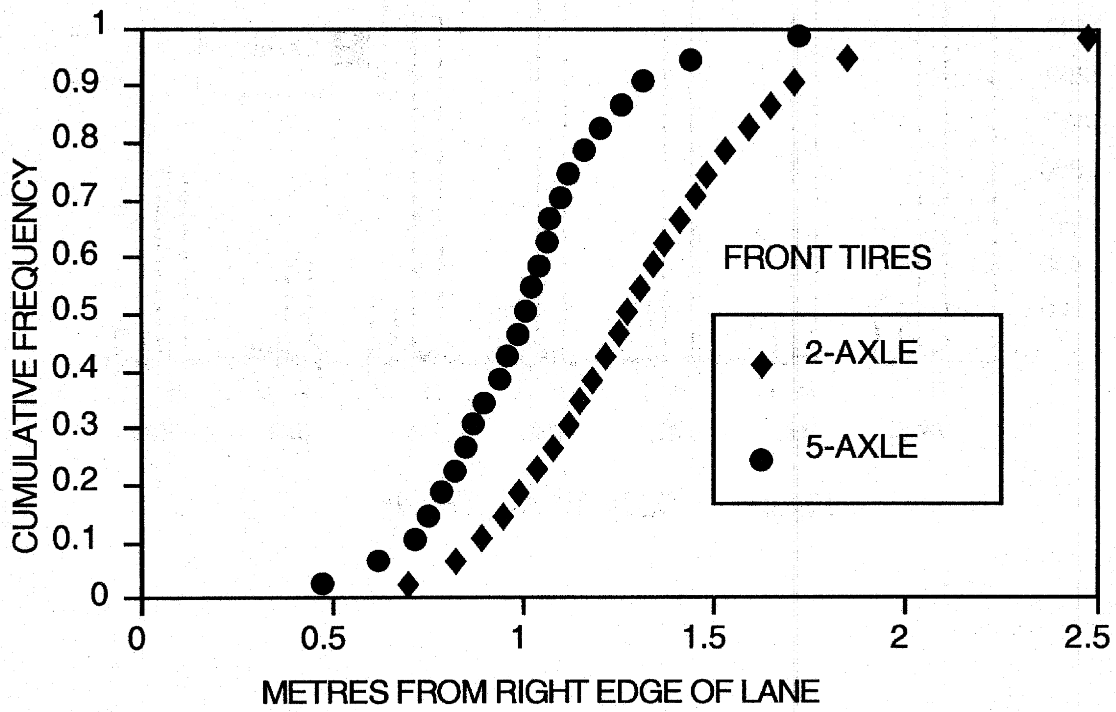

Figure 5. Lateral Position, Right Lane

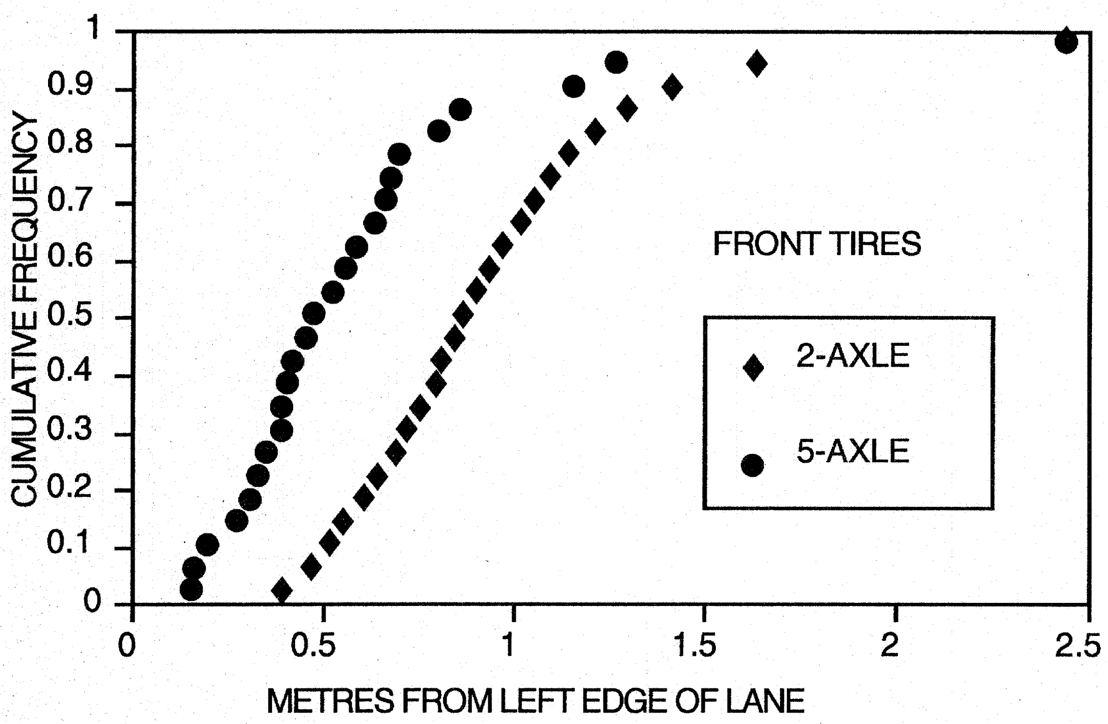

Figure 6. Lateral Position, Left Lane

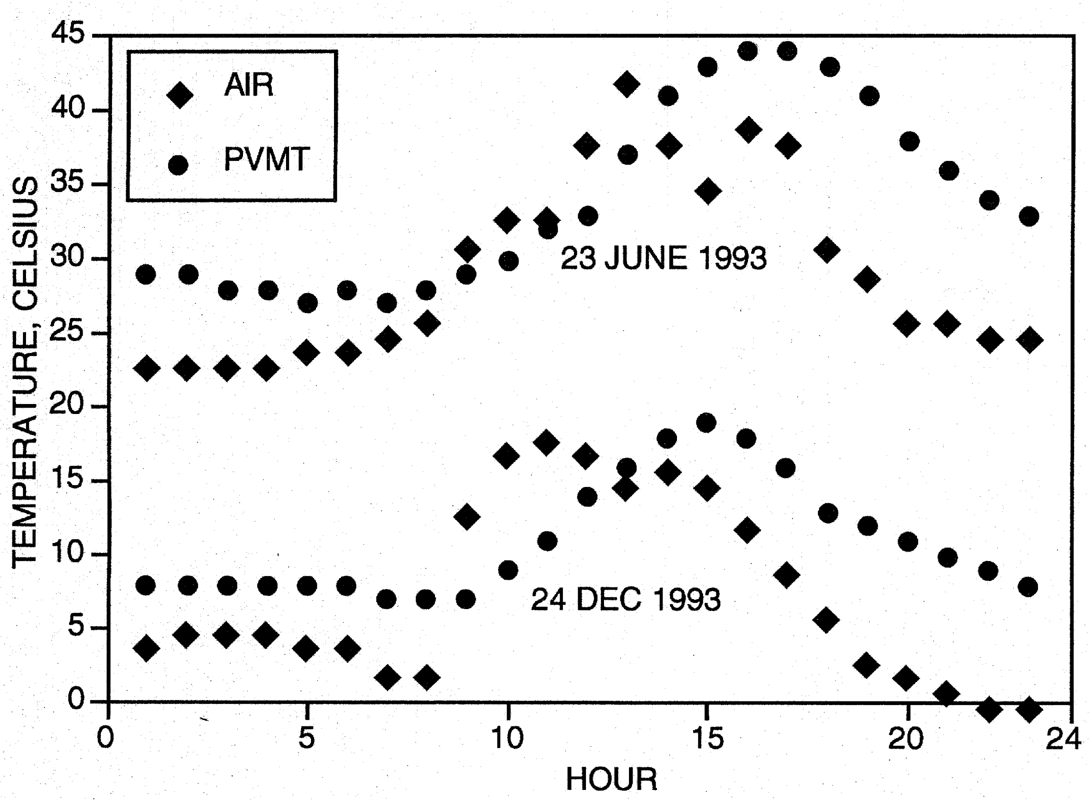

Figure 7. Hourly Temperature

FIELD TESTS OF TRAVEL TIME SURVEY METHODOLOGIES AND DEVELOPMENT OF A STANDARDIZED DATA PROCESSING AND REPORTING SYSTEM

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FIELD TESTS OF TRAVEL TIME SURVEY METHODOLOGIES AND DEVELOPMENT OF A STANDARDIZED DATA PROCESSING AND REPORTING SYSTEM

ABSTRACT

Field tests of travel time data collection and survey methodologies were conducted in Boston, Seattle, and Lexington, Kentucky, in 1993. This project was initiated by the Federal Highway Administration (FHWA) in recognition of the importance of developing consistent and standardized methodologies for travel time and speed data collection. The six methodologies tested included: license plate matching using video cameras, license plate matching using portable computers, floating cars, probe vehicles, AVI (automatic vehicle identification) buses, and volume data generated from the loop detector systems. The project was administered by the Volpe National Transportation Systems Center (Volpe Center) in coordination during the field tests with the three selected metropolitan planning organizations (MPOs) and corresponding agencies. The data processing, analysis, and evaluation of alternative data collection methods was performed at the Volpe Center.

This paper summarizes the field tests, preliminary results of data analysis, a comparison of alternative travel time data collection methods, and costs and effectiveness in terms of sample size and data quality. A prototype data processing and reporting system is being developed at the Volpe Center as a byproduct of the project. The system can be used as a model for the future implementation of standardized data processing and reporting activities for travel time and speed data collection. The ultimate goal is to enable a nationally uniform program of data collection that would provide continuous and consistent travel time and speed data to allow trend and intercity comparison. The data collected may be used by the states and MPOs as a primary source for congestion management systems, as outlined by the Intermodal Surface Transportation Efficiency Act (ISTEA) requirements.

FIELD TESTS OF TRAVEL TIME SURVEY METHODOLOGIES AND DEVELOPMENT OF A STANDARDIZED DATA PROCESSING AND REPORTING SYSTEM

INTRODUCTION

Consistent data collection and monitoring of urban travel times and speeds are essential to the understanding of travel congestion and management of traffic. A call by the Federal Highway Administration (FHWA) in 1991 for copies of urban travel time studies in the United States indicated, that 1) little effort is being expended nationally to capture travel time data, 2) whatever data exist are collected sporadically, and 3) data are not collected in a manner which would allow meaningful intercity comparisons as part of a national program.

This Standardized Travel Time Surveys and Field Tests Project was initiated by the Office of Highway Information Management of FHWA in 1992. Field data collection and tests of survey methodologies were conducted in the summer and fall of 1993 in Boston, Massachusetts, Seattle, Washington, and Lexington, Kentucky. The Volpe National Transportation Systems Center (Volpe Center) administered the project for the FHWA and coordinated research activities during the field tests with the three selected metropolitan planning organizations (MPOs) and corresponding agencies. The principal agencies participating in the field tests were:

- Boston Central Transportation Planning Staff (CTPS)
- Boston SmartRoute Systems
- Puget Sound Regional Council (PSRC)
- Washington State Transportation Center (TRAC)
- Lexington-Fayette Urban County Government (LFUCG), Traffic Engineering Division

Each MPO participated fully in the stages of survey planning, training, coordination of equipment purchasing and sharing, development of survey procedures, and field data collection. The Volpe Center performed the data processing, analyses, and evaluation of the methodologies. To accommodate these activities, a prototype data processing and reporting system was developed as a byproduct of the project.

The objective of this project is to identify the costs and effectiveness of alternative methods for collecting urban travel time and speed data. The ultimate goal is to establish a nationally uniform program of data collection that will provide continuous and consistent travel time and speed data to allow trend and intercity comparison. The data collected may be used by the states and MPOs as a primary source for congestion management systems as outlined by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requirements.[1] The database system developed in the project, Urban Travel Time Survey System (UTTSS), will be further enhanced and used as a model for standardized data processing, report generating, and analysis for future implementations of travel time and speed data collection.

Six data collection methodologies were included in the field surveys. Each MPO was asked to field test one or more of the following methodologies:

- License plate matching with video
- License plate matching with portable computer
- Floating car
- Probe vehicle
- AVI (automatic vehicle identification)
- Loop detector

The surveys were conducted on five selected highway corridors or principal arterial streets in each of the three cities, including the route from the downtown central business district (CBD) to the major airport. Two or more methodologies were usually performed simultaneously, covering the same route, distance, and time periods. Statistical and comparative analyses over sample size and data issues could thus be performed across methodologies, cities, and roadway types. Analyses of travel time and speed variation over different route segments and time periods were also conducted and captured in the standardized reports.

This paper summarizes the field tests and preliminary results from the six data collection methods. The analyses focus on the comparison of costs and performance measurements (by virtue of sample size and data quality), as well as the reports generated by the UTTSS system. More detailed reports and analyses of cost, performance, and effectiveness of each method will be documented in the final project report.

METHODOLOGY SELECTION

A review of literature and current data collection practices was conducted as part of the project to identify existing and new methodologies for travel time and speed data collection. Table 1 describes the characteristics of nine methodologies. The top six methodologies were tested in the project.

While traditional travel time studies used traveller interviews or floating car to measure origin-destination (O-D) or route travel time, newer methodologies captured vehicle location and time to measure link travel time of traffic flows or spot speed at fixed locations. Although travel time is considered the best measure of congestion,[2] it is difficult and expensive to collect continuous travel time data in a consistent way. Volume data are often more obtainable and usually counted or predicted along with capacity measures to represent the level of service (LOS) within a facility type. Since travel time is a function of facility type, V/C ratio, and roadway condition (weather, accident occurrences, road constructions), LOS is often used as a surrogate variable for travel times to capture level of congestion.[3]

Sampling and sample size have always been the critical issues in data collection, besides the economic and technical concerns over a methodology. In a formal travel time study, a sufficient sample should be collected to allow for differentiation of travel time and speed variation among locations (downtown to suburban, suburban to suburban), roadway types (freeway, arterial), weekday vs. weekend travels, time of day (peak, off-peak), and between traffic lane (HOV lane).

Table 1. Overview of Travel Time Survey Methodologies

Methodology	Speed Type	**Characteristics**	
License Plate Matching - Video	Link	**Sample:** ▸ Capture up to 60% of vehicles passing lane, 1800 plates/hour w/plate reader ▸ Capture 90% of plates, w/ manual read from video; 10 hours per 1 hour of tape ▸ Full plate **Limitations:** ▸ Capture through traffic only ▸ Difficult to trace origin, destination and direction ▸ Equipment intensive for data collection	**Training:** ▸ High operator skill required **Technology Readiness:** ▸ Currently being tested **Other Traffic Data:** ▸ Traffic Volume ▸ Vehicle Mix ▸ Headway/Density
License Plate Matching - Portable Computer	Link	**Sample:** ▸ Degradation of observer performance over time ▸ Typically partial plate **Limitations:** ▸ Same as above; ▸ High speed limitation ▸ Labor intensive for data collection	**Training:** ▸ Moderate operator skill level required **Technology Readiness:** ▸ Currently available
Floating Car	Link O-D	**Sample:** ▸ Typically 6-12 data samples collected per segment; ▸ No limitations on segment selection **Limitations:** ▸ Sample size limitation ▸ Labor intensive for data collection	**Training:** ▸ Minimal training required **Technology Readiness:** ▸ Currently available **Other Traffic Data:** ▸ Delay ▸ Speed Cycles
Probe Vehicle	Link O-D	**Limitations:** ▸ Data collection procedure needs to be better developed ▸ Labor intensive for data collection and processing ▸ Quality of Data may not be consistent **Training:** ▸ Minimal Training	**Technology Readiness:** ▸ Currently available **Other Traffic Data:** ▸ Delay ▸ Speed Cycles
AVI	Link Spot	**Limitations:** ▸ Lane discrimination available in some options ▸ Infrastructure dependent	**Technology Readiness:** ▸ Currently available
Road Detector Meters (loop detectors, etc.)	Spot	**Limitations:** ▸ Infrastructure dependent ▸ Accuracy level is not consistent	**Technology Readiness:** ▸ Currently available **Other Traffic Data:** ▸ Traffic Volume ▸ Lane occupancy
AVL (GPS, etc.)	Link O-D	**Limitations:** ▸ GPS accuracy may not be sufficient ▸ Infrastructure dependent	**Technology Readiness:** ▸ Currently being tested
Surveillance (fixed location)	Spot	**Limitations:** ▸ Limited to spot speed ▸ Equipment or infrastructure dependent	**Technology Readiness:** ▸ Currently available **Other Traffic Data:** ▸ Traffic Volume
Traveller Interview	O-D	**Limitations:** ▸ Response rates ▸ Data accuracy ▸ Disruption of traffic if wayside	**Technology Readiness:** ▸ Currently available

A sufficient sample size is particularly crucial for capturing the dynamics of traffic flows in a congested environment. In order to measure congestion effectively, more rigorous data collection with small route segments and time durations (15 or 30 minutes) could provide the basis for capturing level of congestion in the form of duration (number or percent of time slices where average travel time exceed a threshold value), spread (number or percent of route miles), or intensity (ratio of peak travel time/speed to the norm travel time/speed).[4]

Data quality and accuracy are other issues in selecting an appropriate methodology. While poor data quality and sample size are often characteristic of traditional data collection methods (low response rates and accuracy in traveller interview, limited sample size with floating car), new technologies (such as AVI or a geolocation system) seem to offer more promising results in terms of accuracy and sampling efficiency. Although implementation of these more advanced technologies for data collection may seem a rational choice from the perspective of technology, system-wide adaptation to these technological advancements and overall transportation investments and improvement (including data collection) depend more on economic and institutional justifications and public policy decisions.

The methodologies selected in the surveys include both conventional and new technologies that are now being used in practice. The surveys emphasized route/segment travel times that would in turn produce average route/segment speeds. Among the six methods, license plate matching using video cameras and an automatic License Plate Reading System were chosen to be tested in all three cities on all fifteen selected routes. As continuous data and traffic scenes could be captured using video, this method was selected as the baseline methodology for the field tests. Data collected on videotapes presented a valuable data source for future research. The database established from the license plate matching was used to compare with other methods.

The selection of methodologies for testing and the matching with MPOs depended on the capabilities and resources of the MPOs, their current methods of obtaining travel time data, their current plans/needs for travel time survey data, and any existing systems or on-going related IVHS activity in their area. A summary of the selected methodologies by city is shown in Table 2 below.

Table 2. Selected Methodologies

	Boston	**Seattle**	**Lexington**
License Plate - Video	X	X	X
License Plate - Portable Computer		X Palmtop	X Laptop
Floating Car			X
Probe Vehicle	X		
AVI		X	
Loop Detector		X	X

CONDUCTING THE FIELD TESTS

The field tests consisted of three phases. The first was a preliminary kick off meeting followed by preparation of survey plans; the second was field training and testing; and the third was the actual survey. Figures 1 to 3 show the survey routes in the three field test cities.

Table 3. Survey Schedule (1993)

City	Participating Agencies	Kick-Off Meeting	Field Training & Testing	Field Survey Schedule
Boston, MA	CTPS SmartRoute Systems Mass Highway	4/26	6/21 - 6/25	6/28 - 7/16
Seattle, WA	PSRC TRAC WSDOT	5/12	7/19 - 7/23	7/26 - 8/20
Lexington, KY	LFUCG, Traffic Engineering Division LFUCG, MPO U. of Kentucky	5/4	9/13 - 9/17	9/20 -10/8

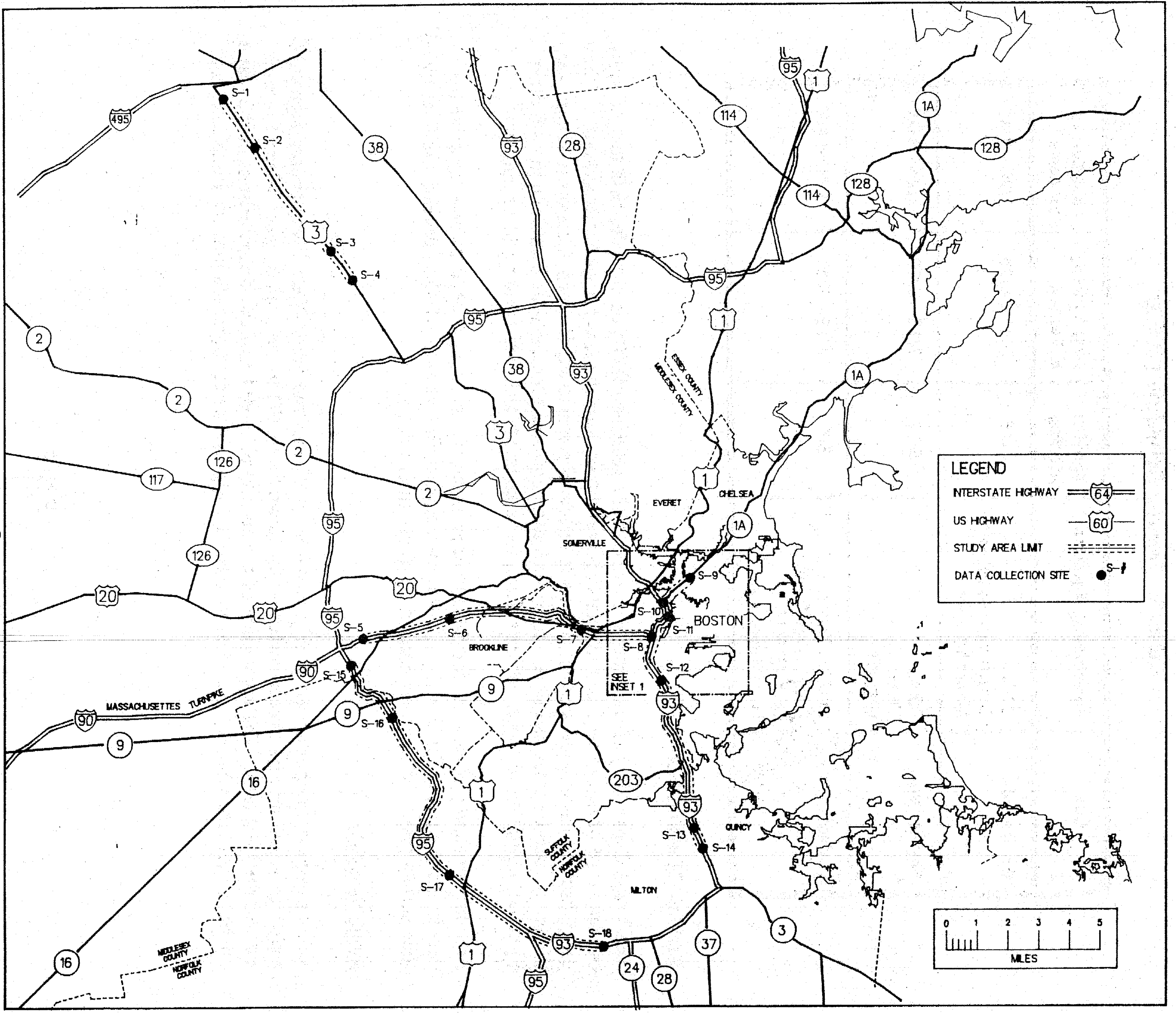
Kick-off Meetings/Survey Plans

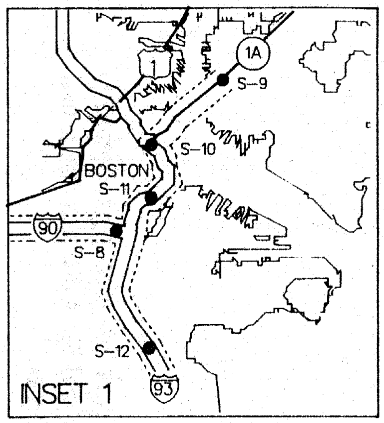
The Volpe Center project team met with each of the selected MPO's prior to the field tests to work out the scope of the surveys and to establish preliminary survey plans for each methodology. These early discussions centered around: route/site selection/preparation, observer location selection, scope of survey, survey dates and times, equipment and personnel procurement, coordination with other agencies, definition of target vehicles, lanes to be covered, and data elements to be collected.

Preliminary survey plans were provided to each of the MPOs as a guideline to help organize the details of the surveys for that city. It was the responsibility of each MPO to develop the final travel time survey plans. Planning continued up to the survey dates.

<u>Route Selection</u>

Route selection was performed jointly by the Volpe Center and the MPOs. Five primary highways and/or principal arterial streets, including the downtown CBD to the airport, were selected in each city for the field tests. The knowledge of the participating MPOs of the characteristics of the major routes in their areas made them ideal to make the appropriate recommendations for route selection.

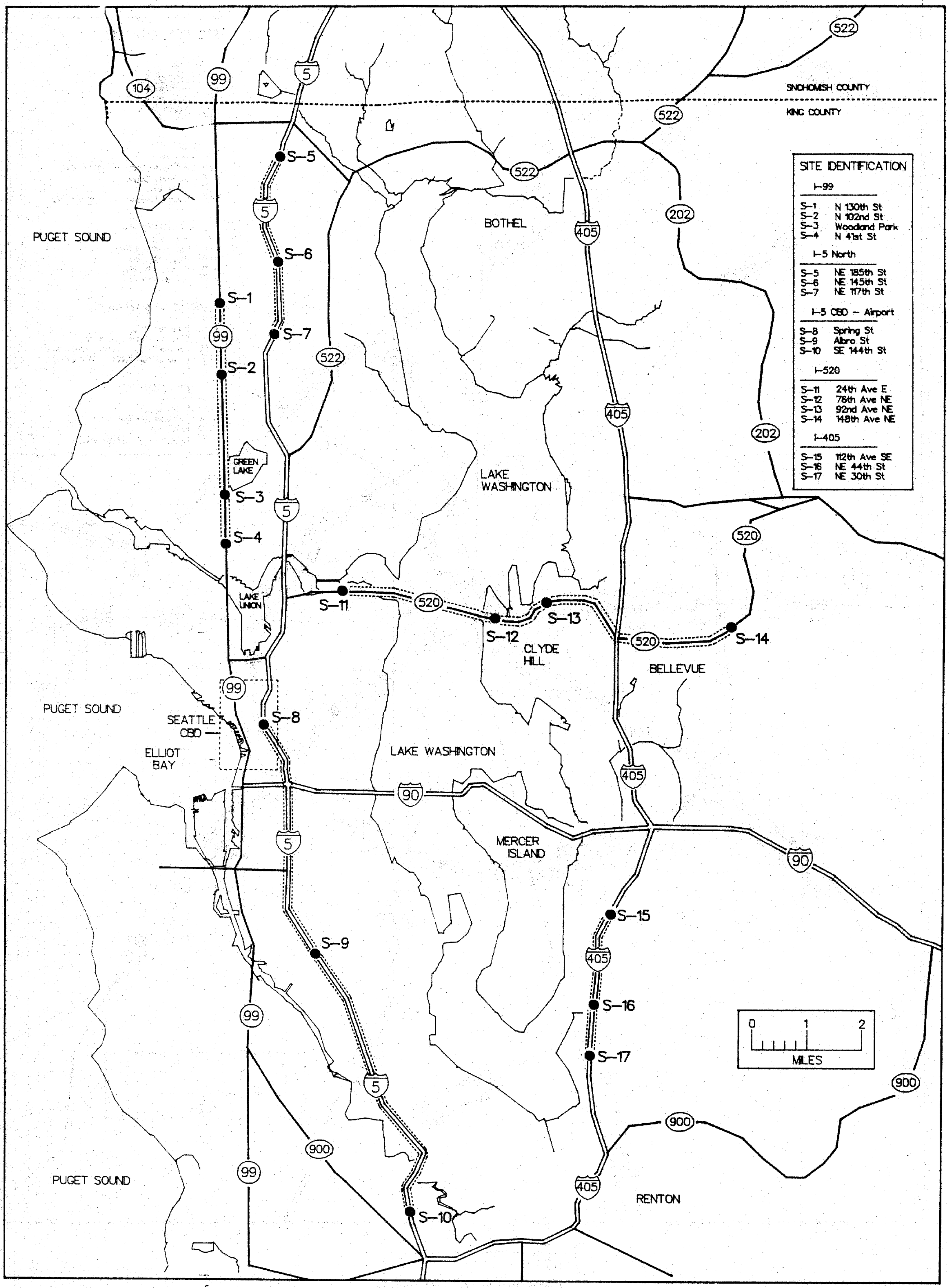




SITE IDENTIFICATION

US-3	
S-1	Riverneck Rd
S-2	Rangeway Rd
S-3	Orchard Rd
S-4	Old Billerica Rd
I-90	
S-5	Lexington St
S-6	Church St
S-7	St Mary's St
S-8	Washington St
Sumner Tunnel	
S-9	Entrance
S-10	Exit
I-93	
S-11	Russia Warf, N Ave
S-12	Boston St
S-13	Boulevard St Ext
S-14	Bates Ave
I-95	
S-15	Grove St
S-16	Highland Ave
S-17	Route 1A
S-18	Ponkapoag Rd

FIGURE 1 BOSTON MA TRAVEL TIME SURVEYS ROUTE DEFINITION



SITE IDENTIFICATION

I-99	
S-1	N 130th St
S-2	N 102nd St
S-3	Woodland Park
S-4	N 41st St
I-5 North	
S-5	NE 185th St
S-6	NE 145th St
S-7	NE 117th St
I-5 CBD – Airport	
S-8	Spring St
S-9	Albro St
S-10	SE 144th St
I-520	
S-11	24th Ave E
S-12	76th Ave NE
S-13	92nd Ave NE
S-14	148th Ave NE
I-405	
S-15	112th Ave SE
S-16	NE 44th St
S-17	NE 30th St

FIGURE 2 SEATTLE WA
TRAVEL TIME SURVEYS
ROUTE DEFINITION

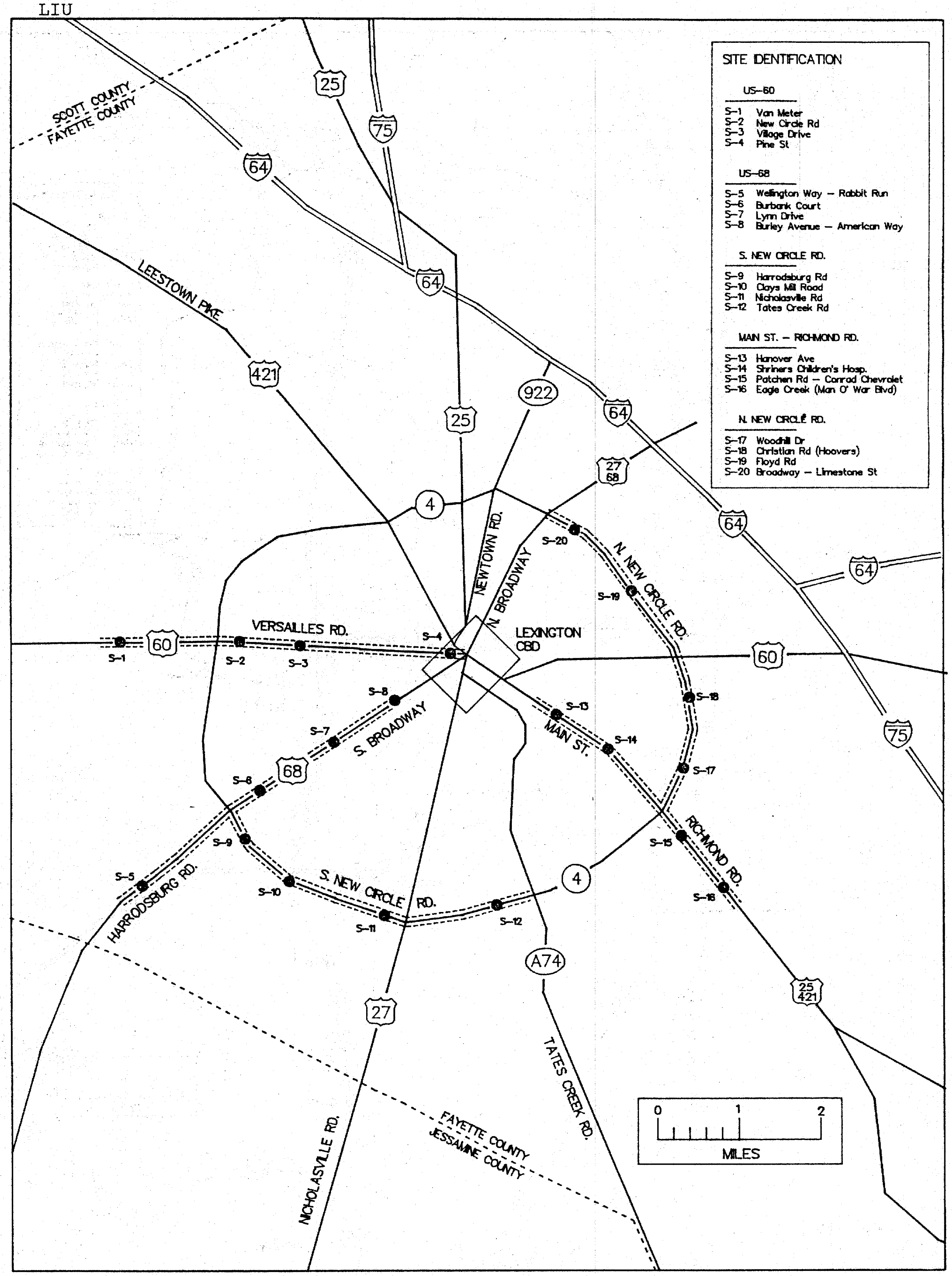


FIGURE 3 LEXINGTON KY
TRAVEL TIME SURVEYS
ROUTE DEFINITION

Road Segment Definition/Observer Locations

All survey sites were coordinated across all of the methodologies to be tested to ensure suitability and compatibility of coverage. Positions for the laptop and floating car methodologies included the same locations as the video methodology.

For each city, all sites were scouted and locations selected prior to the field test/survey. Usually three consecutive segments from the entire length of each of the five routes were selected. The exact location of the observers operating the cameras were determined following reconnaissance on a site-by-site basis. Road segment determination was critical in that it affected equipment and personnel requirements. The locations for the video license plate method were selected first since they had the most restrictive criteria. The video methodology required that cameras be mounted on a tripod at street level or from an elevated location. The observer positions had to be a secure place for the observer with an unrestricted line of vision and hidden from the motorists' view. Video sites were also limited by the angle of the camera to the traffic, position of the sun, and position of shadows. For the Probe methodology in Boston, observation positions were physically marked to help buses and probe vehicles locate their call in points. No preparation was required for the AVI or loop detector methodologies since they were part of existing on-line systems.

Define Target Vehicles

In the video methodology, all vehicles traveling within the lane(s) covered are captured. However target vehicles are excluded in the plate reading processing step via a syntax selection and font identification process. Vehicles typically excluded were commercial vehicles and out-of-state plates.

Define Lanes to Be Covered

For the video and portable computer methods, up to three lanes per route in any direction were selected. For cases where there were more than three lanes, a determination was made as to which would be covered. Decisions to include or exclude HOV lanes, traffic management lanes and turn on/off lanes were made on a site by site basis. Probe and floating car drivers were not instructed to drive in any particular lane, however if they were traveling in an HOV lane it was noted.

Times/Days to be Covered

Field tests were performed over a five month period beginning in mid-June and ending in early October 1993. The survey design strived to strike a balance between the number of staff required, the sample size desired, and the available equipment. Each of four of the five routes were surveyed one full day, the fifth route was surveyed an additional two days. Single day surveys were conducted on Tuesday through Thursday. The survey times covered peak AM and PM, and in some cases mid-day hours. Summer and early fall was selected because of the likelihood of clement weather and the availability of students.

Data Elements to be Collected

Full six digit license plate numbers were captured using the video camera license plate matching technique. In the laptop/palmtop license plate matching, four characters were collected.

Required floating car data were simply noted time past the selected locations. Delay data were also collected although not used for this effort. For the probe methodology, time of call, driver name, probe ID, route, direction of travel, call in location, time past point, and road conditions were reported.

In addition to the data elements required to be collected at the survey, the MPOs agreed to provide other information of the characteristics of the routes and traffic. This included volume counts, composition of the traffic, and general roadway attribute data.

Equipment and Personnel Procurement

Selected MPOs were responsible to buy, lease, or arrange for the use of the necessary equipment and accessories to collect the travel time data. In order to maximize the scope of the surveys and route coverage, an equipment purchasing and sharing agreement was established among the three cities. Twelve sets of video equipment were purchased for the video survey. Each city was responsible for purchasing 1/3 of the total equipment. Equipment leasing was considered, but was found not as cost effective as purchasing and sharing. Each MPO was responsible for preparing (packing, insuring, shipping) the equipment to be sent to the next city. After the Lexington survey each MPO retained four video cameras and the accessory equipment they had purchased or was purchased for them.

Materials required for the probe and floating car methods were minimal. Vehicles were the only major required equipment. Lexington used vehicles owned by the city as the test cars. Seattle and Lexington purchased palmtops/laptops for data collection and laptops for processing the survey data.

MPOs were solely responsible for assigning staff members or hiring of temporary personnel to perform the surveys. MPO's were required to perform the personnel related functions: determining personnel availability and functions, personnel recruitment, preparing the training - developing training procedures and requirements (e.g., equipment, measures, forms, contingencies, etc.), and specifying and scheduling personnel requirements for field data collection.

Coordination with Other Agencies

Coordination was required with agencies such as police and other roadway authorities to provide support. For the Boston probe methodology, SmartRoute Systems was responsible for gaining the cooperation of the MassPort bus drivers and their regular probe drivers.

Field Training and Testing

The second phase was field training and pilot testing. Each MPO was responsible for conducting field training for each of their methodologies to insure operator familiarity and practice in the use of equipment, use of forms, and to practice on-site coordination. The training and testing requirements varied greatly by methodology.

Training in video data collection techniques required two to three days of both in-house and in the field training for each city. Formal in-house training covered a general discussion of traffic surveys, survey planning, survey procedures, camera operation, equipment set-up, crew assignments, and how to handle contingencies.

For the portable computer methodology field crews were provided partially structured familiarity training (practicing data entry) which could take place any time, anywhere, as long as the training is a realistic simulation. Operator familiarity was essential in order to maximize the value of time spent on station. This method requires sustained concentration during the survey especially if performed for high speed traffic lanes.

Training for the probe methodology consisted of distributing a set of instructions (survey procedures and forms), photographs of the call-in locations and route maps to the bus/probe drivers. One week prior to the start of the field test, probe drivers were asked to make practice runs to ensure that they could locate all of the call-in sites, and that they were comfortable with the call-in procedures.

Field Surveys

The following list summarizes the procedures and activities required in setting up field surveys:

- **Date, Route, Site, and Personnel Assignment** - Survey team assignments, scheduling sheets.

- **Equipment Assignment** - Cataloguing of equipment, verification of operational status, equipment pick-up, delivery and storage.

- **Set-Up Time and Procedure** - Preparation of work area, equipment setup and adjustment.

- **Synchronizing Time** - Camera clocks, portable computer clocks, and watches of all survey members were synchronized before the survey and were checked for discrepancies during the survey.

- **Survey Hours and Routine Procedures** - For the video methodology this consisted of tape labeling and changing, time checks, and periodic camera adjustments. All surveyors were required to keep a daily log used to catalogue nonrecurring delays, aberration factors and equipment function. Other factors such as road/bridge construction/maintenance and special events were investigated prior to the surveys.

- **Rover's Responsibilities** - To offer technical advise and ensure video recording quality. Although the rovers were primarily responsible for the video methodology, they were also helpful in directing surveyors for the portable computer method. Rovers carried extra equipment and supplies (cameras, fuses, batteries, rain gear, etc.), collected video tapes, and served as temporary relief and emergency back-up personnel.

- **End of Survey Day** - Breaking down equipment; equipment cleaning, recharging and storage; replacing damaged equipment; collection of survey data (video tapes, portable computer data files); and passing any new instructions or information along to other team members.

- **Security and Safety Awareness** - were addressed as part of the training and were considerations throughout the surveys. Safety equipment such as safety vests and cones, and masks for locations where vehicle fumes were high, were made available to the teams. The safety of the surveyors was of paramount importance, and took precedence over any concerns about equipment or data collection. Equipment was secured as necessary.

COST SUMMARY

The FHWA provided each of the three selected MPO's $50,000 to defray the expenses related to their participation in the tests. Boston's funding included a set aside for SmartRoute Systems of $5,000.

Analysis of Cost Data

Each MPO was required to compile comprehensive cost data for each methodology tested. The summary cost is shown in Appendix Tables A-1, A-2, and A-3 by methodology and city. Costs for each methodology are broken down into three categories - personnel, equipment, and other supplies. Personnel costs include the following categories:

Field Survey - the cost of staff or personnel hired explicitly for these surveys.

Field Coordination/Supervision - cost of personnel not conducting the surveys, such as supervisory personnel and rovers.

Planning and Preparation - costs for planing the surveys and preparing the sites. This include up front meetings with the Volpe Center, any contract negotiations, equipment procurement, etc.

Training - time spent on training for the survey requirements and procedures - both in the field and classroom time is included.

Raw Data Assembly - costs associated with the collection of data related to the roadway attributes and assembling and transferring of the survey data subsequent to the surveys.

Equipment costs include any pieces of equipment required to perform the survey, this includes costs for purchased and/or borrowed equipment. Costs for other supplies include the video tapes required for video method and minor items required for the surveys, such as safety materials, materials for marking, securing and cleaning the equipment, weather protection for the equipment and/or personnel, stopwatches, etc.

Tables 4, 5, and 6 show the direct costs of labor and materials summarized on the basis of route by city and methodology. Each table outlines the breakdown by the scope of the survey, hours and costs spent on surveyors, and other related direct costs required to conduct the survey. In order to specify the scope of a larger survey, a generic cost table is constructed in Table 7 based on the information assembled from the field test experience.

Generic Cost Table

Table 7 shows the costs of travel time data collection based on field surveys for ten route/days using three different methodologies. The generic route and data collection for the license plate method is defined for each route with 4 survey sites (3 route segments), 3 lane coverage on each site, and 12 sets of personnel/equipment as required. Data are collected for 8 hours a day, 4 hours in each peak hour traffic direction.

For the floating car method, a fleet of eight vehicles is scheduled for each 4-hour survey session, twice a day. With the assumption of an average speed of 30mph, it would take about 40 minutes for each 20-mile round trip. Each floating car is expected to complete 5 to 6 trips in a 4-hour survey session. Only one person who does both the driving and data collection is assigned to each vehicle for the cost calculation. If two persons are assigned to each floating car the direct costs would be doubled.

The cost structure is laid out for each of the three methodologies based on the direct labor estimate and the ratio of indirect to direct labor estimate . The parameters (number of sites and lanes, number of hours/lane/day, and $/hour) can be adjusted easily for a specific locality and survey requirements.

The equipment costs reflect those on the current market. The value of investment on equipment should always be considered with the equipment life and rate of utilization. The maintenance and repair costs for the video and computer equipment are relatively insignificant and thus not included in the cost table.

The cost for video license plate processing includes the use of a machine-vision system for automatic license plate reading vs. manual read. The costs of video license plate processing in Table 7 are drawn based on the crude estimates from the contract of automatic license plate processing and a research conducted by the University of Massachusetts at Amherst, involving manual reading and analysis of license plates from video tapes.[5] Since the automatic video license plate processing represents the first operational testing of machine vision technology in the U.S. for travel related data collection, the cost and performance efficiency is expected to improve as the methodology evolves.

The UTTSS is being developed at the Volpe Center for data processing and report generation. The system can be further developed and could be available for distribution under the FHWA plan.

Table 4. Direct Cost (per route) - Video License Plate

	Boston	Seattle	Lexington
Scope of Survey			
Number of Routes	5	5	5
Number of Days per Route	1-3	1-3	1-3
Number of Hours Surveyed per Route per Day	8-10	8	4 (1)
Number of Camera Sites per Route	4	3-4	4
Number of Lanes Covered per Site	2-3	2-4	2
Number of Surveyors per Site	1-2	2-3	2
Number of Surveyors per Route	7-8	8	8
Personnel			
Number of Paid Hours per Surveyor per Day	16	12.5	8
Personnel Cost per Surveyor per Day	$144	$100	$52-$128
Personnel Cost per Route per Day	$1008-$1152	$800	$768
Video Tapes			
Number of Hours of Video Tape per Site per Day	16-30	16-32	8
Number of Hours of Video Tape per Route per Day	64-120	72-96	32
Number of Hours of Video Tape	2	2	2
Number of Video Tapes per Route per Day	32-60	36-48	16
Cost per Video Tape	$12	$12	$12
Total Costs for Video Tapes per Route per Day	$376-$704	$612-$765	$192

Notes:
(1) 7-9am; 4-6 pm

Table 5. Direct Cost (per route) - Portable Computer License Plate

	Seattle (Palmtop)	Lexington (laptop)
Scope of Survey		
Number of Routes	5	1
Number of Days per Route	1-3	4
Number of Days Surveyed	7	4
Number of Hours Surveyed per Route per Day	4 or 8	2 or 4
Number of Sessions	12 (1)	7 (2)
Number of Sites per Route	3-4	4
Number of Lanes Covered per Site	2-4	2
Number of Surveyors per Site	2-4	2
Number of Surveyors per Route per Session	12	8
Personnel		
Number of Persons Participating in the Data Collection	12	22 (3)
Number of Paid Hours per Surveyor per Session	4	3.5 (4)
Personnel Cost per Surveyor per Session	$32	$23-$56 (5)
Personnel Cost per Route per Day	$768 (6)	$639 (7)

Notes:

(1) 6:30-10:30 am; 2:30-6:30pm - 4 Hour Sessions

(2) 7-9am; 11am-1pm; 4-6 pm - 2 Hour Sessions

(3) of the 22 persons who participated in various days and sessions, there were 12 full time and 4 part-time LFUCG employees and 6 students.

(4) 1 hour for set up; 2 hours for data collection; 1/2 hour for breakdown

(5) Hourly wage ranged from $6.50 to $16.00 per hour

(6) 8 hours per day

(7) 7 hours per day

Table 6. Direct Cost (per route) - Floating Car and Probe Vehicle

	Lexington (Floating Car)	Boston (Probe Vehicle)
Scope of Survey		
Number of Routes	2	5
Number of Days Surveyed per Route	1	5
Duration of survey (weeks)	2	3
Number of Hours Surveyed per Route per Day	4 (1)	6-12
Number of Trip Reports per Route per Day	34-41 (2)	10-90
Number of Data Collection Points per Route	14-15 (3)	6-12
Number of Lanes Covered per Segment	2	
Number of Surveyors per Car	2	1
Number of Cars/Number of Probes	3	150(4)
Number of Surveyors per Route	6	
Personnel - Floating Car		
Number of Paid Hours per Surveyor per Day	6	
Personnel Cost per Surveyor per Day	$96	
Personnel Cost per Route per Day	$576	
Personnel - Probe Vehicle		
Number of Data Collectors per Day		1-2
Number of Paid Hours per Probe Driver		$0
Number of Hours per Data Collector per Day		8-12
Personnel Cost per Data Collector per Day		$120-180(5)

Notes:

(1) 7-9 am; 4-6 pm

(2) 34 round trips were completed for Harrodsburg Road; 41 round trips for Richmond Road; only peak hour direction times were collected at each check point

(3) Four data collection locations were required to correspond with the video data collection points. The remaining data collection points were added at the discretion of the MPO. Richmond - 15 data collection points; Harrodsburg - 14 data collection points.

(4) Approximately 150 private and public probes were registered with the SmartRoute Systems at the time of the survey.

(5) A $5,000 contract was issued by the FHWA and the Volpe Center and paid to SmartRoute Systems to support the travel time data collection using their probe vehicles.

Table 7. Generic Cost Table

Generic Route: 10 miles, 3 lanes
3 segments/4 survey sites

Scope of Survey: 10 route-days
8 hours/day

	License Plate Matching - Video -	License Plate Matching - Portable Computer -	Floating Car
Personnel			
Number of Persons	8	12	8
Number of Paid Hours	12	8	8
$/Hour	$10	$10	$10
$/Day	$960	$960	$640
Total Direct Labor (10 days)	$9,600	$9,600	$6,400
Indirect Labor Ratio (field coordination, planning, training, raw data assembly)	1.80	0.50	0.20
Total Labor Cost	$26,880	$14,400	$7,680
Equipment and Supplies			
Sets of Equipment	12	12	8
$/Set	$3,000	$1,800	
Equipment Cost	$36,000	$21,600	- n/a -
Other Supplies	$5,760 ($12/video tape)		$4,800 ($.25/mile)
Total Equipment and Supplies	$41,760	$21,600	$4,800
Video License Plate Processing			
Number of Hours of Tapes	960		
Plate Reader:			
$/Hour of Tape	$40-60		
Total Cost	$48,000		
Manual Read:	20 hours/tape		
$/Tape	$200		
Total Cost	$96,000		
Data Processing and Report Generation	Software developed by the Volpe Center and FHWA		

STANDARDIZED DATA AND REPORT PROCESSING

Prior to the initiation of travel time surveys and field tests project, no standard data formats or processing procedures existed. In order to process data collected from a variety of data sources and types more efficiently and develop procedures to generate standard reports, a centralized database system, Urban Travel Time Survey System (UTTSS), was developed as a byproduct of the project. The system was designed with a unified database structure to process multiple data sources and data types of travel time and speed data along with roadway physical attributes and volume data. It was developed using the Paradox relational database system and its programming language, and it can run on a 486 desktop computer.

This section describes the database structure of the UTTSS and the key data processing steps of raw data assembly, video license plate processing, data loading and conversion, license plate matching, floating car/probe/AVI matching, and report generation. As a result of field tests of the six data collection methods in the three selected cities, a total of ten data sets were processed and analyzed in the database system.

Database Structure

The data structure in the system is comprised of: 1) main database files (license plate/floating car/probe/AVI bus records, loop detector data, route/segment physical attributes); 2) route/node files (used to define route/segments by route direction); and 3) a series of tables that describe the cities, routes, nodes, and methodologies, etc.

The main database contains the main body of data records. Each record in the main database contains two key data elements: vehicle ID and a time stamp, alongside variables of group data description (city, route, node, date, direction, lane number, and methodology). This database structure is applicable to all methodologies, with the exception of the loop detector data.

For the license plate method, a license plate number is the vehicle ID. For floating car, probe vehicle, or AVI method, a vehicle/bus or driver's ID is used as a key for linking all the information collected from separate locations and times in correspondence to a vehicle trip. A trip serial number is also included in the database if it is available for the floating car/probe/AVI method. Since a floating car or probe vehicle is usually captured in several trips during a survey session, it is easier to pull together all the information for one unique trip by selecting the vehicle ID/trip number.

The loop detector data and the physical attributes of routes/segments are treated as link data and stored in separate database files.

The loop detector files contain volume and lane occupancy data collected in the Seattle and Lexington loop detector systems. The data are accumulated every 15 minutes, 24 hours a day for the survey routes and dates.

The roadway attribute data are the measurements and any information that can be used to describe the characteristics of a route and segments. These include: route name, segment description (begin and end nodes), roadway type, land use along the route, length, number of lanes, HOV lanes, posted speed limit, number of entrances/exits within the segment, entrance/exit ramp volume, number of signalized intersections, AM peak volume, PM peak volume, noon volume, percentage trucks, and percentage cars.

Not all the roadway attributes were available at the time of the surveys. The list of data elements can be expanded and included in the standard route/segment description reports when the data become available. The route/segment length and volume from the loop detector table are used and analyzed with the travel time data in the data processing and reporting process.

Raw Data Assembly

During and after the field surveys, the MPOs and corresponding agencies compiled the raw data collected from the fields and sent them to the Volpe Center for subsequent data processing. The license plate video tapes were catalogued and shipped to the contractor - Computer Recognition Systems (CRS) for the video license plate processing using an automatic license plate reading system.

The participating agencies were also requested to send in any written logs (general weather and traffic conditions, accidents, exact survey start and break times, etc.) observed by the surveyors. Additional data forms were sent to the MPOs to collect detailed cost data and physical measurements for the surveyed routes and methodologies.

Video License Plate Processing

The video license plate processing was performed at the CRS facilities in England. The CRS License Plate Reading System (LPRS) is a machine vision system for automatic reading and processing the license plates of vehicles moving at high or low speeds (up to 100 mph). The CRS system was chosen as the testing machine vision system for the project. Other existing machine vision technologies with the potential to develop a system for reading license plates off of videotapes were also examined prior to the selection.

Each two-hour tape was processed with the system and digitized output was produced on a diskette file. Each license plate record contains a six-character license plate number, time stamp, date, site location ID, lane number, and direction. An example of license plate records is shown below. The data were loaded into the UTTSS for license plate matching and report processing.

Table 8. Output of License Plate Video Processing

Plate #	Time	Date	Site-Lane-Direction
116TJL	8:30:01	6/30	A3-1-NB
440WIY	8:30:13	6/30	A3-1-NB
671RVK	8:30:13	6/30	A3-1-NB
688NTR	8:30:15	6/30	A3-1-NB
025189	8:30:23	6/30	A3-1-NB
126TNX	8:30:28	6/30	A3-1-NB
387VEV	8:30:30	6/30	A3-1-NB
796SBZ	8:30:31	6/30	A3-1-NB

Data Loading and Conversion

Since the data mostly came in different formats, special procedures for data conversion and editing were required in the data loading process. Some data sets were received in written forms (floating car and probe vehicle method) therefore requiring the transfer of data into the database format. The license plate data from multiple sources also required extensive checking and correction due to data errors in file format (i.e., inconsistent license plate record format, site numbering, etc.)

Adjust the Time

As correct time is perhaps the most crucial element in a travel time study, the importance of this and procedures for synchronizing camera and computer clocks and personal watches were stressed repeatedly during the surveys. However, time errors were still found on numerous occasions. This often happens in large scale surveys involving multiple routes, days, personnel, and equipment sets.

Special effort was also taken in adjusting the start time on each two-hour video license plate file. The actual start time on each videotape was frequently off by a few seconds and up to a few minutes as the start time on each output file was set according to the start time written on the tape label. These errors usually happened when the tape was changed at each two-hour mark during a four-hour or six-hour video session. An editing and time correction step was inserted into the process by playing back the videotapes to locate the recorded voice time on tape mark, as well as checking any written logs with the start or break time information.

Delete False Records

After data are converted and loaded into the database system, a data screening step is applied to eliminate most bad records resulting from poor license plate reading.

Any 6-character license plate number identified with: a) any three consecutive identical numbers or characters (i.e., AAA@@@, @@@AAA, 333@@@, @@@999); or b) any combination of four or more of the characters (I,L,O,1,0), is automatically removed from the database. Those are the most common errors produced from poor license plate images (due to cracked characters, problems related to undesired contrast, focus, or sizing of the pictures, etc.).

License Plate Records by Site

Following the data loading step, a series of site status reports can be generated, at the user's option. These reports consist of number of license plate records by direction, site, hour, lane, or by individual performer (for laptop or palmtop method). The reports are grouped and produced by survey date and route.

By analyzing site specific data with a particular data source and methodology, an analyst could obtain a preliminary evaluation of the level of data acquisition by location, hourly distribution, and the surveyors' performance. Performance level at specific locations and hours could be detected early before an analysis is conducted. License plate matching rates and other parameters of various methods could be determined based on this information.

License Plate Matching

License plate matching is performed for license plates captured between an upstream location and a downstream location at any given route segment. The standard matching procedure is designed to perform license plate matching for each consecutive route segment on a route where data are collected. In license plate matching, the data collected from all lanes at the same location are combined for matching with the data collected at another location. The whole range of data collection during a survey session (2 to 6 hours) is processed, and the matching results are produced for each 30 minute time slice duration.

The system is designed to be fully automated and user-interacted. Options are provided to the user for selecting a particular data source/methodology for reviewing the data, conducting an analysis, or extracting a report. The user can select any given route(s), date(s), segment(s), hour(s), and lane(s) for license plate matching and reports. The user can also change the time slice value or the threshold speed limit for screening false matches, or can just follow routine selection procedures and the system will generate standard reports utilizing standard analysis procedures.

Combining All Lanes

License plate matching with combined lane traffic provides the best chance of plate matching between locations. However, this process may disregard any lane speed variation or lane changing behavior.

Since speed variation between lanes (HOV lanes, traffic management lanes), or lane changing behavior (merging or exiting traffic) is commonly seen at many highway locations, license plate matching based on selected or crossing lane traffic can be performed at the user's discretion. However, the matching results depend on an overall good sampling design that would bring sufficient sample rates captured at specific or all lanes of interest.

Full Time Range Matching

Standard license plate matching is designed to capture any and all matches during the entire duration of data collection up to the end of each survey day. For any license plate captured at an upstream location, it could result in no match to multiple matches of the plates captured at a downstream location. The program is intended to capture multiple matches over a large time span. The setback is, however, that the processing could take substantially large amount of time with a large data set.

In the current phase of field testing and methodology development, it is important to detect the propensity of a given methodology toward false plate matching. The more stringent matching procedure can be implemented when the performance of a methodology is more consistent. A procedure with a dynamic and narrower time range for license plate matching can be developed in the enhancement program in the UTTSS to improve the overall efficiency (i.e., reducing computer processing time) for license plate matching and processing.

30 Minute Time Slice

The 30 minute time slice is chosen as the default value in the standard program because 1) certain methodologies included in the field tests do not generate large samples for the 15 minute time slice, and 2) the range of the sample size of license plate methods is uncertain.

Interim File of Plate Matches

The plate matches are stored in an interim file before the report generating procedure is initiated. The elapsed time is calculated for each match, along with matched license plate number, times recorded at both locations, and the source ID's for the original data files where data are stored. The interim file can be reviewed in the system or printed as a list of records at the user's option. The information is useful for cross checking of matched plates with the original source data.

Elapsed Time Distribution

Based on the interim file of license plate matches, a table of elapsed time distribution is generated for each segment. Table 9 shows the frequency distribution of elapsed times in 10 minute increments by each 30 minute time slice based on a route segment of 93 Southeast Expressway in the Boston test.

The validity of a method can be discerned by looking at the elapsed time distribution. In a normal elapsed time distribution, the elapsed times tend to concentrate in one or two adjacent columns of elapsed time while the outliers fall outside the normal range. An example of wide distribution of multiple false matches produced from partial plate matching will be discussed in the section of comparison of methodologies.

Table 9. Elapsed Time Distribution Report

City: Boston State: MA Route: Route 93 S/SE Date: 7/13/93
Direction: N
Site 1: Boulevard Street Extension Site 2: Boston Street

Time	0-10	10-20	20-30	30-40	40-50	50-60	> 60 min.	Total
06:30AM - 07:00AM	2	123	0	1	0	0	7	133
07:00AM - 07:30AM	0	188	0	0	0	0	3	191
07:30AM - 08:00AM	0	105	0	0	1	0	1	107
08:00AM - 08:30AM	0	86	10	0	0	1	3	100
08:30AM - 09:00AM	0	56	62	0	1	0	0	119
09:00AM - 09:30AM	37	80	2	0	0	1	1	121
09:30AM - 10:00AM	102	0	1	0	0	0	1	104
10:00AM - 10:30AM	100	0	0	0	0	0	0	100
SubTotals:	241	638	75	1	2	2	16	975

Screening False Matches

The extreme outliers from false matching should be rejected and removed from the valid elapsed time sample set. The standard program set maximum (85 mph) and minimum (15 mph) speed limit as the threshold values for determining the invalid outliers. The maximum and minimum elapsed time is calculated from dividing segment distance by the threshold speed limits as the upper and lower bound of acceptable elapsed time. As the result of the screening procedure, an elapsed time outside the boundary of elapsed time is rejected from the data set.

Outliers usually result from one of three circumstances: 1) an illegal match from two different vehicle plates captured as two identical plates (or partial plates); 2) a real vehicle travelling at an unusual speed (either very fast or slow); or 3) in a very rare event, a vehicle left (or parked on the roadside) and later returned to the segment and captured as part of the two broken trips. In any of the three events, the majority of real or unreal outliers would be eliminated from the database of valid license plate matches.

The maximum or minimum speed limit for the threshold elapsed times can be changed to reflect certain conditions in any location or time. In a highly congested corridor where traffic is constantly stalled and the average speed approaches or drops below 15 mph, the 15 mph minimum speed limit should be reduced or dropped entirely.

Segment Status and Performance Measurements

The results from standard license plate matching are produced in the segment status report for each segment. Table 10 shows the segment status report of the same sample in Table 9 during the morning traffic in the 5 mile stretch of 93 Southeast Expressway in Boston.

Table 10. Segment Status Report

Maximum speed limit 85 mhp <==> Minimum speed limit 15mph

City: Boston   Route: Route 93 S/SE   Date: 7/13/93
Direction: N
Segment: 2 of 3   Boulevard Street Extension   to Boston Street
Distance: 5.16 mi   Posted Speed: 55 mph   Average Speed: 25.56 mph

Time	# of Plates Site 1	# of Plates Site 2	Plate Matches	Average Elapsed Time	Stand. Dev.	Maximum Elapsed Time	Minimum Elapsed Time	Average Speed	Vol	Elapsed Times Outside of +/- 2 Std
06:30 - 07:00AM	747	693	125	00:11:55	00:01:19	00:19:43	00:09:46	25.98		5
07:00 - 07:30AM	1,057	1,043	188	00:12:55	00:01:05	00:16:01	00:11:16	23.96		9
07:30 - 08:00AM	1,163	1,246	105	00:14:42	00:01:29	00:18:23	00:12:33	21.05		4
08:00 - 08:30AM	1,057	1,211	92	00:16:49	00:01:36	00:20:28	00:13:01	18.41		7
08:30 - 09:00AM	1,044	1,062	64	00:18:50	00:01:09	00:20:37	00:16:08	16.44		2
09:00 - 09:30AM	1,120	1,374	116	00:11:43	00:02:45	00:17:46	00:07:05	26.41		4
09:30 - 10:00AM	1,035	1,224	102	00:06:26	00:01:26	00:08:45	00:03:47	48.06		0
10:00 - 10:30AM	932	1,081	99	00:06:00	00:01:22	00:08:23	00:03:42	51.60		0

The basic statistics in terms of number of matches and number of plates recorded at either site are produced for each time slice. The remaining columns show the average elapsed time and speed calculated from the sample set in each time slice. The maximum and minimum elapsed time, and standard deviation show the range of elapsed times and normality within each 30 minute time slice. The volume counts are included if the data are available from loop detectors. The last column shows the number of elapsed times falling outside the plus and minus two standard deviations from the mean elapsed time.

Floating Car/Probe/AVI Matching

The data from the floating car, probe vehicle, or AVI method are stored in the same database structure as the license plate method. A special report is generated as the list of trip records during a survey period for any of the three methods. There are usually more observation points included in a floating car or probe vehicle data collection, and all the location codes and times are reported in the trip records.

The standard reports utilized for license plate matching can also be applied to produce the elapsed times, average speeds, and segment statistics for the predefined route/segments based on a floating car or probe vehicle method. Multiple matches resulting from the same vehicle ID in separate trips are usually detected and eliminated from the real matches when the screening procedure (using the maximum and minimum speed rule) is applied.

Report Generation

Standard reports for a methodology can be selected and produced at the user's option. The reports are:

- Site Status Reports
- Elapsed Time Distribution Report
- Segment Status Report - average elapsed times and speeds; and statistics
- Route Status Report - average elapsed times and speeds
- Route/Segment Description Report
- Floating Car/Probe/AVI Report

Tables 9 and 10 show the elapsed time distribution and segment status report for one segment of the Southeast Expressway in Boston. Table 11 shows the entire route status report of average elapsed times and speeds of all three route segments.

Table 11. Route Status Report

City: Boston
Direction: N
Route: Route 93 S/SE
Date: 7/13/93

Segment:	1 of 3	Bates Avenue	to Boulevard Street Extension	.74 mi
	2 of 3	Boulevard Street Extension	to Boston Street	5.16 mi
	3 of 3	Boston Street	to Exit 22 - Russia Wharf/Northern Avenue	2.25 mi
			Route Total:	8.15 mi

	Segment 1		Segment 2		Segment 3		Route	
Time	Average Elapsed Time	Average Speed	Average Elapsed Time	Average Speed	Average Elapsed Time	Average Speed	Average Elapsed Time	Average Speed
06:30AM - 07:00AM	00:01:42	26.19mph	00:11:55	25.98mph	00:02:13	61.02mph	00:15:49	30.90mph
07:00AM - 07:30AM	00:01:40	26.52mph	00:12:55	23.96mph	00:02:15	60.21mph	00:16:50	29.04mph
07:30AM - 08:00AM	00:01:39	26.91mph	00:14:42	21.05mph	00:02:13	60.88mph	00:18:34	26.33mph
08:00AM - 08:30AM	00:01:40	26.63mph	00:16:49	18.41mph	00:03:01	44.74mph	00:21:30	22.74mph
08:30AM - 09:00AM	00:02:05	21.33mph	00:18:50	16.44mph	00:04:44	28.51mph	00:25:39	19.06mph
09:00AM - 09:30AM	00:01:14	35.84mph	00:11:43	26.41mph	00:04:00	33.70mph	00:16:58	28.82mph
09:30AM - 10:00AM	00:01:12	36.93mph	00:06:26	48.06mph	00:03:44	36.12mph	00:11:23	42.96mph
10:00AM - 10:30AM	00:01:14	35.98mph	00:06:00	51.60mph	00:03:01	44.65mph	00:10:15	47.67mph

ANALYSIS OF DATA

The analysis of travel time and speed data is conducted in two ways: 1) level of performance by methodology in terms of sample size and data quality; and 2) statistical analysis of travel time and speed distribution with respect to sample size, speed level, time period, and the relationship with volume. Since the results of field test data collection are not consistent across the routes by methodology, the analysis of data in this section focuses on the results of selected routes and segments. The following section summarizes the comparative results of alternative methods.

Tables 9 and 10 show the standard reports of elapsed time distribution and segment statistics for the northbound traffic on the middle segment of the Southeast Expressway in Boston. Table 11 is the standard route status report in which the three route segments are summarized by the average times and speeds from the segment status reports. Tables 12, 13, and 14 are analyses of travel time data extended from those in Tables 9 and 10.

93 Southeast Expressway, Boston

The 93 Southeast Expressway/Central Artery route is an 8 mile stretch between Dorchester, the southern boundary of Boston and downtown. This is one of the most congested corridors in Boston carrying a heavy daily traffic volume into and out of the downtown area. The route also connects downtown to Logan Airport through the harbor tunnel. The 7.7 billion dollar Central Artery and Third Harbor Tunnel project currently under development will move the downtown portion of the expressway underground and should ease of some of the heavy traffic problems.

The segment analyzed in this section is two miles south of the downtown area between Boston Street and the Boulevard Street Extension, a 5.16 mile stretch. There are three lanes on the expressway in each direction, with a posted speed limit of 55 mph. There are four entrance and three exit ramps within the segment in the northbound direction.

Sample Rate

In Table 10 the standard segment status report, the first three columns show the number of valid plate matches and number of plates captured at the two observation sites of the segment. Table 12 shows the same matching statistics plus the original total and number of deleted matches due to the 15 mph and 85 mph speed rules. The last column shows the percent matching rates of the captured license plates at the upstream observation location. Any match with an elapsed time falling outside the minimum and maximum elapsed times are excluded from the sample. For this segment, an average of 680 license plates per hour per lane, 2,040 plates per hour per site, were captured at Boulevard Street from the license plate reader. An average of 12% of the captured plates at the Boulevard Street overpass found a valid match at Boston Street. An average of 122 matches in each 30 minute time slice is obtained during the four hour morning survey. This level of sample acquisition is reasonably good considering that a significant amount of traffic had entered or exited between the two locations.

The column showing the number of records deleted by the 15 and 85 mph speed rules is a prerequisite step in the standard program to remove extreme outliers which mostly resulted from false matching.

Table 12. Number and Percent of Plate Matching

City: Boston
Direction: N
Segment: 2 of 3
Distance: 5.16 mi

Route: Route 93 S/SE
Date: 7/13/93
Boulevard Street Extension to Boston Street
Posted Speed: 55 mph Average Speed: 25.56 mph

Time	# of Plates Site 1	# of Plates Site 2	Qualified Plate Matches	# of Elapsed Times outside of +/- 2 Std	# of Matches Deleted by the 15/85 mph Rule	Original Plate Matches	% of Matching
06:30 - 07:00AM	747	693	125	5	8	133	18%
07:00 - 07:30AM	1,057	1,043	188	9	3	191	18%
07:30 - 08:00AM	1,163	1,246	105	4	2	107	9%
08:00 - 08:30AM	1,057	1,211	92	7	8	100	9%
08:30 - 09:00AM	1,044	1,062	64	2	55	119	11%
09:00 - 09:30AM	1,120	1,374	116	4	5	121	11%
09:30 - 10:00AM	1,035	1,224	102	0	2	104	10%
10:00 - 10:30AM	932	1,081	99	0	1	100	11%
Total	8,155	8,934	891	31	84	975	12%

Change in Minimum Speed Rule

The number of deleted records are relatively small compared to the remaining valid matches except when traffic approached near 15 mph during the peak between 8:30 and 9:00am. 55 records in this half hour time period were rejected largely due to the 15 mph minimum speed rule. By replacing the 15 mph minimum speed rule with the 30 minute maximum elapsed time (i.e., 10.3 mph), the rerun of the segment status report is shown in Table 13.

Table 13. 30 Minute Segment Status Report - with New Speed Rule

Maximum speed limit 85 mph <==> Minimum speed limit 10.3 mph
(Maximum elapsed time 30 minutes)

City: Boston
Direction: N
Segment: 2 of 3
Distance: 5.16 mi

Route: Route 93 S/SE
Date: 7/13/93
Boulevard Street Extension to Boston Street
Posted Speed: 55 mph Average Speed: 24.32 mph

Time	# of Plates Site 1	# of Plates Site 2	Plate Matches	Average Elapsed Time	Stand. Dev.	Maximum Elapsed Time	Minimum Elapsed Time	Average Speed	Vol	Elapsed Times Outside of +/- 2 Std
06:30 - 07:00AM	747	693	125	00:11:55	00:01:19	00:19:43	00:09:46	25.98		5
07:00 - 07:30AM	1,057	1,043	188	00:12:55	00:01:05	00:16:01	00:11:16	23.96		9
07:30 - 08:00AM	1,163	1,246	105	00:14:42	00:01:29	00:18:23	00:12:33	21.05		4
08:00 - 08:30AM	1,057	1,211	96	00:17:00	00:01:48	00:21:43	00:13:01	18.21		5
08:30 - 09:00AM	1,044	1,062	118	00:20:11	00:01:47	00:24:00	00:16:08	15.33		5
09:00 - 09:30AM	1,120	1,374	118	00:11:54	00:03:03	00:22:57	00:07:05	26.01		2
09:30 - 10:00AM	1,035	1,224	103	00:06:35	00:01:59	00:20:41	00:03:47	47.05		1
10:00 - 10:30AM	932	1,081	99	00:06:00	00:01:22	00:08:23	00:03:42	51.60		0

In comparing Table 13 with Table 10, 54 more records (an increase from 64 to 118) were gained in the 8:30 to 9:00am time slice after the 15 mph rule was dropped. The average speed is reduced from 16.44 mph to 15.33 mph. Three other adjacent time slices were affected only slightly (increased additional matches by 1, 2, and 4 each), while the other four time slices were not affected. The change in the speed limit rule has minimum impact on the average elapsed time and speed calculation on this segment because the matches rejected by the speed rule are all close to the 15 mph speed limit. The effect should be much more severe if the average speed is far below the 15 mph limit, that most of the actual matches would be rejected by the rule.

The Mean and Variance of Travel Time and Speed

Overall, samples of valid plate matches in all eight time slices in Table 13 are statistically sufficient. Within each time slice, the standard deviation (root mean square error) is fairly consistent except for the 9:00-9:30am time slice. The average elapsed time for this 5.16 mile segment ranges from 6 minutes (10:00-10:30am) to 20 minutes (8:30-9:00am) in each time slice. The average elapsed time for the entire four hour period is 12 minutes and 44 seconds with an average standard deviation of 1 minute and 44 seconds from the eight time slices. The average speed for the four hour period is 24.32 mph.

For the 952 matches, the maximum elapsed time is 24 minutes and the minimum is 3 minutes 42 seconds. The two extreme values happened to be found in the two time slices with the highest and lowest elapsed time. Although it is probable that there are still false matches left in the sample, the effect could be negligible because there are few outliers shown in Table 9 in all columns with elapsed time less than 60 minutes. The spread between the maximum and minimum elapsed times within each 30 minute time slice ranges from 5 minutes to 17 minutes. This is primarily due to the steadiness or the dynamics of the flow patterns during each half hour span. The spread tends to be greater in the slice near the beginning or the tail of a peak traffic period.

15 Minute Time Slice

One can further investigate the effect of elapsed times, speeds, and flow patterns by changing the time slice to 15 minutes. Table 14 is generated with the 15 minute time slice value and the new speed criteria (the 30 minute maximum elapsed time instead of 15 mph minimum speed).

In comparing Tables 13 and 14, the average elapsed times and speeds have not changed significantly between the corresponding 15 minute and 30 minute slices. However, the spread between the maximum and minimum elapsed times in most of the 15 minute slices is reduced in comparison with the spread in the 30 minute slices. They range between 3 to 5 minutes in most of the time slices (11 out of 16) with a few exceptions. The average standard deviation of the sixteen 15 minute time slices is reduced to 1 minute and 17 seconds compared to 1 minute and 44 seconds calculated from the eight 30 minute slices.

The largest average elapsed time is now 21 minutes and 29 seconds with the average speed of 14.41 mph in the 8:30-8:45am slice, compared to the largest elapsed time as 20 minutes and 11 seconds and 15.33 mph in the 8:30-9:00am slice. The last and additional time slice between 10:30 and 10:45am is shown with an average elapsed time of 5 minutes and 23 seconds with a speed of 57.48 mph based on 5 matches captured after 10:30am.

Table 14. 15 Minute Segment Status Report - with New Speed Rule

Maximum speed limit 85 mph <==> Minimum speed limit 10.3 mph
(Maximum elapsed time 30 minutes)

City: Boston
Route: Route 93 S/SE
Date: 7/13/93
Direction: N
Segment: 2 of 3 Boulevard Street Extension to Boston Street
Distance: 5.16 mi
Posted Speed: 55 mph
Average Speed: 24.32 mph

Time	# of Plates Site 1	# of Plates Site 2	Plate Matches	Average Elapsed Time	Stand. Dev.	Maximum Elapsed Time	Minimum Elapsed Time	Average Speed	Vol	Elapsed Times Outside of +/- 2 Std
06:30 - 06:45AM	363	145	61	00:11:15	00:00:58	00:13:38	00:09:46	27.51		3
06:45 - 07:00AM	383	547	64	00:12:33	00:01:17	00:19:43	00:11:08	24.68		1
07:00 - 07:15AM	519	477	101	00:12:39	00:00:58	00:15:07	00:11:27	24.49		8
07:15 - 07:30AM	538	566	87	00:13:15	00:01:08	00:16:01	00:11:16	23.37		6
07:30 - 07:45AM	635	679	78	00:14:06	00:01:05	00:16:51	00:12:33	21.97		2
07:45 - 08:00AM	527	567	27	00:16:28	00:01:00	00:18:23	00:14:46	18.80		0
08:00 - 08:15AM	536	485	45	00:16:04	00:00:54	00:18:22	00:14:42	19.28		3
08:15 - 08:30AM	520	725	51	00:17:50	00:01:58	00:21:43	00:13:01	17.36		1
08:30 - 08:45AM	480	517	60	00:21:29	00:01:08	00:24:00	00:18:25	14.41		4
08:45 - 09:00AM	563	545	58	00:18:51	00:01:17	00:21:46	00:16:08	16.42		2
09:00 - 09:15AM	540	626	53	00:14:10	00:01:57	00:17:46	00:09:51	21.86		1
09:15 - 09:30AM	579	747	65	00:10:04	00:02:31	00:22:57	00:07:05	30.76		2
09:30 - 09:45AM	570	676	54	00:06:58	00:01:19	00:08:45	00:04:20	44.46		0
09:45 - 10:00AM	464	548	49	00:06:09	00:02:28	00:20:41	00:03:47	50.28		1
10:00 - 10:15AM	495	547	56	00:05:51	00:01:21	00:08:23	00:03:42	52.86		0
10:15 - 10:30AM	437	534	43	00:06:11	00:01:22	00:08:22	00:03:45	50.04		0
10:30 - 10:45AM	37	380	5	00:05:23	00:01:35	00:08:29	00:04:03	57.48		0

Develop Congestion Measures

Based on the information revealed in Table 14 (which is in concert with Table 13) a minimum acceptable speed of 30 mph is used to define congestion during the rush hours, the level of congestion on this route segment can be described as:

1. Duration of Congestion - Congestion started at or before 6:30am at Boulevard Street Extension and lasting three hours until around 9:30am for the traffic in this segment up to Boston Street.

2. Intensity of Congestion - The average elapsed times for the peak hour between 8:00 and 9:00am is 18 minutes and 33 seconds (or an average speed of 16.68 mph). The peak/off-peak ratio of average elapsed time is greater than 3.0 if the 6 minute elapsed time (51.6 mph) in the 10:00 - 10:30am slice is used as the normal elapsed time.

The aggregate travel time or delay time (defined as <u>excess delay time which exceeds the maximum acceptable travel time</u>), as well as other system measures such as VMT (vehicle miles travelled) and VHT (vehicle hours travelled), can also be measured if adequate volume data are available.

COMPARISON OF METHODOLOGIES

This section focuses on the comparison of alternative data collection methods for selected routes/segments where multiple methodologies were tested. The sample size and comparative results are listed in the tables for the tested route/segments. They are followed by analyses.

Richmond Road, Lexington

Richmond Road is a 3 mile arterial street from Downtown Lexington to the southeast suburb, 2 lanes in each direction. This is a boulevard street with extended tree lines in the middle. Table 15 presents the results from two morning surveys in the second segment. This is a 1.35 mile segment with eight signalized intersections. Peak hour timing plans were implemented during the morning hours between 7:00 to 9:00am.

Methodologies Tested

- License Plate Matching with Video
- License Plate Matching with Laptop Computer
- Floating Car
- Loop Detector

Survey Conditions

September 21 - dark in the morning until about 7:25am, mostly cloudy; light to moderate traffic.

September 23 - dark until 7:27am, light rain turned to cloudy; light to moderate traffic.

Analysis

Video License Plate

- ineffective during the first half hour due to darkness;
- sample rate low but generally sufficient and accurate (elapsed time distribution, Table 16);
- percent or volume of traffic captured at the first site but exited before the second site could be considerably high on this signalized arterial street;
- effects due to darkness and roadside license plate videotaping (rather than from bridge locations) need to be improved.

Laptop License Plate

- higher sample rates than video method, effective on roadside arterial street license plate data entry;
- moderate distribution of false matches (elapsed time > 10 minutes, Table 16);
- average elapsed times and standard deviations are comparable to but greater than those from the video plate matches; at least 13 outliers are still retained in sample set due to the maximum elapsed time rule (20 minutes maximum elapsed time) applied.

Table 15. Travel Time Surveys, Richmond Road, Lexington, Kentucky

Survey Date: Tuesday, 9/21/93

Segment 2 of 3 Patchen Road (Conrad Chevrolet) to Shriners Children's Hospital Distance: 1.35 mi Direction: W
85 mph maximum speed 20 min. (4 mph minimum speed) maximum time

	Video License Plate			Laptop License Plate			Floating Car			Loop
Time	# of Plate Matches	Ave. Elap. Time	Std Dev.	# of Plate Matches	Ave. Elap. Time	Std Dev.	# of Obser-vations	Ave. Elap. Time	Std Dev.	Vol
7:00-7:30AM	1	03:16	0:00	28	04:32	3:49	7	02:19	0:11	894
7:30-8:00AM	22	03:11	1:12	88	03:45	1:35	5	03:33	0:56	1,227
8:00-8:30AM	47	03:15	1:27	105	03:32	3:33	5	02:06	0:13	866
8:30-9:00AM	38	03:07	0:57	102	02:38	1:26	6	02:17	0:06	753

Survey Date: Thursday, 9/23/93

Segment 2 of 3 Patchen Road (Conrad Chevrolet) to Shriners Children's Hospital Distance: 1.35 mi Direction: W

	Video License Plate			Laptop License Plate			Floating Car			Loop
Time	# of Plate Matches	Ave. Elap. Time	Std Dev.	# of Plate Matches	Ave. Elap. Time	Std Dev.	# of Obser-vations	Ave. Elap. Time	Std Dev.	Vol
7:00-7:30AM	0		0:00	65	03:31	3:08				816
7:30-8:00AM	36	03:36	1:29	122	04:05	2:53				1,149
8:00-8:30AM	26	03:00	2:05	105	02:53	1:51				896
8:30-9:00AM	13	02:15	0:13	87	02:26	1:28				695

Floating Car

- sample is derived from continuous runs of the three LFUCG floating car team;
- the average times are significantly less than the license plate results in 3 of the 4 half hour time slices with the exception in the peak period (7:30-8:00am);
- the standard deviation is consistently small due to the cluster of samples (2 minutes apart from each vehicle), representing one fifth of each 20 minute round trip cycle captured by the 3 floating cars;
- suggests the bias caused by unbalanced and insufficient sampling design.

Loop Volume

- is comparable between the two days and correlated well with the average time and speed data.

Table 16. Comparison of Elapsed Time Distribution

Richmond Road, Lexington, KY
- Video License Plate - 9/21/93

Segment 2 of 3 Patchen Road (Conrad Chevrolet) to Shriners Children's Hospital Distance: 1.35 mi Direction: W

Time	0-10 min.	10-20	20-30	30-40	40-50	50-60	> 60 min.	Total
7:00-7:30AM	1	0	0	0	0	0	0	1
7:30-8:00AM	22	0	0	1	0	0	0	23
8:00-8:30AM	46	1	0	0	0	0	0	47
8:30-9:00AM	38	0	0	0	0	0	0	38
Subtotal	107	1	0	1	0	0	0	109

Richmond Road, Lexington, KY
- Laptop License Plate - 9/21/93

Segment 2 of 3 Patchen Road (Conrad Chevrolet) to Shriners Children's Hospital Distance: 1.35 mi Direction: W

Time	0-10 min.	10-20	20-30	30-40	40-50	50-60	> 60 min.	Total
7:00-7:30AM	26	2	1	0	2	0	3	34
7:30-8:00AM	87	2	1	3	1	2	3	99
8:00-8:30AM	97	8	2	6	1	0	0	114
8:30-9:00AM	101	1	0	0	0	0	0	102
Subtotal	311	13	4	9	4	2	6	349

All four methodologies tested indicate a consistent traffic pattern which peaks in the 7:30-8:00am time slice. The traffic condition is generally moderate for the small arterial system. The level of data collection for the video and laptop license plate methods are both sufficient and reasonably good. The performance of laptop method can be improved by selecting a smaller elapsed time range for screening matched data (e.g. reducing the maximum elapsed time from 20 minutes to 10 minutes). For the floating car method, a more evenly distributed sample design (e.g., 5 minute separation from each car) with a few more samples are needed.

I-5 North, Seattle

I-5 is a major interstate highway going through Downtown Seattle from north to south. The test was conducted on a 4 mile stretch, 7 miles north of Downtown Seattle. There are 4 lanes including one HOV lane in each direction. This is also a test site with extensive loop detectors and 10 AVI stations. The AVI project included 49 AVI buses, each equipped with a hockey puck size transponder, running on HOV lanes during the commuting hours. The bus ID (hockey puck number) and time were recorded on the tape stored in the cabinets near the loop stations every time the bus traversed the locations.

Methodologies Tested

- License Plate Matching with Video
- License Plate Matching with Palmtop Computer
- AVI Buses
- Loop Detector

Survey Conditions

August 4 - sunny clear sky, a 12 car accident occurred near 117th Street site at 7:50am, traffic back up; cleared around 8:45am, traffic slowly getting back to normal.

General Comments

The Seattle tests were conducted on five routes, over seven days, and completed within a 14 day period. More than 20 surveyors, mostly hired through a temporary employment agency, were involved in the survey. Probably due to the strenuous schedule and the intensity of data collection, the performance level among individual surveyors was largely inconsistent, especially for the palmtop method. However, the largest volume of data in the field tests was collected in the Seattle surveys, including some very interesting findings.

Analysis of Video License Plate and AVI Methods

Table 17 shows the results from the morning surveys comparing the video license plate and AVI methods. The segment selected for AVI between 185th and 120th Street (3.57 miles) is not identical, but is comparable to the two segments on I-5 North between 185th and 117th Street (3.94 miles). The average speed of the HOV lane AVI buses is used to compare with the average traffic.

An interesting finding from the table appears to be the effect of the 12 car accident near 117th Street between 7:50-8:45am. The number of the resulting matches were substantially reduced since the incident but the average elapsed times and speeds were captured effectively during and following the incident. In the 8:00-8:30am time slice before the accident was cleared, the average elapsed time for the 4 mile route increased from the norm of 4.5 minutes to 44 minutes.

For the AVI buses, they travelled consistently from 5:30am until after 7:30am with an average speed of 58 mph. The average speed from the video license plate matching before 7:30am was 51 mph. It should be noted, however, that the clocks used between the two sources might not be identical.

Table 17. Travel Time Surveys, I-5 North, Seattle, Washington

Survey Date: Wednesday, 8/4/93

Video Route Segment:
Segment 1 of 2 NE 185th Street to NE 145th Street Distance: 2.14 mi Direction: S
Segment 2 of 2 NE 145th Street to NE 117th Street Distance: 1.80 mi Direction: S

AVI Route Segment:
Station 1: NE 185th Street Station 2: NE 120th Street Distance: 3.57 mi Direction: S

85 mph maximum speed 60 maximum elapsed time (to capture the effect of non-recurring congestion)

	Video License Plate								AVI		
	Segment 1			Segment 2			Route		AVI Segment		
Time	# of Matches	Ave. Elap. Time	Ave. Speed	# of Matches	Ave. Elap. Time	Ave. Speed	Ave. Elap. Time	Ave. Speed	# of Matches	Ave. Elap. Time	Ave. Speed
5:30-6:00AM									1	3:51	55.64
6:00-6:30AM									5	3:42	57.79
6:30-7:00AM	156	3:11	40.28	119	1:23	78.15	4:34	51.73	8	3:38	58.85
7:00-7:30AM	112	3:12	40.04	98	1:26	75.27	4:38	50.93	5	3:49	56.22
7:30-8:00AM	87	4:09	30.92	131	9:03	11.94	13:12	17.92	4	9:03	23.68
8:00-8:30AM	22	20:12	6.35	97	23:35	4.58	43:48	5.40			
8:30-9:00AM	12	12:54	9.96	41	5:21	20.18	18:15	12.96			
9:00-9:30AM	36	5:18	24.26	58	1:49	59.23	7:07	33.22			
9:00-10:00AM	54	5:14	24.53	40	2:13	48.63	7:27	31.71			
10:00-10:30AM	55	4:35	27.99	38	1:46	61.04	6:21	37.19			

According to the Washington State Transportation Center (TRAC) which provided the AVI data, the station clocks used for the AVI system have a drift rate ranging from .5 seconds to 2 seconds a day.

Analysis with the Palmtop Data

The 4-character (3 numbers plus 1 character) license plate matching with the palmtop computer proved unsuccessful in Seattle. Over 7 days, 12 four-hour sessions on 5 routes, were scheduled and performed using the plamtop computer data collection method with a 12 person crew. Despite the fact that a large number of license plate records were collected and a substantial effort was paid to data editing and corrections, the results from the 4-character license plate matching show consistent problems with the high degree of multiple false matches.

Table 18 shows the 10 minute elapsed time distribution with the palmtop method for the southbound morning traffic on Segment 1 of I-5 North. Based on the elapsed time distribution in the two time slices (6:30-7:00am, 7:00-7:30am) before the accident, only 8 matches in each of the two slices are obtained in the column with elapsed time less than 10 minutes, compared to a total of 173 matches in the hour. The valid matches can be even fewer because the average elapsed time in the two time slices for the segment is 3 minutes (derived from 268 matches from the video license plate matching).

In general, the low number of matches resulting from palmtop computers is due to the low plate capturing rates in high speed lanes of traffic and the distance from the location of data collectors. These factors impede data collection where sites are over high speed lanes from a typically high overhung bridge. The relatively large number of false matches across all the columns in the elapsed time distribution are common results in all route segments in the Seattle tests using the palmtop method. The problems were found in most of the license plates captured that the fourth character appeared to be always one of the first six letters from A to F. Followed by inquiries with the TRAC personnel and further investigation with the Washington license plates, it was learned that the majority of the plates were issued since about 1985 with the new design (3 numbers, a space, and 3 letters) for the Washington State centennial in 1986. The Washington State Department of Licensing is making the plates in sequential alphabetical order, and at the time of the survey during 1993, was just starting to hand out plates with the letter F. The Washington State DOT has since decided to abandon the license plate matching process with the 4-character matching for collecting routine travel time data.[6] They also decided to wait for more automated technologies to become operational.

Table 18. Elapsed Time Distribution - Palmtop License Plate

I-5 North, Seattle, WA
- Palmtop License Plate -
8/4/93

Segment 1 of 2 NE 185th Street to NE 145th Street Distance: 2.14 mi Direction: S

Time	0-10 min.	10-20	20-30	30-40	40-50	50-60	> 60 min.	Total
6:30-7:00AM	8	3	8	9	8	7	62	105
7:00-7:30AM	8	10	6	2	1	5	36	68
7:30-8:00AM	7	2	2	3	3	6	26	49
8:00-8:30AM	3	5	15	8	2	1	18	52
8:30-9:00AM	4	3	3	1	3	4	13	31
9:00-9:30AM	4	3	1	0	4	6	3	21
9:30-10:00AM	7	4	4	2	0	0	0	17
10:00-10:30AM	4	1	0	0	0	0	0	5
Subtotal	45	31	39	25	21	29	158	348

CONCLUSIONS AND RECOMMENDATIONS

The knowledge and experience gained from designing and conducting a series of travel time survey field tests, as well as the collection, processing, and analysis of data, have been tremendous. A broad perspective of the strengths and weaknesses of a range of data collection methods was provided by the field experience, as were issues related to the multiple steps of data processing and special handling of data problems. Those are the challenging tasks which confront today's practice and use in travel data collection.

The methodologies tested included data downloading and conversion from the existing infrastructure (loop and AVI data) and extensive data collection and processing involving existing and new methodologies (license plate matching with video or portable computer, automatic license plate reading with a machine vision system, floating car, and probe vehicle data collection). For some of those tested methodologies, survey procedures were developed during the surveys. There is certainly room for improvement in the consistency and quality of data collection with each methodology. It is, however, promising that results on many routes and segments have generated meaningful statistics and sufficient samples which can describe the dynamics of travel times and traffic congestion very effectively.

The cost to collect travel time data is primarily driven by the level and intensity of data requirements, despite the variations in the costs involved with different methodologies and equipment. Cost efficiency could be improved substantially by certain methodologies with the increased performance of data sample and consistency of data quality. In conclusion, the choice of the most effective way to collect and utilize travel time data should be determined based on 1) a well-designed survey plan which defines the scope and level of data requirements; 2) a well-defined (standardized) survey procedure, coupled with a standardized data processing and analysis process; and 3) the selection of suitable data collection method(s) that is cost effective and meets the data requirements.

What is the right level of data requirements for travel time data collection? In travel time data collection, the level of data requirements should be addressed, more specifically, by parameters such as: network coverage and route selection, number of days, hours, and frequency of data collection in respect to a specific urban area type and a certain level of congestion. The criteria for choosing the level of data collection should not only be determined by the legislative requirements (e.g., the 1990 Clean Air Act Amendment (CAAA) and the 1991 ISTEA), but more importantly, should be driven by the range of local data needs for traffic monitoring, congestion management, and impact analyses of various transportation programs and activities.

Sampling design and sample requirements are again the fundamental questions to be addressed. The sample size collected in many routes/segments in the field tests surpassed the minimum sample required for the analysis of travel time and speed variation. There is certainly a need in future research, perhaps through the data collected from the field tests, to develop a standard for sample requirements (i.e., minimum or optimal sample size for a roadway type) for travel time data collection.

Why are standard survey procedures with standardized data processing important? Standardized survey procedures (e.g., forms, synchronized clocks, labeling and cataloguing, survey logs, data formats, etc.) are crucial for standardized data processing. They assure the overall quality of data collection. Data processing and analysis can be more costly and time consuming than data collection, especially if data are collected inconsistently with the data formats and organization required with a large volume of data collection.

The standardized data processing and reporting system (UTTSS) has been developed as a byproduct of the project and is designed to process multiple data sources and data types, with a unified database structure. Standardized reports can be generated with the internal and external data (route segment description, distance, link volume, etc.) stored in the database system. With the standardized data formats and data processing procedures, the information processing and reporting for travel time and speed data will be more efficient. The standardized and consistent database and report can also provide the basis for trend analysis and intercity comparison. There is virtually no limitation on a city in the selection of any methodology and collection of any amount of data to process the information effectively with the system using a state of the art desktop computer (i.e., a 486, 66 megahertz, or up).

How to select an effective methodology? The selection of a methodology depends on the level of data requirements and the performance/effectiveness of the methodology. The results of the field tests and the preliminary evaluation of the methodologies demonstrate there is no single methodology that is deemed perfect for any city type or roadway condition. A floating car test is still easy to perform and could be suitable for a small city network with a good survey and sample design. License plate matching (either video or portable computer) shows promising results, but not without some flaws in achieving a larger sample size. Most of the errors due to partial plate or false plate matching could be screened out and removed from the valid sample sets with a carefully designed data screening procedure and analysis of license plate characters. Video license plate matching offers a higher level of accuracy with full plate matching, but is still relatively more expensive ($ per plate match) and could take more time for video license plate processing. The advantage of the video method is the creation of backup video tapes which contain the original records of vehicle plates as well as the traffic scenes during the surveys which allow additional analyses using the video data (i.e., vehicle counts, mix, density, etc.). The field tests proved the concept using the license plate (or a similar approach) as a valid method in capturing the continuous and dynamic travel time data collection of vehicle flows beyond a floating car method. The AVI buses in Seattle and loop detector in Lexington provided fairly consistent and reasonable data. Either methodology depends on the existing roadway infrastructure. The AVI data covered only a small route segment in Seattle and a limited number of samples.

In summary, continuous and consistent travel time data collection can provide valuable information to understand the dynamics of traffic flows and level of congestion. It is recommended that, for a suitable methodology on a given transportation network, comprehensive data collection (number of miles, days, hours, etc.) should be considered for the development of a baseline, system-wide travel time data collection. The data collected can be integrated, through the standardized database and report system, with other transportation measurements (volume, mode splits, accidents, etc.). The information developed is not only useful for a congestion management system, but will also benefit many emerging transportation activities called for by the ISTEA, CAAA, and IVHS impacts assessment.[7] When the characteristics of the network travel patterns are established and better understood, more focused sample designs on a small number of route and time segments (e.g., one hour of the peak period rather than four hours duration for recurring congestion) can be performed for interim or repeated data collection for traffic monitoring and congestion management.

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(6) Washington State Transportation Center (TRAC), "HOV Lane Evaluation and Monitoring Tool", Final Technical Report, Research Project T9233, Task 7 - HOV Lane Usage Analysis and Evaluation Tool, February 1994.

(7) Little, Cheryl, Liu, Tai K., et.al., "Development of A Model-Based Framework for IVHS Benefit Analysis", Presented at the IVHS America Third Annual Meeting, April, 1993.

Table A-1. Cost Summary - Video License Plate Matching Methodology

	Boston				Seattle				Lexington			
A. Personnel												
	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs
Field Survey (1)	8	7	3	$7,920	8	7	3	$5,600	8	7	3	$5,376
Field Coordination/Supervision	2	7	3	$5,401	1.5	7	3	$3,413	2	7	3	$672
Planning and Preparation (2)	3-5		6	$10,608	1		3	$2,000	2		8	$1,920
Training (3)	10	3	1	$9,032	10	3	1	$8,736	10	3	1	$9,024
Raw Data Assembly (4)	1-3		8	$1,987	2		0.5	$800	1		2	$900
			Grand Total	$34,948			Grand Total	$20,549			Grand Total	$17,892

Notes:

(1) The surveyors participating in the Boston test were graduate or college students who worked at CPTS as summer interns. For Lexington, the surveyors were LFUCG staff and summer students. For Seattle, most surveyors were hired through a temporary employment agency.

(2) For Boston this amount should be adjusted for survey planing. Nearly half of this cost was spent in contract negotiation, selection and coordination for equipment purchasing and methodology development.

(3) The training was provided by a contractor paid separately from FHWA project funds. The estimated costs for video training ranges from $1,500-$2,500 per day including travel and equipment shipping expenses. $2,000/day is used for this cost.

(4) Cataloging and shipping equipment and video tapes for processing; assembling physical attribute data for the survey routes.

Table A-1. Cost Summary - Video License Plate Matching Methodology, continued

	Boston				Seattle				Lexington				
B. Equipment													
	Cost per Set	Number of Sets Purchased	Number of Sets Borrowed	Total Cost Purchased	Cost per Set	Number of Sets Purchased	Number of Sets Borrowed	Total Cost Purchased	Cost per Set	Number of Sets Purchased	Number of Sets Borrowed	Total Cost Purchased	Total Costs for All Cities
Video Set: Camcorder, 15x lens, 2x extender lens, tripod, power adapter	$2,534	4	8	$10,136	$2,562	4	8	$10,248	$2,562	4	8	$10,248	$30,632
Accessories: TV monitor, batteries, battery recharger, tape rewinder				$1,574				$2,002				$1,574	$5,150
	Grand Total $11,710				Grand Total $12,250				Grand Total $11,822				$35,782
Notes:													

	Boston			Seattle			Lexington			
C. Video Tapes and Other Supplies										
	Unit Cost	Number of Video Tapes	Total Cost	Unit Cost	Number of Video Tapes	Total Cost	Unit Cost	Number of Video Tapes	Total Cost	Total Cost for All Cities
Video Tapes (5)	$12	362	$4,344	$12	291	$3,492	$12	112	$1,344	$9,180
Other (sundry items)			$200			$200			$450	$850
	Grand Total $4,544			Grand Total $3,692			Grand Total $1,794			$10,030

Notes:
(5) The number of video tapes used. The number of video tapes purchased was slightly higher.

Table A-2. Cost Summary - Portable Computer License Plate Matching Methodology

	Seattle (Palmtop)				Lexington (Laptop)			
A. Personnel								
	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs
Field Survey (1)	12	7	3	$6,776	22	4	2	$2,192
Field Coordination/Supervision (2)	1	3		$600	1	4	2	$392
Planning and Preparation	1		2	$1,000	1		1.2	$768
Training (3)	11	1/2	1	$1,280		1	2	$590
Raw Data Assembly (4)	1	1	1	$200	1	4	1	$112
			Grand Total	$9,856			Grand Total	$4,054

Notes:

(1) For Seattle, most surveyors were hired through a temporary employment agency. Some were unemployed engineers, students, etc. 8 persons were on-site for each 2 hour data collection session.

(2) For Seattle this consisted of 1 hour to collect data at the end of each day.

(3) In lexington, training was done in separate sessions in the office or on-site during the one hour set-up time; and average of 2 hours per person was spent for training.

(4) For Lexington this cost was for cataloging logs and tapes for shipment and processing. Download data to th e central computer and copies of data files were made for data processing at the Volpe center. A total of 7 hours was attributed to this effect.

Table A-2. Cost Summary - Portable Computer License Plate Matching Methodology, continued

	Seattle				Lexington				
B. Equipment									
	Unit Cost	Number Purchased	Number of Sets Borrowed	Total Cost Purchased	Unit Cost	Number Purchased	Number of Sets Borrowed	Total Cost Purchased	Total Costs for All Cities
Laptop/Palmtop - Survey	$0.00	12	0	$7,595	$2,746	3	5	$8,238	$15,833
Laptop - Data Collection/Processing	$4,436	1	0	$4,436					$4,436
Software (5)	$75	1	0	$75					$75
Accessories									$0
				Grand Total $12,106				Grand Total $8,238	$20,344

Notes:
(5) For Lexington developed in house.

	Seattle			Lexington			
C. Other Slupplies							
	Unit Cost	Quantity	Total Costs	Unit Cost	Quantity	Total Costs	Total Costs for All Cities
Other Sundry Items							$0.00
- None -	$0.00	0	$0.00		0	$0.00	$0.00
			Grand Total 0.00			Grand Total $0.00	$0.00

Notes:

Table A-3. Cost Summary - Floating Car Methodology

	Lexington			
A. Personnel				
	Number of Staff and/or Surveyors	Number of Days	Duration of Task (in weeks)	Total Costs
Field Survey (1)	6	2	1	$1,152
Field Coordination/Supervision	1	2	1	$0
Planning and Preparation	1	1	1	$80
Training	7	1	1	$160
Raw Data Assembly	1	10	1	$528
			Grand Total	$1,920

Notes:
(1) 1 staff; 6 surveyors

B. Equipment			
	Unit Cost	Quantity	Total Cost
Vehicles	$0	3	$0.00
		Grand Total	$0.00

C. Other Supplies			
	Unit Cost	Quantity	Total Cost
Vehicle Milage (2)	$0.25	450 Miles	$112.50
Stop Watches			$48.00
Clip Boards			$8.76
Other (sundry items)			$169.26
		Grand Total	$338.52

Notes:
(2) An average of 6 miles was used for one round trip with 75 round trips = 450 miles

ACQUISITION AND ANALYSIS OF LICENSE PLATE DATA USING VIDEO AND MACHINE VIDEO TECHNOLOGY

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Presented at
National Traffic Data Acquisition Conference
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ABSTRACT

ACQUISITION AND ANALYSIS OF LICENSE PLATE DATA USING VIDEO AND MACHINE VISION TECHNOLOGY

Two examples of the use of license plate data acquired with video camcorders are discussed: the 1991 origin-destination cordon survey conducted in the Boston region by the Central Transportation Planning Staff of the Boston MPO/Massachusetts Highway Department and the 1993 travel time studies conducted by the Volpe National Transportation Systems Center and the Federal Highway Administration with the cooperation of the Boston, Seattle and Lexington, Kentucky MPO's.

The CTPS external cordon survey was part of a comprehensive origin-destination study designed to provide data with which to update transportation planning models for use in the Boston region. License plates on vehicles in the traffic stream were recorded at 51 locations on an arc running from Salisbury, on the Massachusetts/New Hampshire border, through Fitchburg, Mass., down to the Massachusetts/Rhode Island border at Providence and on out to Brewster at the western end of Cape Cod. Video camcorders were used to acquire license plate images at all stations, with the exception of a handful of very light volume locations. The video tapes were analyzed manually, frame-by-frame. A sample of license plates records was transcribed to a computer file that was used by the Motor Vehicle Registry to determine the mailing address of each registrant, to whom a mailback questionnaire was sent. Approximately 130,000 license plates were processed in this fashion. Significantly, it took about ten hours to process each hour of videotape recording.

The experience gained in capturing and analyzing license plate images in the course of the CTPS survey were put to use in the VNTSC/FHWA travel time field trials. The primary purpose of this set of studies is to compare the effectiveness and cost of various methods for estimating travel times on segments of urban arterial and expressway networks. Among the methodologies employed were: license plate matching using video camcorders and laptop or palmtop computers; "probe" vehicles and floating cars, and; simulations based on loop detector data. Different methodologies were employed in the different cities; however video camcorders served as the base methodology in all cases. A total of approximately 1500 hours of videotape was collected between July and September, 1993. These tapes were processed using automatic license plate readers in a British laboratory. Twelve lane-hours of tape covering a segment of Boston's Southeast Expressway were also analyzed frame-by-frame at the University of Massachusetts Amherst. Plate recognition, plate matching, travel time means and variances, and four-character vs. full-plate matchings are reported on for both the manual and machine vision processing.

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ACQUISITION AND ANALYSIS OF LICENSE PLATE DATA USING VIDEO AND MACHINE VISION TECHNOLOGY

INTRODUCTION

With few exceptions, every motor vehicle operating on a public street or highway is required to display a unique identifying marker...a license plate. As unique, readily visible markers, license plates have long been used by engineers and planners as data sources for cordon line origin-destination, travel time, and other traffic studies. Typically, these studies have involved large numbers of field personnel operating under conditions that are conducive to distraction and observational/recording errors. Office reduction of field data has also been labor intensive, especially where very short data processing times are essential, as when questionnaires are to be mailed to vehicle registrants.

Data recording devices of varying kinds have been employed to facilitate the acquisition of license plate records in the field and the processing of these records in the office. The use of audio tape recorders makes fieldwork somewhat easier and more accurate, but the transcription of audio records is a slow process and, unless the recording is very clear, can be subject to unacceptable high rates of transcription error. Laptop computers, and their miniaturized counterpart, the palmtop computer, in the hands of adept typists facilitate the acquisition of license plate records in the field and, more importantly, store these data in machine readable form, thus eliminating transcription costs and errors completely.

Although they are generally improvements over pencils and clipboards, these electronic devices can record only what a human observer can see, identify, and retain long enough to enter into the recording device. Under certain conditions, for example, in slow-moving traffic, human capacities of sight, speed, accuracy and diligence may be fully equal to the task; in the case of high-speed, high-volume expressway traffic, they clearly are not. These limitations, fortunately, can be overcome through the use video cameras and recorders. Video cameras/recorders are capable of capturing clear images of license plates on vehicles moving in streams of high-speed, high-volume traffic under almost any daylight condition. Modern camcorders are light and highly portable. Perhaps most importantly, camcorders fully adequate for license plate recording are readily available in the consumer market, where competition will continue to drive the technology forward and the price down.

Recording license plate images on video tape has, however, one significant drawback; it is still necessary to transfer these video images into a digital, computer-readable form for subsequent processing and analysis. True, it is easier and more accurate for a human operator to read clear, still, video images in the office that to read moving license plates from a highway overpass, but the reading of video tape is a time consuming, laborious process. Transcribing video tape license plate images into a digital format can however, be accomplished through the use of specialized computer software/hardware systems. This technology, often referred to as "machine vision", has long been used in many commercial and industrial applications. Its application to traffic analyses in general, and to license plate reading in particular, is gaining increasing currency.

In what follows, we report on two instances in which video camcorders were used to record license plate images. The first instance was in connection with a cordon line origin-destination survey conducted by the Central Transportation Planning Staff (CTPS) in the Boston region. The second was as part of a series of field trials of various methods for estimating travel times on expressways and urban arterials sponsored by the Federal Highway Administration (FHWA) in cooperation with the Volpe National Transportation Systems Center (VNTSC) and traffic and transportation planning staffs of the Boston, Seattle and Lexington, KY, Metropolitan Planning Organizations. This latter application involved the use of machine vision technology.

THE 1991 BOSTON REGION ORIGIN-DESTINATION CORDON STUDY

The Boston Region O-D study was conducted by CTPS for the purpose of collecting household and travel data with which to update the agency's transportation planning models (1). The external cordon survey involved the collection of license plate data at fifty-one locations on an arc running from Salisbury, on the Massachusetts/ New

Hampshire border, through Fitchburg, MA, down to the Massachusetts/Rhode Island border at Providence, and out to Brewster, at the western end of Cape Cod. A sample of license plate records was transcribed to a computer file. This file was used by the Massachusetts Motor Vehicle Registry and comparable agencies in New Hampshire and Vermont to determine the mailing address of each registrant, to whom a mailback questionnaire was sent. Approximately 130,000 license plates were processed in this fashion.

The initial decision to use a license plate based mail survey was a consequence of an earlier decision to avoid the interference with traffic that roadside interviews inevitably entail. Although it was anticipated in the planning of the survey that a mix of pencil and paper, laptop computer, and voice recorder setups would provide the field data, video camcorders proved to be the only feasible way to obtain a sufficient number of license plate records at all but a few very light volume stations.

The field setups involved the use of one or more HI-8 camcorders mounted on tripods placed on the highway shoulder or median. Each camera was powered by a 12-volt marine battery, which provided sufficient energy to operate the camera for up to twelve hours per day, three days per week. A single camera was generally sufficient to obtain clear, readable images on two adjacent lanes. Two cameras were typically used on three-lane setups and three cameras in the few cases where four lanes were observed. Readable images were readily obtained in the dim light of early morning, near dusk, and in rain.

A sample of the license plate records on each two-hour field tape was transcribed to a computer file in the office as soon as possible after taping so as to minimize the time between the sighting of a vehicle at a given location and receipt by the registrant of that vehicle of a questionnaire pertaining to the vehicle's use on that day. This process involved an operator displaying video images of a sample of license plates on a video monitor screen and entering each plate's alphanumeric characters and state designation into a computer file. A tape player capable of holding a still image without jitters in the "pause" mode was used to insure readability. Approximately ten hours of office time were required to process one hour of videotape.

ESTIMATING TRAVEL TIME ON A SECTION OF THE SOUTHEAST EXPRESSWAY, BOSTON

A series of field trials was conducted during the summer of 1993 under the auspices of the Federal Highway Administration for the purpose of comparing the effectiveness and cost of various methods of estimating travel times on segments of urban arterial and expressway networks. The studies were designed by the Volpe National Transportation Systems Center and were carried out in Boston, Seattle, and Lexington, KY, with the cooperation of the traffic and transportation planning staffs of those cities' Metropolitan Planning Organizations (2). Among the methodologies employed were: license plate matching using video camcorders and laptop or palmtop computers; IVHS probe vehicles and buses equipped with an automatic vehicle identification system; floating cars; and simulations based on loop detector data. Different combinations of methodologies were employed in each of the test cities; however, video camcorders served as the base methodology in all cases. A total of 1500 hours of videotape records was collected between July and September, 1993. The videotapes were subsequently processed by a machine vision system to estimate travel times on each of the forty or so route segments included in the study.

A typical video setup involved placing camcorders on overpasses over each traffic lane in one direction at four locations along an urban expressway segment. On a three-lane (one direction) section of expressway, three camcorders would be set at each of four locations, thus defining three contiguous segments for which the travel time of each vehicle entering <u>and</u> exiting a given segment could be measured. The license plates of all vehicles passing through the camera's field of view were recorded at the beginning and end of a given segment along with the time of each observation to the nearest second. By matching license plates observed at the beginning and end of a segment and subtracting the entering time for each matching plate from its exiting time, a measure of the time it took each recorded through vehicle to traverse the segment was obtained. A more detailed explanation of these procedures is provided in the following section, in which their application on a segment of the Southeast Expressway (I-93) in Boston is discussed.

Comparison of Manual and Machine Vision Analysis of Video License Plate Images

Video tape records obtained at two locations along Boston's Southeast Expressway (I-93) were analyzed for the purpose of comparing measures of travel time obtained through machine vision analysis of these records with a very careful and detailed manual analysis of these same records. The field data in question were obtained during the morning and evening peak periods on a sunny weekday in July, 1993, at the Boston Street and Bates Avenue overpasses of the Southeast Expressway. The expressway is three lanes wide in each direction at these two locations. Boston Street lies about two miles (3.3 km) south of the Boston CBD; Bates Avenue is almost exactly six miles (10 km) south of Boston Street. There are five off-ramps and four on-ramps in the northbound direction between Bates Avenue and Boston Street and six off-ramps and five on-ramps in the southbound direction between these two locations.

Three video camcorders on tripods were placed on an overpass over each of the three northbound expressway lanes at the two observation sites during a two-hour morning peak period (6:30 am - 8:30 am) and over the three southbound lanes during a two-hour afternoon peak period (4:30 p.m. - 6:30 p.m.). A total of 12 lane-hours of video tape of all traffic passing these two sites during this four-hour period were thus recorded. Using a combination of stopwatches and the camcorders' own time keeping mechanisms, the clock time of each observation was determined. Each two-hour video tape was processed by a machine vision system that automatically "read" those license plates that were legible to the system, matched putatively identical plates observed at both the Bates Avenue and Boston Street observation sites, and computed the travel time for each vehicle so identified.

These same twelve hours of videotape records were painstakingly analyzed by a team of research assistants at the University of Massachusetts Amherst (3). Each two-hour tape was displayed frame-by-frame on a video monitor. The number of vehicles observed in each fifteen minute period was recorded and, for that same fifteen minute interval, each observable license plate was entered into a computer file along with the actual instant, to the nearest second, at which that license plate was observed in the field. Three tape-hours were reread by an operator other than the one who originally transcribed those license plate records into the computer files in order to estimate the transcription error rate. The error rate thus determined was 1.3 percent, or one mistranscribed plate record in seventy-five readings.

The results obtained by manual analysis of the videotaped license plate images were compared with the results obtained by use of a machine vision system. Comparisons were made of: 1) Number of license plates read; 2) Number of license plates correctly read by the machine vision system; 3) Number of plate matches at the two observation sites, and; 4) Mean travel times between the two observation sites. In addition, a comparison was made between mean travel times obtained from an analysis of whole plate matches (using the manually transcribed tape records) with travel times obtained by analyzing license plate records for which only the first four characters were used. And, finally, calculations were made of how the range in the variance about the mean fifteen minute travel times changed with the sample size of the data used to compute the mean travel time. The results of these several analyses are summarized below.

Comparison of Manual and Machine Vision License Plate Recognition and Matching Rates

The frame-by-frame manual analysis of the continuous videotape images of each lane of traffic at the observation site provides an inclusive record of every vehicle passing through the camera's field of view. Of the approximately 37,000 vehicles observed at the Bates Avenue and Boston Street sites during the four peak hours included in this analysis, 33,576, or roughly 90 percent, displayed readable license plates. Plates could not be read on ten percent of the vehicles for one of several reasons: either the plate was missing, so dirty or damaged as to be illegible, or mounted in such a way as to be partially or wholly obscured, usually by a bumper hitch or other appendage; the plates on vehicles that were in the process of changing lanes as they passed through the camera's field of view were also occasionally not fully in view.

As shown in Table 1, of the 33,576 license plates that were fully readable, 16,184, roughly one-half, were "read" by the machine vision system. These machine "readings" were compared on a plate-by-plate basis with the manual records to determine the number that were read correctly. Roughly one-third of the machine records matched exactly the records obtained manually. The error rate in the manual transcription of license plate records from videotape to computer file was 1 in 75 or 0.013. Crediting the machine vision system with all mismatches attributable to human error results in a "correct" reading rate of this system of (5,332 + 0.013 (33,576)) / 33,576 = 17.2%.

Table 2 summarizes the results of attempting to match the license plates observed at the Boston Street site (designated as C2 in the table) with those observed at the Bates Avenue location (C4). Since the expressway segment between Boston Street and Bates Avenue contains several on- and off-ramps, many vehicles either exited or entered (or both) between the two viewing stations and as result only a fraction of the observed license plates could be expected to match. Of the 15,329 license plates read manually in the northbound lanes at both Bates Avenue and Boston Street, only 3,079 (20%) were observed at both locations; comparable figures for southbound traffic are 18,247 and 4,372 (24%).

The total number of matched pairs resulting from the manual analysis of the videotape records (7,451) should be compared with the total of matched pairs (614) provided by the machine vision analysis of these same videotape records. The manually-derived 7,451 matches is a reasonably accurate estimate of the number of vehicles that passed both Bates Avenue and Boston Street during the periods included in this analysis. Of this 7,451 "base", 614, or 8.2 percent, were accurately captured by the machine vision system.

Computations of Travel Time

Since each license plate video image is associated with the time to the nearest second at which that license plate was observed, the time between matching observations could be readily and accurately calculated. The arithmetic means and standard deviations of travel times of northbound traffic for each of eight fifteen-minute periods between 6:31 a.m. and 8:31 a.m. are shown in Table 3. The coefficient of variation of mean travel time (the standard deviation divided by the mean) ranges from a high of 28.4 percent to a low of 4.2 percent. Since close to 100 percent of the through traffic passing through both stations is included in the data from which these statistics are derived, the means, standard deviations and coefficients of variation can be taken as describing accurately these characteristics of the population of traffic moving between Bates Avenue and Boston Street during the particular times and day of observation, essentially free of measurement or statistical error.

Having available a nearly complete record of travel times for the period under analysis allows us to determine the sampling errors that would result if samples of this population were used to estimate mean travel times. Figure 1 illustrates the range of sampling error that is associated with samples of different sizes of the population of through traffic moving from Bates Avenue to Boston Street in the fifteen minute period 6:31 a.m. to 6:46 a.m. Twenty random samples were selected from each sample-size group, beginning with size 50 and increasing in 50 vehicle increments to size 350 (of a total population of 382 matched pairs)[*]. The minimum and maximum standard deviations around the mean travel time for each sample size group are presented in the Figure. The range of standard deviation narrows rapidly as the sample size increases from 50 to 100, and then narrows more slowly as the size of sample increases from 100 to 350. The graph reaches closure at sample size 382, which is also the population size.

Identical analyses of travel time data for each of the other fifteen minute intervals in the morning and afternoon peak periods revealed roughly the same relationship between sample size and range of sampling variation. These analyses suggest that a random sample of about 100 matched pairs over a fifteen minute interval will provide about as good an estimate of travel time as will a 100 percent sample. This conclusion applies only to the traffic observed in the present analysis; considerably more analysis of traffic on other facilities would be required before this specific finding could be generalized with any reasonable degree of confidence.

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[*] For the purpose of this analysis, vehicles for which the calculated travel time was less than 400 sec. or greater than 1800 sec. between Bates Ave. and Boston St. were removed from the data set. Four vehicles were removed for this purpose, reducing the number of plate matches during the 6:31 a.m. - 6:46 a.m. interval from 386 to 382.

Table 1. Comparison of Manual and Machine Vision Recognition Results

Direction	Location	No. of Plates Recognized Manually	No. of Plates Recognized by Machine	No. of Identical Recognitions
North	Bates Ave.	6,544	3,648	941
Bound	Boston St.	8,785	5,259	1,743
South	Bates Ave.	8,688	4,060	1,455
Bound	Boston St.	9,559	3,217	1,193
Total		33,576	16,184	5,332

Source: A. Hu, "Use of Video/Machine Technology to Estimate Travel Time"

Table 2. Comparison of Plates Matched at Two Locations

Direction	Data Obtained by Manual Method					Data Obtained by Machine				
	No. of Recognized Plates		No. of Matched Pairs	% of Matched Pairs		No. of Recognized Plates		No. of Matched Pairs	% of Matched Pairs	
	C2	C4		C2	C4	C2	C4		C2	C4
North Bound	8,785	6,544	3,079	35.0	47.3	5,259	3,648	310	5.9	8.5
South Bound	9,559	8,688	4,372	45.7	50.3	3,217	4,060	304	9.4	7.5

Source: A. Hu, "Use of Video/Machine Technology to Estimate Travel Time"

Table 3. Estimation of 15-Minute Mean Travel Times of Northbound Traffic Using Manual Procedure and All Matched Pairs

Bates Ave. Arrival Time a.m.	Number of Matched Pairs	Mean Travel Time, min.	Standard Deviation, min.	Coefficient of variation, %
6:31 - 6:46	386	13.77	2.77	20.1
6:46 - 7:01	394	14.28	1.25	8.8
7:01 - 7:16	385	15.30	4.35	28.4
7:16 - 7:31	476	15.90	2.38	15.0
7:31 - 7:46	482	16.83	1.02	6.1
7:46 - 8:01	532	18.43	1.85	10.0
8:01 - 8:16	353	18.35	0.77	4.2
8:16 - 8:31	87*	19.72	0.93	4.7
TOTAL	3095			

*Low number of matches due to camcorder malfunction.

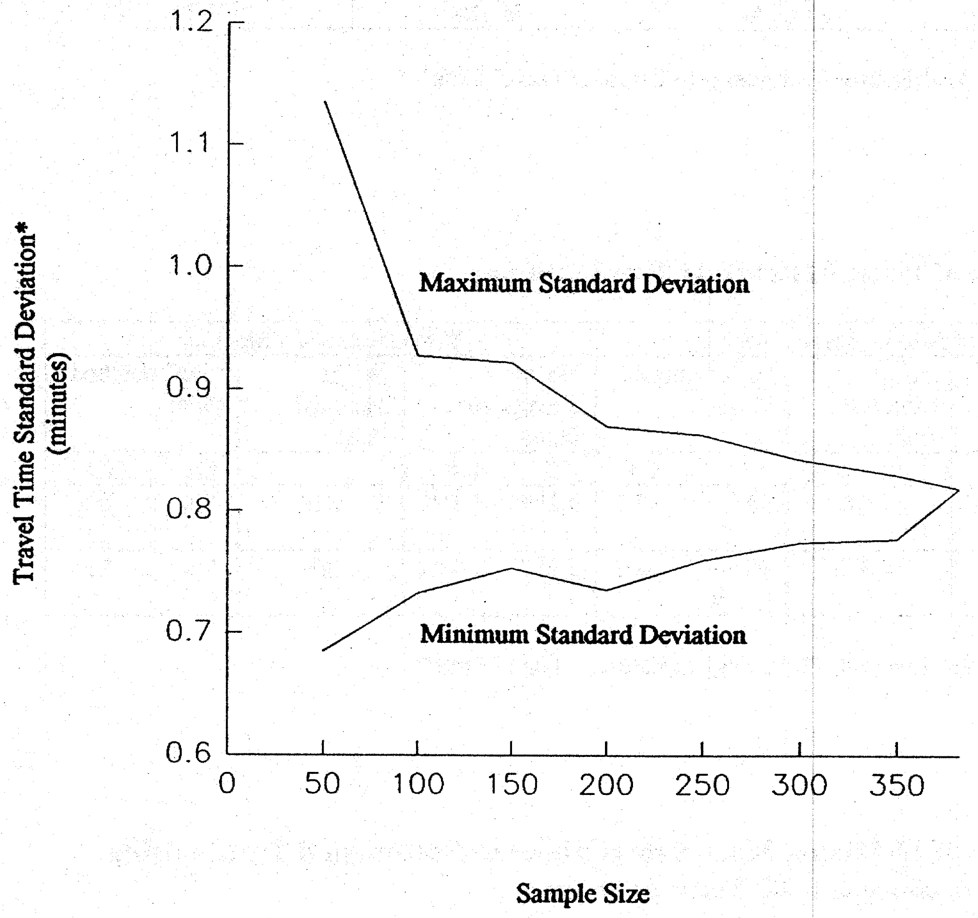

Figure 1. Standard Deviation Range vs. Sample Size
(North Bound, 6:31 a.m. - 6:46 a.m.)

* Range of 20 estimates of standard deviations at given sample size.

Source: A. Hu, "Use of Video/Machine Technology to Estimate Travel Time"

Comparison of Manual and Machine Vision Estimates of Travel Times

A comparison of mean travel times for eight fifteen-minute periods between 6:31a.m. and 8:31a.m. as computed by manual and machine vision analysis is shown in Table 4. The machine vision travel time estimates were provided by the Volpe National Transportation Systems Center. These estimates are based on videotape observations at Boston Street and Boulevard Street Extension, which lies 0.77 miles north of Bates Avenue. The manual estimates in Table 4 were derived from the data upon which Table 3 is based with the following two adjustments: 1) Sixteen plate match pairs that resulted in excessively high or low travel times wee discarded, and 2) mean travel times between Boulevard Street Extension and Boston Street were computed by prorating the Bates Avenue - Boston Street travel times by the ratio of the Boulevard Street Extension - Boston Street/Bates Avenue - Boston Street segment lengths, that is, by a ratio of 5.16/5.93. The data presented in Table 4 suggest that the machine vision estimates of travel time do not differ significantly from those obtained by manual analysis of the videotape records, the largest difference being 4.4 percent.

Comparison of Travel Time Estimates Using Whole Plate and Partial Plate Matchings

A common procedure in using license plate matching for various traffic studies is to record only a portion of the license plate -- typically the first four characters. This procedure facilitates the observation and recording process, but can be a source of significant measurement error. This phenomenon is illustrated in Tables 5, and 6, in which estimates of mean travel times and standard deviations resulting from whole and four-character plate matchings are compared. In each instance, the statistics are derived from the license plate records obtained through the detailed manual analysis of the videotape images. The "Whole Plate Match" columns are based on matches using the full set of alphabetic and numerical characters displayed on each readable license plate. The "First Four Characters Match" columns are taken from these same license plate records, the difference being that for these columns only the first four characters of each plate record is used.

Table 5 reports mean and variance calculation based on "raw" match data, that is all observed matches regardless of how reasonable the travel times computed from those matches might be. The errors that such unqualified use of plate matching data can produce is most clearly seen in the negative values for mean travel times recorded for the 8:01 - 8:16 and 8:16 - 8:31 intervals under the Four Character heading. These errors arise from the large numbers of spurious matches that result from using only the first four characters of typically 6-character plates. Over the two hour period reported on in Table 5, almost three-quarters (74%) of the four character matches were spurious. A marked reduction in the number of spurious matches is attained by eliminating matches that produce travel times less than a specified, reasonable, value or greater than a specified value. As shown in Table 6, setting travel time limits of 400 seconds minimum and 1800 seconds maximum--equivalent to 53 mph (89 kph) and 12 mph (20 kph)-- results in the elimination of 16 of the 3095 full plate matches and 1838 of the 5379 four character matches. As a result, the percent of mismatched four character plates drops from 74 percent to 15 percent. Changes are also seen in the travel time means and standard deviations for both groups. Mean travel times using whole plate matches change very little when the few very small and very large travel time matches are removed; however, the variances around these means are reduced significantly. For example, removing four outliers from the 386 matches recorded during the 6:31 - 6:46 interval results in a reduction in the standard deviation from 2.77 minutes to 0.8 minutes and a corresponding reduction in the standard error of estimate from 20 percent to 6 percent. Improvements in the results of the four character matchings are even more dramatic; the estimated mean travel times fall closely into line with estimates based on the full plate matches, and the standard deviations around the means are reduced ten-fold.

CONCLUSIONS AND RECOMMENDATIONS

Experience to date with the use of video camcorders to acquire license plate data for subsequent use in origin-destination or travel time studies is encouraging. Large amounts of accurate, verifiable data can be gathered in this way at reasonable cost. Indeed, video camcorders may often be the only way to obtain adequate license plate data in high speed, high volume traffic. As demonstrated above, working with partial plate records can lead to erroneous estimates of travel times unless spurious matches are carefully eliminated. Partial plate records are of little use in cordon surveys intended to provide home address data.

Table 4. Comparison of 15-minute Average Travel Times, Southeast Expressway Northbound, Boulevard Street Extension to Boston Street, as calculated by Manual and Machine Vision Analysis of Videotape License Images

Time Period	Manual				Machine Vision				t_m-t_{mv},	t_m-t_{mv},
a.m.	t,min	S,min	Coef. of Var, %	n	t,min	S,min	Coef. of Var., %	n	sec.	%
6:31-6:46	11.77	0.82	7.0	382	11.25	0.97	8.6	61	0.52	4.4
6:46-7:01	12.37	0.68	5.5	391	12.55	1.28	10.2	64	-0.18	-1.5
7:01-7:16	12.99	0.70	5.4	382	12.65	0.97	7.7	101	0.34	2.6
7:16-7:31	13.73	0.90	6.6	473	13.25	1.13	8.5	87	0.48	3.5
7:31-7:46	14.62	0.80	5.5	481	14.10	1.08	7.7	78	0.52	3.6
7:46-8:01	14.95	0.73	4.9	530	15.47	1.00	6.5	27	-0.52	-3.5
8:01-8:16	15.96	0.77	4.8	353	16.07	0.90	5.6	45	-0.11	-0.7
8:16-8:31	17.16	0.93	5.4	87*	17.83	1.97	11.0	51	-0.67	-3.9

*Limited n due to camcorder malfunction.

Table 5. Comparison of Whole Plates Match with First Four Characters Match (No Limitation)

Bates Ave. Arrival Time, AM	Whole Plates Match		First Four Characters Match	
	No. of Matched Pairs	Mean Travel Time & (Standard Deviation)	No. of Matched Pairs	Mean Travel Time & (Standard Deviation)
6:31 - 6:46	386	13.77 (2.77)	614	30.54 (29.62)
6:46 - 7:01	394	14.28 (1.25)	626	25.03 (24.60)
7:01 - 7:16	385	15.30 (4.35)	624	21.94 (22.66)
7:16 - 7:31	476	15.90 (2.38)	724	14.70 (19.52)
7:31 - 7:46	482	16.83 (1.02)	803	10.40 (21.99)
7:46 - 8:01	532	18.43 (1.85)	945	4.82 (27.21)
8:01 - 8:16	353	18.35 (0.77)	665	-3.45 (32.82)
8:16 - 8:31	87	19.72 (0.93)	378	-29.39 (40.87)
Total	3095		5379	
% Mismatched	(5379 - 3095) / 3095 = 74%			

Source: A. Hu, "Use of Video/Machine Technology to Estimate Travel Time"

Table 6. Comparison of Whole Plates Match with First Four Characters Match

(Min. Travel Time = 400 sec.; Max. Travel Time = 1800 sec.)

Bates Ave. Arrival Time, AM	Whole Plates Match		First Four Characters Match	
	No. of Matched Pairs	Mean Travel Time & (Standard Deviation)	No. of Matched Pairs	Mean Travel Time & (Standard Deviation)
6:31 - 6:46	382	13.53 (0.82)	431	14.10 (2.84)
6:46 - 7:01	391	14.22 (0.68)	439	14.74 (2.84)
7:01 - 7:16	382	14.93 (0.70)	624	15.25 (2.41)
7:16 - 7:31	473	15.78 (0.90)	531	15.94 (2.25)
7:31 - 7:46	481	16.80 (0.80)	554	17.12 (2.54)
7:46 - 8:01	530	18.33 (0.73)	634	18.33 (2.12)
8:01 - 8:16	353	18.35 (0.77)	411	18.24 (2.07)
8:16 - 8:31	87	19.72 (0.93)	110	18.58 (3.20)
Total	3079		3541	
% Mismatched	(3541 - 3079) / 3079 = 15%			

Source: A. Hu, "Use of Video/Machine Technology to Estimate Travel Time"

The primary impediment to the widespread use of videotape is the inordinate length of time required for manual transcription of videotape records to computer files. Machine vision processing of tapes for this purpose is a very promising but as yet not fully proven alternative to manual transcription. The level of operator skill required to obtain tape images of sufficient clarity and contrast to insure high read rates by machine vision systems is considerably greater than the level of skill required to obtain images readable by the human eye. Operator skill requirements will become less of a problem as camcorder and machine vision system technologies continue to improve.

An alternative procedure using both manual and machine processing should be considered. Machine vision technology lends itself to a hybrid manual/machine approach to license plate image transcription. The machine vision system used in the FHWA/VNTSC studies employs a "plate trigger" that identifies the region of the field of view in which a license plate appears and stores an image of this license plate in its memory. The rate of success of the image capture is considerably higher than the rate of success of image interpretation, or "reading". It is a relatively simple matter to display these captured license plate images on a video screen, where they can be viewed by a human operator and entered manually into a computer file, thus reducing the time required for the operator to search the field tape for each plate image. A test of this hybrid approach is planned.

The adequacy of any procedure for estimating travel times cannot be properly determined in the absence of clear specifications of how precise travel time measures should be. Consider the analysis discussed in the previous sections of this paper. "Travel time" was implicitly defined as the mean time required by vehicles traveling between two points (Bates Avenue and Boston Street) on a section of the southeast Expressway during a four-hour period on a July weekday in 1993. Averages were computed for fifteen minute intervals, a period of time arbitrarily specified by the author. Neither the definition of travel time nor the interval of time over which averaging should take place were related explicitly to the congestion monitoring objectives of the Intermodal Transportation Efficiency Act of 1991 (ISTEA), in respect to which travel time measurements have been mandated.

The manual analysis of videotape license plate images resulted in travel time estimates with a standard error of estimate in the order of five to ten percent once excessively high or low travel times had been discarded. Is this level of variation appropriate to meet the ISTEA mandates; is it too high?; is it too low? Would a machine vision system capable of producing travel time estimates with standard errors of estimate in the range of 20 to 30 percent be adequate? Without answers to questions of this sort, the best the analyst can do is rank different procedures on the basis of relative cost and precision. Whether any, or all, provide "adequate" measures of travel time can only be determined within the context of externally specified standards of "adequacy".

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