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NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **303**

FEASIBILITY OF A NATIONAL HEAVY-VEHICLE MONITORING SYSTEM

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

TRANSPORTATION RESEARCH BOARD EXECUTIVE COMMITTEE 1988

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FEASIBILITY OF A NATIONAL HEAVY-VEHICLE MONITORING SYSTEM

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AREAS OF INTEREST:

- Administration
- Planning
- Forecasting
- Socioeconomics
- User Needs
- Transportation Safety
- Vehicle Characteristics
- Traffic Flow, Capacity, and Measurements
- (Highway Transportation)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.
DECEMBER 1988

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will be of special interest to transportation administrators, operations engineers, and researchers involved in highway planning and design, weight enforcement, and automatic clearance of trucks through weigh stations and ports of entry; and to long-haul and variable-route motor carriers who need on-demand communication and truck location information for fleet and driver management. Information on the technical, operational, and economic aspects of a national heavy vehicle monitoring system are provided. Data from market surveys, literature reviews, interviews, field observations, and statutes and case law reviews provide the basis for the research findings on the feasibility of developing a national heavy-vehicle monitoring system that is capable of meeting the needs of federal, state, local, and private concerns. The availability and application of new technologies form the basis for many of the recommendations presented in the report.

Extensive information on heavy-vehicle movement is collected by federal, state, and local governments to support highway planning and design activities, weight enforcement programs, and tax administration. Information is also collected by motor carriers to improve the operational efficiencies of their fleets. Even with the comprehensiveness of current collection efforts, the data are often not as complete or as accurate as desired for the intended purposes. The collection and processing of this information is a burden to both government and private industry in terms of dollars costs, paperwork, delays in the transport of goods, and the exposure of personnel to safety hazards. The research conducted under NCHRP Project 3-34, "The Feasibility of a National Heavy-Vehicle Monitoring System," was directed at assessing the feasibility of applying the new heavy-vehicle monitoring technologies in an integrated way to improve the cost effectiveness of collecting, transmitting, and processing this information.

A few of these new technologies are currently being evaluated in the Crescent Demonstration Project, a multi-jurisdictional project involving a group of western states, Canadian provinces, and motor carriers to demonstrate the utility of an integrated electronic heavy-vehicle monitoring system. Building on information generated from the Crescent Project, other related studies, and numerous interviews, this report contains the results of an evaluation of the feasibility of applying new technologies in the areas of weigh-in-motion, automatic vehicle classification, automatic vehicle identification, automatic vehicle location, and onboard computer vehicle management systems at the national and regional levels. The authors concluded that a national heavy-vehicle monitoring system is feasible if it is organized as a set of coordinated and voluntary systems, rather than as a single mandatory system. In addition to the technical aspects, the researchers identified and evaluated markets, organization and management issues, legal and institutional issues, and costs and benefits related to heavy-vehicle monitoring.

The researchers conclude their description of a feasible national heavy-vehicle monitoring system by identifying a number of emerging areas that require further research.

CONTENTS

ACKNOWLEDGMENTS

The Co-Principal Investigators for NCHRP Project 3-34 and major authors of this report were Lance R. Grenzeback, Joseph R. Stowers, and Ashok B. Boghani.

Lance R. Grenzeback is Senior Associate with Cambridge Systematics, Inc. He was responsible for the overall technical direction of the project and served as Principal Investigator during Phase I of the project when he was Senior Consultant with Arthur D. Little, Inc. Dr. Joseph R. Stowers is President of Sydec, Inc. He served as the project's Chief Economist and Co-Principal Investigator. Dr. Ashok B. Boghani is Manager of the Transportation Technology and Management Group at Arthur D. Little, Inc. He served as the project's Chief Engineer and as Principal Investigator during Phase II of the project.

The authors wish to acknowledge the excellent cooperation and assistance provided to us by the American Association of State Highway and Transportation Officials, the American Trucking Associations, the HELP Program, the Owner-Operators Independent Drivers Association of America, the Western Highway Institute, the California Trucking Association, the Pennsylvania Motor Truck Association, and the Association of American Railroads.

We also want to acknowledge the assistance provided to us by the staffs of all of the state agencies, state motor carrier associations, and motor carriers who met with us over the last year and responded to our inquiries and surveys.

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FEASIBILITY OF A NATIONAL HEAVY-VEHICLE MONITORING SYSTEM

SUMMARY

The objective of this project was to determine the feasibility of a national heavy-vehicle monitoring system (HVM). A system was required which would provide information of the location and characteristics of heavy trucks and their use of the nation's highways. The information would be collected by using new technologies for weighing (trucks)-in-motion (WIM), automatic vehicle classification (AVC), automatic vehicle identification (AVI), automatic vehicle location (AVL), and onboard computer vehicle management systems (OBC/VMS). This information would then be relayed to other locations by ground or satellite communication links, processed by computers, and made available to users. The following illustration briefly describes the technology.

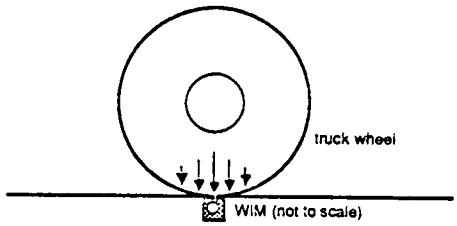
There is no national HVM system in operation today, but there is pressure for more and better HVM information through increased use of automation. Competition in the motor carrier industry has put pressure on motor carriers to operate their fleets more efficiently, and deteriorating highways and budget deficits have placed demands on government to improve pavement management and utilize transportation revenues more efficiently.

Other transportation sectors are moving rapidly to develop better monitoring systems for their operations. The railroads are developing industry standards for automatic train control systems (ATCS). Container ship operators are writing standards for radio-frequency identification of transportation equipment (RITE). And both the Federal Government and the private sector are developing satellite-based automatic vehicle location and communication (AVL/C) systems applicable to trucks, railroads, ships, and planes.

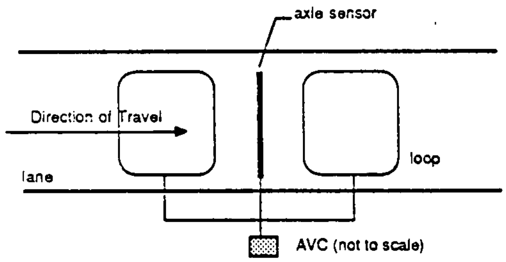
Within the highway industry, a consortium of 13 state departments of transportation (DOTs) has proposed demonstration of an integrated WIM, AVC, and AVI system to meet the data collection needs of state DOTs and motor carriers. The Heavy-Vehicle Electronic License Plate (HELP) System Development Program is testing and evaluating WIM, AVC, and AVI equipment and system designs. A demonstration project based on the HELP research will deploy the equipment at sites along the "crescent corridor"—Interstate 5 and Interstate 10—in six states between Washington and New Mexico.

These activities have generated much interest and concern about a national HVM system. Thus, NCHRP Project 3-34 was initiated in response to this need to define the opportunities for a national HVM system and address the issues that it raises.

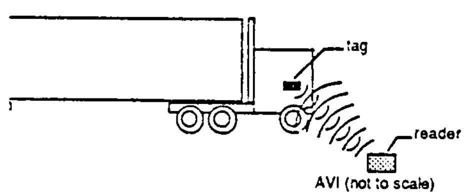
The research focused on five major concerns: markets, technology, legal and institutional issues, organization and management, and impacts, costs, and benefits. Interviews with more than 300 people were conducted in the public and private sectors that would be affected by a national HVM system. Market surveys were conducted of motor carrier firms and owner-operators; and, with the assistance of the American Association of State Highway and Transportation Officials (AASHTO), state agencies involved in heavy-vehicle monitoring were surveyed. The technological feasibility of HVM equipment and systems was evaluated through literature reviews, analyses, interviews, and field observations. And statutes and case law were reviewed to explore the legal and institutional ramifications of a national HVM system. Alternative scen-



WIM Weigh-in-Motion measures dynamic axle weight at highway or slower speeds with accuracies of plus or minus five to fifteen percent compared to static weight. Scales, pressure sensors, or strain sensors are installed in the pavement or on bridges. Axle weight is measured as the tires roll over the sensors. WIM can measure single and tandem axle weights and, when coupled with a vehicle detection device (see AVC), can accumulate gross vehicle weight.

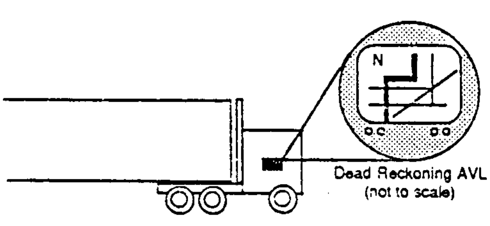


AVC Automatic Vehicle Classification classifies trucks by vehicle length, number of axles, and axle spacing. Sophisticated systems can distinguish dozens of truck types. A loop of wire in the pavement detects the metal mass of the truck moving across it while a pressure plate or other sensor in the pavement counts the axles. With two loops and careful timing, an AVC computer can also calculate vehicle speed.



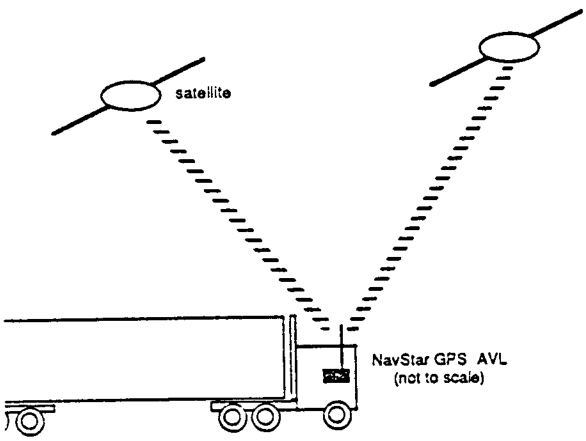
AVI Automatic Vehicle Identification uses light, microwaves, or low power radio waves to "read" an electronic license plate at highway speeds. A transponder "tag" (wallet-size or smaller, some with built-in, long-life batteries) is mounted on the outside of the truck. Each tag has a unique identification code and may hold temporary information (e.g., a commodity code or permit number). An interrogator/receiver "reader" is installed in the pavement or on the roadside. As the truck passes, the reader "illuminates" the tag causing it to transmit back its code and data.

AVL Automatic Vehicle Location calculates the location of truck or trailer. There are three types of AVL:

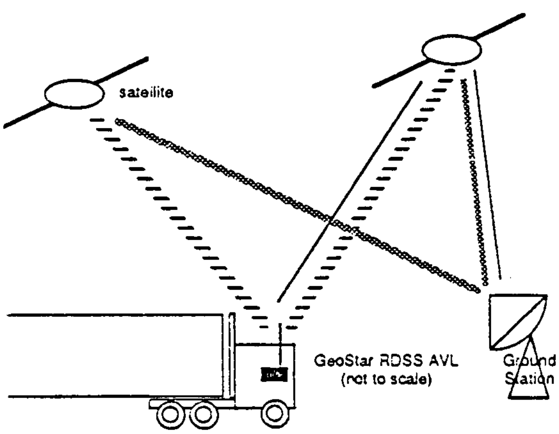


- **Dead reckoning AVL** uses a magnetic compass and odometers to track distance and direction of travel from a known starting point. Vehicle tracking must be continuous. With recalibration every twenty miles, dead reckoning AVL is accurate within one hundred feet or better. The newest systems plot the truck's path and current location against an electronic roadmap displayed on a video screen in the truck cab. Location information can be stored onboard or transmitted to the fleet office.

• **Radio determination AVL** uses radio signals to measure the distance between a truck and two or more known points. Location is calculated by trilateration.

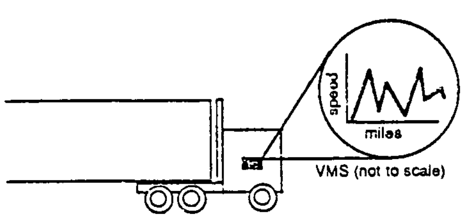


Government radio determination systems use one-way signals. The **Loran-C** system transmits from a network of ground towers and the **NavStar Global Positioning System (GPS)** from a network of satellites. Trucks are equipped with receivers and computers to decode the signals and calculate location, or data can be transmitted to a central computer for processing. Vehicle tracking can be continuous or intermittent. Loran-C is accurate within several thousand feet and GPS within several hundred feet. Location information can be stored onboard or transmitted to the fleet office.



Proposed commercial **radio determination satellite services (RDSS)**, such as Geostar, use timed, two-way signals. A satellite transmits a timed interrogation signal that is received, marked and retransmitted by a transceiver on the truck. The marked signal is captured by two satellites and relayed to a ground computer that calculates the truck's location. Vehicle tracking can be continuous or intermittent. Geostar is predicted to be accurate within several dozen feet. Location information can be relayed back to the truck or to the fleet office.

Proposed commercial **mobile satellite services (MSS)** will provide satellite-based cellular telephone service. They have proposed similar two-way location services and could be linked to Loran-C and GPS equipment.



VMS **Vehicle Management Systems** are onboard computers with sensors to record mileage, speed, rpms, engine temperature, etc. The newest VMS systems provide a keyboard and display screen permitting the driver to enter information and recall information (e.g., fuel purchased, delivery instructions). Data from other systems, such as AVL, can be stored for later retrieval or transmission to the fleet office.

arios were generated for organizing and managing a national HVM system. The system scenarios explored different market arrangements, technologies, and levels of public and private sector participation. Fifteen scenarios (including wholly public, wholly private, and joint public-private management schemes) were developed and screened; the seven most viable were assessed in detail, and three (a private-sector satellite-based system, a private-sector roadside-based system, and a state roadside-based system) were recommended for further consideration as models for a national HVM system.

Cost-benefit analyses were conducted on three applications that might be undertaken by a state HVM system—data collection for highway planning, design, and research; weight enforcement; and automatic clearance of trucks through weigh stations and ports of entry.

The findings reveal that there is a large potential market for heavy-vehicle monitoring, but it is highly fragmented with several distinct markets rather than a single, unified national market. State agencies need heavy-vehicle monitoring data for highway planning, design, and research; weight enforcement; and weigh station clearance. Long-haul, variable-route motor carriers need on-demand communication and truck location information for fleet and driver management. In addition, there are emerging markets for heavy-vehicle monitoring information for toll collection, marine, rail, and truck terminal management, and the monitoring of shipments of very hazardous materials.

Deployment of a national HVM system, as a single system or as a set of complementary systems, is technologically feasible. The components—WIM, AVC, AVI, AVL, OBC/VMS, telecommunication systems, and computers—are available or under development. Current research, testing, and demonstrations will address the outstanding issues of reliability and cost-effectiveness.
standing issues of reliability and cost-effectiveness.

There are no legal objections within existing statutes and case law to the use of WIM for the collection of truck weight data for weight enforcement and planning purposes. Similarly, there are no legal objections to the use of AVI as an "electronic license plate" for the identification of vehicles. Vehicles are not equated with individuals, and the courts have generally held that persons traveling in a vehicle on a public road have no reasonable expectation of privacy.

Nevertheless, constitutional challenges to mandatory AVI are likely. Drivers who operate trucks on an employment basis for large companies will have little basis to object, but owner-operators are in a position to argue that the location of their truck is the same as their personal location for a large proportion of the time, including extended periods when they are strictly off-duty. It is expected that the privacy issue will be decided on the degree of perceived intrusion created by an HVM system that employs AVI. A thin system of AVI stations, similar in effect to the automation of existing weigh stations, is not likely to be equated by the courts with a continuous surveillance system that threatens an invasion of privacy. A dense or thick net system capable of continuously tracking a vehicle comes closer to the type of surveillance to which truck drivers object and may be close enough to monitoring to attract judicial sympathy for a constitution challenge.

There is no apparent political consensus among the states or the motor carrier industry on the need for a national HVM system. Within the motor carrier industry, there is support for uniform regulation of the industry and actions, such as a national HVM system, if they facilitate trucking and the competitive position of the industry; but there are countervailing concerns about the confidentiality of business information, the cost-effectiveness of a publicly managed national HVM system, and the equity of state tax administration. Most carriers would strongly prefer to have a private sector corporation manage a national HVM system.

Among states there is strong support for a national HVM system that provided planning data, but limited support for a system to enforce tax administration. On the basis of interviews and surveys of state agency administrators involved in highway operations and motor carrier regulation, only one-third of the states have the necessary technical, managerial, and political resources to mount an HVM system without a national consensus and considerable federal financial backing.

As a consequence, it is expected that three types of HVM systems could emerge. The three systems could co-exist as complementary and competitive services, with one or two eventually dominating. The three alternatives and their maximum market potential in the next few years are: (1) a private-sector satellite-based HVM system(s) providing high quality fleet management and communication services to about 30 percent of heavy trucks; (2) a private-sector roadside-based HVM system(s) providing cost-effective communication, data transmission, and limited fleet management services to about 40 percent of heavy trucks; and (3) a state roadside-based major routes system(s) providing heavy-vehicle monitoring for state data collection, weight enforcement, and weigh station operations. Fifteen to 20 percent of states will develop these systems; several will also develop tax reporting and audit services for participation carriers.

If satellite and roadside systems are offered concurrently, it is expected that there will be substantial overlap with many carriers subscribing to both services. The total market share with overlap would still be about 40 percent of the heavy-truck fleet. This market is comprised of motor carriers who need and can afford sophisticated fleet management support.

The findings concerning the costs and benefits of state HVM applications lead to the conclusion that it is cost effective for states to develop HVM application for data collection, weight enforcement, and weigh station clearance.

With respect to the use of WIM/AVC for data collection to support highway planning, design, and research, FHWA's *Traffic Monitoring Guide* recommends sufficient data collection sessions to achieve 95 percent confidence that the mean values of the truck weights observed are within plus or minus 10 percent of the actual weight of the truck population. This criterion can be achieved for five-axle, tractor-semitrailer trucks (3S2's) using portable WIM/AVC at temporary sites. If permanent WIM/AVC sites are established, this criterion can be achieved for all vehicles with approximately the same number of sites.

Concerning the use of WIM for weight enforcement screening, a strategy of allocating enforcement effort to highway segments and time periods in proportion to the volume of heavy-vehicle VMT combined with randomized deployment of primary- and wing-enforcement teams among those highway segments was judged to be most productive. Benefits to the state were measured in terms of reduced pavement damage; net benefits were greatest at about two and one-half times the current level of effort for an "average state." The cost-benefit analysis conducted in this study suggested that doubling fees and fines for overweight travel would be as effective as doubling the level of enforcement.

The use of WIM, AVC, and AVI for automatic weigh station clearance was found to be feasible and cost effective for states and participating motor carriers. A strategy of preclearing and bypassing AVI-equipped trucks—allowing the trucks to bypass a weigh station at highway speeds without slowing or stopping—generated the greatest net benefits for motor carriers and states. The "average weigh-station state" could expect to break even on its investment in an automatic weigh station clearance system if 15 percent of the statewide heavy truck fleet participates in the program. The primary benefits of an automatic clearance program accrue to participating carriers in the form of lower operating costs from reduced delays. These benefits accrue to legal carriers; clearance programs will have a negligible effect on illegal operators who can detour around weigh stations.

The activities of this project finally lead to the following recommendations:

1. *Recommendations Concerning a National HVM System*

• Develop an open, coordinated national HVM system that comprises satellite, roadside, and state systems.

• Establish a national HVM forum to coordinate the development and resolution of policy and technical issues among these systems.

• Establish state-level HVM forums to coordinate actions by state highway, police, tax, motor vehicle, and motor carrier agencies.

• Establish national training programs for HVM technology and management.

• Promote uniform equipment and information standards.

• Develop model HVM statutes and regulations applicable to public and private HVM systems for enactment by states.

• Revise the *Traffic Monitoring Guide* to support the use of WIM and AVC for data collection.

2. *Recommendations Concerning State Data Collection*

• States should apply WIM and AVC technologies to improve state data collection programs.

• The overall level of deployment should be increased.

• Monitoring should be increased on non-Interstate highways.

• Route segments of longer length should be sampled rather than the short HPMS sections.

• Longer duration weigh sessions should be considered.

• FHWA should revise the *Traffic Monitoring Guide* to support the use of WIM and AVC for data collection.

3. *Recommendations Concerning State Weight Enforcement*

• States should apply WIM technology to improve state weight enforcement programs.

• Enforcement efforts should be allocated proportionally to heavy-truck VMT.

• States should operate weight enforcement teams with primary and wing units to prevent overweight trucks from detouring around enforcement sites.

• Mobile enforcement teams should be deployed on a randomized pattern to prevent systematic detouring.

• States should evaluate their fines and penalties in light of the impacts on pavements and enforcement costs, and increase the average cost of fines for overweight travel as warranted.

4. *Recommendations Concerning Weigh Station Clearance*

• States should apply WIM, AVC, and AVI technology to develop automatic weigh station clearance programs.

• Weigh-station states should adopt a "preclear and bypass" strategy.

• Port-of-entry states should adopt a "sorting" strategy.

• Participation in weigh station clearance programs should be voluntary for motor carriers and states.

• Weigh station clearance programs should be undertaken in concert with a statewide, mobile weight enforcement program as recommended above.

With the completion of this project, the following areas emerge as requiring further research:

• A pilot program in one or more states that would demonstrate the potential productivity gains through actual application of WIM, AVC, and AVI technologies for weight enforcement screening, weigh station clearance, and the reduction of paperwork associated with permits and audits.

- A synthesis of practice to document recent state experience with WIM, AVC, and AVI in sufficient detail to be useful to other states in program planning and implementation decisions.
- Practical research to support improved weight enforcement programs.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

Various types of information on heavy vehicles are collected by federal, state, and local governments to support highway planning and design activities, as well as to carry out weight enforcement programs and tax administration. Collecting and processing this information is extremely costly from the viewpoint of both government and private industry, and in many cases the data are not as complete or as accurate as desired for the intended purpose. In addition to actual dollar costs, the present system suffers from burdensome paperwork (as currently being studied by the National Governors' Association), operator inconvenience and potential hazard, lack of enforcement uniformity, and inconsistency among the individual states. International inconsistency is also a concern. The potential use of the collected information for other purposes (e.g., by private industry in fleet and operations management, and by enforcement agencies in locating stolen equipment) has also not been fully explored.

New technologies in automatic vehicle identification, automatic vehicle classification, and weigh-in-motion are considered to potentially offer a more cost-effective approach to the collection of heavy-vehicle data. The interest in AVI systems, integrated with AVC or WIM, is so great that a group of western states and Canadian provinces has embarked on a multijurisdictional project to demonstrate the utility of an integrated electronic heavy-vehicle monitoring system. This project, called the Crescent Demonstration Project, is limited in scope and is not designed to address all of the questions and problems involved in the implementation of a multijurisdictional, national or international system. As an example, the Crescent Project does not fully address the strategies, sample size, data requirements, data collection systems, institutional issues, and costs and benefits of implementing such an integrated AVI/AVC/WIM system.

Therefore, there is a need to evaluate the feasibility of applying these relatively new technologies at the national and regional levels and to build on the existing knowledge from the Crescent Project and other related studies. Institutional issues such as privacy, access to competitive information, and potential for manipulation and evasion of the system will be major determinants of feasibility and acceptability. These issues will thus play a prominent part in the evaluation.

RESEARCH OBJECTIVE

The objective of this research was to identify and evaluate the needs, issues, requirements, and feasibility of using an automated system (AVI/AVC/WIM) as a cost-effective, statistically sound replacement or supplement to existing heavy-vehicle data collection systems. The research encompassed: (1) the identification of different system-design configurations for the integration of AVI, AVC, and WIM to provide appropriate levels of monitoring and related confidence levels; (2) amount of equipment/automation to achieve different objectives; (3) site location criteria on a state, regional, and nationwide scale; and (4) an economic analysis of issues associated with implementation and operation.

RESEARCH APPROACH

The project research plan addressed five major issues:

1. *Market.* Is there a sufficient market for HVM information to warrant the development and deployment of a national HVM system?
2. *Technology.* Is the technology for heavy vehicle monitoring available, reliable, cost-effective, and appropriate for a national HVM system?
3. *Legal and Institutional Framework.* What are the legal and institutional ramifications of a national HVM system for individual truck drivers? For motor carrier firms? For state agencies? For the Federal Government? For the public?
4. *Organization and Management of HVM Systems.* What alternative HVM systems address the opportunities and constraints posed by the market, technology, and the legal and institutional framework?
5. *Impacts, Costs, and Benefits.* What are the impacts of a national HVM system? Who will pay? Who will benefit? And, by how much?

The research was conducted in seven tasks, as follows.

Task 1—Define the Problem. The issues to be addressed were divided into four areas—market, technology, legal, and institutional issues. Interviews were conducted with more than 300 people in the public and private sectors who would be affected by a national HVM system. Market surveys were conducted of motor carrier firms, owner-operators; and with the assistance of the American Association of State Highway and Transportation Officials (AASHTO), state agencies involved in heavy vehicle monitoring were surveyed. The technological feasibility of HVM equipment and systems was evaluated through literature reviews, analyses, field observations, and interviews. And, finally, statutes and case law were reviewed to explore the legal ramifications of a national HVM system.

Task 2—Develop and Screen Alternative HVM System Scenarios. Alternative HVM system scenarios were generated, each encompassing different markets, technologies, and levels of public and private sector participation. Fifteen scenarios were developed and screened. The seven most viable were assessed in detail.

Task 3—Conduct a Preliminary Assessment. A structured assessment of the seven HVM scenarios was conducted to select three alternatives for further development and assessment. The assessment focused on market shares in both the public and private sectors; operational factors, including the effectiveness of the HVM system for fleet management; economic effects, including effects on competition; and sociopolitical factors, including concerns about government monitoring and tax equity.

Task 4—Prepare an Interim Report. The Phase I Interim Report (January 1987) documented that there was a market for heavy-vehicle monitoring information, monitoring was technologically feasible, and current statutes and case law did not preclude the development of a national HVM system. However, there was no apparent political consensus on the need for a single, integrated, national system, and little expectation that a consensus would emerge within the near future.

That report also recommended that the project explore three complementary scenarios through which such a national system might emerge. These scenarios were: (1) Roadside Corporations Voluntary System, (2) Satellite Corporations Voluntary System, and (3) State Major Routes Voluntary System.

After reviewing the Phase I report, the panel decided to focus on one scenario, State Major Routes Voluntary System; however, the scope of the analysis was substantially increased. The research team was directed to develop and analyze the costs and benefits of three applications that might be performed by a state HVM system: (1) data collection for highway planning, pavement and bridge design, needs studies, and related programs; (2) weight enforcement; and (3) automatic clearance at ports of entry, weigh stations, and other inspection sites.

These applications became the focal points of Phase II of the research project, which involved the following tasks:

Task 5—Analyze Costs and Benefits of the Three HVM Applications. A cost-benefit analysis was conducted of each application taking into account impacts on motor carriers, state and federal governments, shippers and receivers, and the public. Strategies and benefit-cost analyses were developed for incremental and optimal levels of deployment to determine the extent of benefits and costs realized with an HVM system.

Task 6—Outline Implementation Issues. Implementation issues involved in starting up an HVM system were outlined and a demonstration program was sketched out for the states.

Task 7—Prepare a Final Report. This report summarizes the findings from Phases I and II and presents the research team's conclusions and recommendations.

GLOSSARY

The acronyms used in this report are defined, as follows, for the reader's convenience:

ATA American Truckers Association
ATCS automatic train control systems
AVC automatic vehicle classification
AVI automatic vehicle identification
AVL automatic vehicle location
AVL/C automatic vehicle location and communication systems
AVMT automatic vehicle-miles traveled

EDI electronic data interchange
EFT electronic funds transfer
ESAL equivalent single axle load

GPS global positioning system

HELP Heavy Vehicle Electronic License Plate System Development Program
HPMS Highway Performance Monitoring System
HVM heavy vehicle monitoring system

IRP International Registration Plan

LTL Less-than-truckload
LCV Longer combination vehicles

MSS mobile satellite service

NGA National Government Association

OBC/VMS onboard computer vehicle management systems

RDSS radio determination satellite service
RITE radio identification of transportation equipment

SHRP Strategic Highway Research Program

TMG Traffic Monitoring Guide

VMS vehicle management systems
VMT vehicle-miles traveled

WIM weigh-in-motion

FINDINGS—FEASIBILITY OF A NATIONAL HEAVY-VEHICLE MONITORING SYSTEM

MARKETS

A national heavy vehicle monitoring system would provide information on the location and characteristics of heavy trucks and their use of the nation's highways.

The findings of the survey conducted to determine if there was sufficient demand to support the development and deployment of a national HVM system indicated that the potential market for HVM information is large, but highly fragmented. Table 1 is a summary of the potential users of HVM information. The table also gives the primary functions to which they would apply this information.

Within this large potential market, the key market segments are: state highway agencies, state police and state DOT truck weight enforcement units, long-haul, variable-route motor carriers, state DOT weigh stations and ports of entry, weight-distance tax states, very hazardous materials carriers, toll facility operators, interstate motor carriers, and terminal operators.

These markets are described in the following paragraphs starting with the key public sector markets, then key private sector markets, and, finally, joint public-private markets.

State Highway Agencies

State highway agencies need statistical data on truck weights and truck movements for highway planning and pavement and bridge maintenance. Counts of the number of trucks and estimates of vehicle size and axle weight are critical for these functions. The states spend more than $25 million annually on heavy vehicle data collection programs, with current budgets ranging from less than $100,000 to more than $5,000,000 per state. The national average is about $500,000 per state.

To serve this market, an HVM system would have to deploy WIM/AVC equipment in highway travel lanes, but continuous monitoring would not be required because statistical sampling suffices for most highway planning functions.

State highway agency interest in an HVM system is high and will continue to grow as the HELP Program's Crescent Demonstration Project and the Strategic Highway Research Program (SHRP) are implemented. The Strategic Highway Research Program is a multi-year research effort to improve the state of knowledge in asphalt characteristics, long-term pavement performance, maintenance cost effectiveness, concrete bridge protection, cement and concrete durability, and snow and ice control. The program is being conducted under the auspices of the American Association of State Highway and Transportation Officials and administered by the National Research Council. SHRP is establishing 1,560 pavement test sites across the country. In the initial years, the program hopes to have, with the states' assistance, continuous vehicle counts, quarterly vehicle classification samples, and an annual axle weight sample. Longer term plans call for collecting all data continuously.

It is estimated that 80 to 90 percent of state highway agencies would participate in an HVM system that collected truck and axle weight data. (These estimates of the number of states that would participate in the various HVM systems are based on professional judgment supported by this project's survey of state agencies, interviews with state transportation officials, and review of states' experiences with other national highway management and motor carrier regulation.) At present, state highway agencies comprise the single strongest market for heavy truck monitoring information, but the survey of state agencies found no consensus, as yet, on the most appropriate data collection methods, mix of equipment, or strategy for deployment.

State Police and State DOT Truck Weight Enforcement Units

State police and state DOT truck weight enforcement units need data on truck weights for weight enforcement. Exact measurements of gross vehicle weight (within 0.5 percent) and axle weight (within 3 to 4 percent) are desired for enforcement. It is estimated that the states spend more than $120 million annually on weight enforcement programs with current budgets ranging from less than $100,000 to more than $10,000,000 per state. The national average is about $2,700,000 per state annually.

To serve this market, an HVM system would have to deploy WIM and AVC equipment at weigh stations, ports of entry, or in highway travel lanes (for screening). The hours of operation would vary widely by state. Some would operate fixed sites continuously, some only during peak travel periods, and others would operate randomly by hours or by sites.

Fifty to 60 percent of state police and state DOT enforcement units would use an HVM system that collected truck weight data for enforcement purposes. This market is expected to increase over time, but in the interviews and surveys conducted in this study it was found that state police and state DOT enforcement units were conservative in their assessment of the potential benefits of automation. Their current interest in a national HVM system is only moderate.

Weight-Distance Tax States

Weight-distance tax states and other states with mileage-based taxes need information on truck weight and truck movements for the administration of these taxes. Accurate and reliable truck identification and data on miles accumulated in the state are needed for this function.

To serve this market, an HVM system would have to deploy either WIM and AVL or WIM and AVI equipment at state borders, along interstate highways and other principal arterials, and along some lower functional class routes. Data could be

Table 1. Potential users and application of heavy vehicle monitoring information.

PUBLIC SECTOR

- State and Regional Agencies
  - Highway Agency
    - Highway and Facilities Planning
    - Pavement and Bridge Design
    - Transportation Policy and Cost Allocation
  - Motor Vehicle Agency
    - Vehicle Registration
    - Trip Permit Administration
  - Police
    - Weight Enforcement
    - Safety, Size, Speed, and Hazardous Materials Enforcement
    - Registration, Permit, and License Enforcement
  - Port Authority
    - Terminal Management
    - Security
  - Public Utilities Commission
    - Gross Receipts or Usage Tax Administration
    - Operating Authority Administration
  - Revenue Agency
    - Fuel Tax Administration
  - Toll Road Authority
    - Toll Collection
    - Weight, Size, and Speed Enforcement
    - Planning and Design
- Federal Agencies
  - DOD/Military Traffic and Materials Command (MTMC)
    - Hazardous Materials Monitoring
  - DOT/Federal Highway Administration
    - Transportation Planning and Policy Analysis
    - Highway Cost and Revenue Allocation
    - Regulation (including hazardous materials)
    - Design Standards
  - DOT/Research and Special Projects Administration
    - Hazardous Materials Monitoring
  - Federal Bureau of Investigation
    - Stolen Vehicle and Goods Recovery
  - Postal Service
    - Fleet Management
- Metropolitan County/City/Town Agencies
  - Metropolitan County/City Engineer
    - Planning, Pavement, and Bridge Design
  - Police/Fire Emergency Services
    - Enforcement
    - Hazardous Materials Monitoring
  - Transit Agency
    - Fleet Management

PRIVATE SECTOR

- Motor Carriers
  - National/Regional/Intercity (long/medium haul)
    - Fleet Management
    - Vehicle Operation
    - Driver Management
    - Tax Reporting
    - Reducing On-Route Delays
  - Local/Metropolitan (short haul; pickup and delivery)
    - Fleet Management
    - Vehicle Operation
    - Driver Management
    - Tax Reporting
    - Reducing On-Route Delays
- Rail Carriers
  - TOFC/COFC/RoadRailer Operators
    - Terminal Management
    - Equipment Management
  - Hazardous Materials Rail Carriers
    - Fleet Management
- Marine Carriers
  - Container and Ro/Ro Ship Operators
    - Terminal Management
    - Equipment Management
- Freight Forwarders
  - Agents and Brokers
    - Fleet Management
- Shippers/Consignees
  - Manufacturers (just-in-time operations)
    - Fleet/Goods Management
  - Wholesalers/Retailers
    - Fleet/Goods Management
- Service Industries
  - Truck Stop Operators (fuel, repair services)
    - Credit Security
    - Vehicle Location
  - Insurance Companies
    - Vehicle Safety Compliance
    - Hazardous Materials Risk Management
  - Equipment Lessors (truck, rail, marine)
    - Equipment Management
    - Vehicle/Equipment Operation Compliance
- Motor Vehicle Equipment Manufacturers
  - Market Research and Vehicle Design

used for spot checking of records during random audits of motor carriers' reports or for direct estimation of weight-distance tax liabilities, including fuel use taxes, registration fee proration, and mileage-based taxes. The applications will vary considerably by state.

Perhaps 10 percent of the states would use HVM information for tax administration. Although there has been considerable discussion and interest in weight-distance taxation, this will remain a small market—albeit an important market in a very few states—for the near future. Only ten states have enacted mileage-based taxes and, of these, only Colorado administers the tax on the basis of actual operating weight and distance carried. There appears to be no current movement in other states to adopt weight-distance taxes. Proposed weight-distance tax legislation has been defeated readily in several states, and no immediate change in this pattern is anticipated. A recent report on the feasibility of a national weight-distance tax done by Price Waterhouse (*1*) for the Federal Highway Administration suggested that self-reporting by motor carriers would be the most cost-effective method of implementing a national weight-distance tax.

Long-Haul, Variable Route Motor Carriers

Long-haul, variable route motor carriers (i.e., operating unscheduled services over routes that vary by customer) need communication services and truck location information for fleet and driver management. These firms currently spend $1,000 to $1,500 or more per truck annually on long-distance communication services (primarily long-distance telephone).

Frequent, on-demand, two-way communication and approximate truck location are needed to realize improvements in estimating time of arrival, preventing unauthorized stops, improving use of equipment, providing "just-in-time" delivery to manufacturing operations, and improving routing.

To serve this market, an HVM system would have to include either a nationwide satellite-based AVL service incorporating two-way communications or closely spaced, roadside AVI equipment with telecommunication links covering most major truck routes. Service reliability and cost will be the most important factors.

It is estimated that an HVM system offering these services could capture 25 to 35 percent of heavy trucks operating on the nation's highways. There are 1.9 million heavy trucks on the road. Out of this fleet, 1.1 million are used in long haul operations—interstate, regional, and intrastate—beyond the range of conventional two-way radio and cellular telephone services (see Table 2).

Within this group, special commodity carriers and large motor carrier firms are most likely to purchase on-demand communication and vehicle location services for fleet management. More than 500,000 heavy trucks (29 percent of the high priority group) are likely to purchase HVM services (see Table 3).

The motor carrier segments most interested in fleet management service are large, for-hire, special commodity carriers and large, for-hire, general freight carriers, followed closely by private, special commodity fleets—but all are currently looking to private sector satellite-based AVL/C suppliers for these services. Most truckers interviewed would prefer not to participate in a state-managed HVM system because of concerns about confidentiality of business data, possible mandatory use of transponders, reliability, and cost-effectiveness.

A state roadside HVM system would have to meet several criteria in order to compete successfully for this market with satellite-based AVL/C systems or expand the market. These criteria would include nationwide deployment, high reliability, installation and operating costs substantially below that of competitive satellite-based systems, and private sector operation of at least that portion of the system that tracks vehicles for fleet management or tax reporting purposes.

Interstate Motor Carriers

Interstate motor carriers need mileage information for tax reporting. Mileage per state for each individual truck is needed for this function. Carriers spend about $125 per truck per year on tax reporting. The cost for small firms and owner-operators is significantly higher, averaging about $300 per truck annually.

To serve this market, an HVM system would have to deploy one of several technologies—AVL, AVI, or a combination of AVI and onboard VMS computers—capable of tracking mileage by state.

Fifty to 60 percent of heavy trucks might participate in an HVM system that provided data on mileage by state for tax reporting. Already, 15 to 20 percent of heavy trucks are equipped with VMS that can record mileage by state. But cost will be an important factor in capturing this market, because, in the survey, motor carriers rated improvements in tax reporting as relatively less important to their operations than improvements in fleet and driver management, vehicle operations, and reductions in on route delays. Organization and management of the HVM system will also be an important factor in serving this market; the survey found that carriers would be reluctant to participate in a state-managed HVM system because of concerns about confidentiality of business data and equity of tax enforcement among the states.

Terminal Operators

Marine, rail and truck terminal operators are interested in automatic identification of containers, container chassis, refrigeration units, trailers, and truck-tractors for terminal management. Valid and reliable identification is critical for efficient storage and retrieval of equipment in large marshalling yards.

To serve this market, an HVM system would need to provide durable and low cost AVI transponders that can be mounted on containers and trailers and AVI readers that can be linked to the terminal master's office. Because containers are used in intermodal and international service, the HVM system would have to adopt AVI standards so that transponders and interrogators made by different manufacturers could communicate with each other.

The marine container industry is moving rapidly to develop standards for radio frequency identification of transportation equipment (RITE). This is a cooperative effort among container ship operators, container owners, AVI equipment manufacturers, and the Federal Maritime Administration working through the American National Standards Institute. Representatives from the highway and trucking industries are now participating in the RITE meetings.

Thirty percent of truck-trailers may eventually be equipped with AVI transponders for terminal management. Deployment of this equipment will likely be driven by the needs of marine

Table 2. Motor carrier industry market segments.

	SERVICE AREA	ROUTE TYPE	FIRM TYPE	HEAVY TRUCK
HEAVY TRUCKS (>26,000 lbs GVW) 1,919,000	NATIONAL, REGIONAL, INTRASTATE OPERATIONS (beyond two-way radio, cellular telephone range) 1,110,000	VARIABLE ROUTES 615,000	For-hire, Special Commodity, Class II/III	280,000
			For-hire, General Freight, Class II/III	110,000
			For-hire, Special Commodity, Class I	110,000
			Private, Special Commodity Fleet, Medium/Small	115,000
		MIXED ROUTES 280,000	Private, General Freight Fleet, Large	70,000
			For-hire, General Freight, Class I	210,000
		FIXED ROUTES* 215,000	Private, Special Commodity Fleet, Large	50,000
			Private, General Freight Fleet, Medium/Small	165,000
	LOCAL OPERATIONS (within range of two-way radio, celluar telephone) 809,000	VARIABLE ROUTES 117,000	For-hire, General Freight, Class II/III	45,000
			For-hire, Special Commodity, Class I/II/III	72,000
		MIXED ROUTES 487,000	Private, General Freight/Special Commodity Fleet, Medium/Small	485,000
			For-hire, General Freight, Class I	2,000
		FIXED ROUTES* 205,000	Private, Special Commodity Fleet, Large	95,000
			Private, General Freight Fleet, Large	110,000
			TOTAL:	1,919,000

* Predominately Fixed Routes, some Variable

Source: Arthur D. Little, Inc. Estimates

terminal/container ship operators and railroads rather than motor carriers, who generally have less complex terminal operations. Nevertheless, there are large private and for-hire carriers that operate large truck terminals and could benefit from terminal management systems designed to control and document movement into, out of, and within terminals. These markets will grow as more transportation companies automate the door-to-door, multimodal tracking of containers, truck-trailers, and piggy-back trailers as a service to shippers and consignees.

Toll Facility Operators

Toll facility operators are interested in automatic truck identification, classification, and weighing for toll collection, billing, maintenance, and planning. Motor carriers have some interest in reducing delays on route and minimizing the amount of cash that must be carried by drivers. Valid and very reliable truck identification is critical for these functions.

To serve this market, an HVM system would have to provide

Table 3. Participation in HVM system by motor carrier segment.

TYPE OF FIRM	HEAVY TRUCKS	PARTICIPATION RATE PERCENT	PARTICIPATION RATE TRUCKS
For-hire, Special Commodity Carrier, Class I	110,000	60%	66,000
For-hire, General Freight Carrier, Class I	210,000	60%	126,000
Private, Special Commodity Fleet, Medium/Small	115,000	60%	69,000
Private, Special Commodity Fleet, Large	50,000	50%	25,000
For-Hire, Special Commodity Carrier, Classes II/III	280,000	50%	140,000
Private, General Freight Fleet, Large	70,000	40%	28,000
For-Hire, General Freight Carrier, Classes II/III	110,000	40%	44,000
Private, General Freight Fleet, Medium/Small	165,000	40%	66,000
TOTAL	1,110,000		564,000
PERCENT ALL HEAVY TRUCKS	58%		29%

Source: Arthur D. Little, Inc. Estimates

truckers with reliable AVI transponders and equip toll booths with AVI readers linked to automated billing services. To make the service economical for truckers, the HVM system would have to adopt AVI standards so that transponders and interrogators made by different manufacturers could communicate with each other, and truckers would need only one transponder for all participating toll facilities. A regional or national billing service would have to be established and operated under contract with toll authorities.

As many as 60 percent of toll road operators and 45 percent of heavy trucks would participate in an HVM system for automated toll collection services. Interest in automated toll collection and billing is limited today, but growing steadily. Four major toll authorities are currently testing automated systems and others are considering tests.

State DOT Weigh Station and Ports-of-Entry

State DOT weigh station and port-of-entry operators and motor carriers have a common interest in improving and speeding up clearance procedures at weigh stations, ports of entry, and roadside inspection sites. This would be facilitated by automating the identification of trucks and the review of truck registration, operating authority, and permit data, including temporary permits in lieu of registration, oversize/overweight permits, and fuel permits.

To serve this market, an HVM system would need to provide truckers with reliable AVI transponders and equip state weigh stations and other inspection sites with AVI readers and computerized data base services.

Initially, 15 percent of the states and 15 to 30 percent of trucks would participate in an HVM system for weigh station clearance. Motor carrier and state interest in automated clearance is low to moderate at this time except in a very few western states, but the potential market is relatively large and may grow as the success of the National Governors' Association and other standardization efforts grow. Oregon DOT and Oregon motor carriers are presently running a limited demonstration of this service; the results of their demonstration will provide a better indication of the potential of this type of HVM service.

Very Hazardous Materials Carriers

Carriers and shippers of very hazardous materials (nuclear weapons, radioactive materials, very hazardous chemicals, and munitions) need on-demand communications and frequent vehicle location information for fleet management, security, and

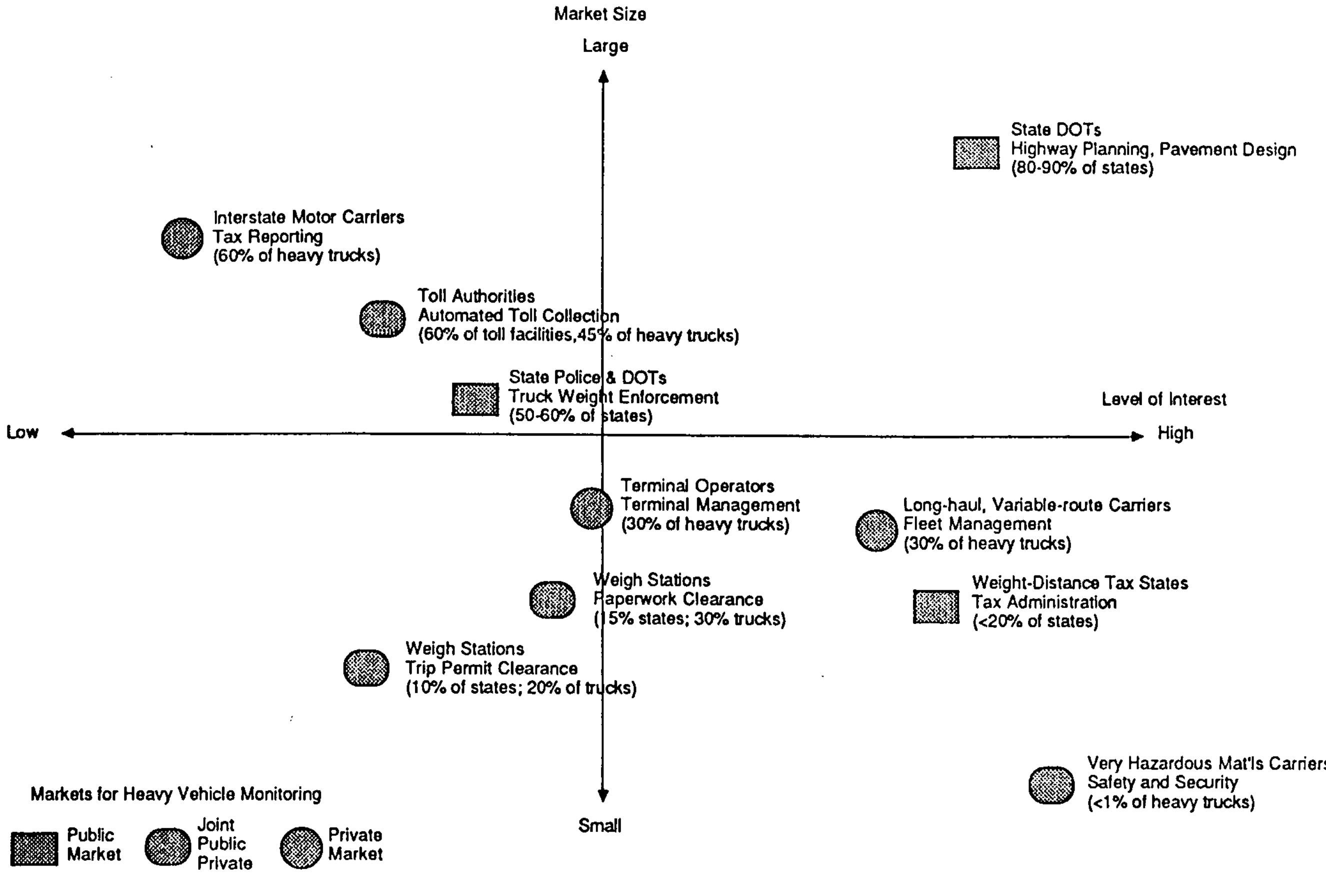


Figure 1. Probable markets for heavy-vehicle monitoring.

public safety. To serve this market, an HVM system would have to provide a nationwide AVL/C service. Reliability and security will be important factors.

This market is less than 20,000 heavy trucks or about 1 percent of all heavy trucks. There are an estimated 467,000 trucks employed in hazardous material shipment, but the majority of these carry liquified petroleum gas and gasoline for local distribution and operate within the range of conventional two-way radio and cellular telephone service.

In summary, there are a number of highly fragmented markets for HVM information. The markets with the highest level of interest in a national HVM system are relatively small. The potential for much larger markets exists, but will take time to develop and organize. Figure 1 shows the relative size and potential interest of the various markets.

TECHNOLOGY

Information on heavy trucks—their whereabouts, characteristics, and use of the highways—would be collected by utilizing new technologies for weighing (trucks)-in-motion, automatic vehicle classification, automatic vehicle identification, automatic vehicle location, and onboard vehicle management systems. This information would be relayed to other locations by ground and/or satellite communication links, processed by computers, and made available to users. Together these systems would comprise an HVM system.

The primary finding, in review of the systems and technologies for heavy vehicle monitoring, is that development of a national HVM system is technologically feasible. The technology is available or under development and appropriate for a national HVM system, but numerous issues of reliability and cost-effectiveness must be resolved before a national HVM system can be implemented. The key findings for each technology are summarized below.

Weigh-In-Motion Technology

Weighing (trucks)-in-motion is an available and appropriate technology. There is sufficient experience with WIM to warrant continued development and deployment. Over the next 5 to 10 years, the number of suppliers of WIM equipment are expected to increase and the unit cost of WIM equipment to decrease from the current level of about $150,000 for load cell installations to a future level of $10,000 to $15,000 for piezoelectric cable technology. The Strategic Highway Research Program, the HELP Program's Crescent Demonstration Project, and increased federal funding for pavement rehabilitation and truck weight enforcement should be sufficient stimuli to ensure continued WIM development.

Of the available WIM systems, piezoelectric cable systems appear to be the most attractive for HVM. They are sufficiently accurate at highway speeds—axle weights are within plus or minus 5 to 15 percent of those obtained from static scales—for planning, weight enforcement screening, and some tax administration functions, but improved accuracy will be needed for actual weight enforcement. Iowa and Minnesota DOTs are currently field testing piezoelectric WIM systems. These tests will help resolve concerns about accuracy, installation costs, and long-term durability and reliability.

Fiber optic cable WIM systems may become an alternative and competitive technology within a number of years. The cost of fiber optics is low, there are many suppliers and, when compared to piezoelectric cable, production quality may be relatively easier to control. As experimental data become available, this issue should be resolved.

It is expected that permanent low speed WIM systems will slowly replace static scales at state weigh stations. The new generation of low speed WIM scales will be accurate enough for weight enforcement and will permit more rapid processing of trucks than the current deep-pit, static mechanical scales.

Capacitive WIM mats and strips are suitable for short-term, dry weather data collection, but are not durable enough for long-term planning or weight enforcement functions.

Highway speed WIM technology is not accurate enough to be used for enforcement under current state truck weight statutes. WIM systems measure dynamic load, but current statutes are written for static load. The forces exerted on the road by the tires of a moving truck as it bounces up and down on its springs can be significantly different from the forces exerted on a static scale when the truck is at a standstill or running slowly on smooth pavement. The magnitude of the difference depends on many factors, including the roughness of the road surface, road curvature, truck speed, and the condition of the truck's tires, springs, and shock absorbers. The road conditions can be controlled to a degree, but vehicle dynamics cannot be controlled. It is anticipated that the accuracy of high speed WIM systems will improve significantly over the next 10 years and approach but not attain the accuracies required by current statutes.

Automatic Vehicle Classification Technology

Automatic vehicle classification (AVC) is an available and proven technology. It is accurate enough for use in an HVM system. There are an adequate number of suppliers, and the SHRP program will generate enough demand for AVC equipment to ensure continued research and development over the next 5 to 10 years.

Vehicle detection loops, a major component of AVC systems, break relatively easily and have a limited life in the pavement. Experience suggests that 25 percent of loops break within 2 to 3 years of installation because they are improperly installed. Replacement costs could become a major problem especially on high volume highways.

Machine vision is a promising new technology that could be used for vehicle detection and vehicle classification. The technology uses small video cameras to view a section of highway. The video image is processed by a microcomputer to detect the shape and movement of vehicles. This is an emerging technology and, if successfully developed, offers a means of studying vehicles and traffic patterns without installing equipment in the pavement and disrupting traffic.

Automatic Vehicle Identification Technology

Microwave, radio frequency, and optical automatic vehicle identification (AVI) systems are available and could be used in an HVM system. Comparative testing is needed to determine which technology is most appropriate for highway and trucking applications. Most of the experience to date with these systems has been in controlled industrial environments and may not be directly transferable to the public highway environment. The Crescent Demonstration Project has started a series of field and laboratory tests that may resolve some of the questions about AVI technology.

Current AVI systems are incompatible. Transponders and interrogators/receivers made by different manufacturers cannot communicate with each other. The highway and motor carriers must set or adopt standards covering operating frequency and data formats, or tolerate proliferation of nonconforming AVI systems and the attendant higher costs and confusion, as they have tolerated, for example, nonuniform fuel use permit systems. The marine container industry is working toward a standard for radio frequency identification of transportation equipment (RITE), but there is no guarantee that the RITE standard will be appropriate for highway and trucking applications.

Active (e.g., battery-powered) transponders may be necessary to ensure acceptable performance when AVI equipment is used at high speeds on multilane highways. Most AVI systems are low power systems, and their accuracy and reliability deteriorate with increasing distance between the "tag" (the transponder on the truck) and the "reader" (the interrogator/receiver antenna). Powered transponders can significantly expand the communication range of AVI equipment improving accuracy and reliability. Active transponders may also help overcome interference problems. Present systems place the reader on the roadside where one passing truck may shadow another truck from the reader or in the pavement of each lane where a truck changing lanes may overlap two antennae with a resulting misread. The Crescent Demonstration field tests are addressing this issue.

Public concern about low energy microwave radiation may limit the use of microwave or near microwave AVI systems to industrial environments, such as marine container and rail terminals. Current microwave AVI systems operate within the safety levels set by the American National Standards Institute (C95.1–1981). Microwave radiation from a pavement antenna will not penetrate the metal flooring of car or truck, and exposure is negligible at highway speeds. Nevertheless, relatively little is known about the effects of low energy radiation and situations may arise (e.g., blocked traffic with the driver outside the vehicle standing on an antenna with an equipment failure that provides full continuous antenna power) that must be taken into account in designing an HVM system for public roadways.

AVI transponders are not tamperproof. Optical systems can be blocked by spray paint or tape; microwave and radio frequency systems can be shut down simply by covering the transponder or the reader with a sheet of metal. All the AVI systems can be temporarily jammed; radio frequency systems are particularly susceptible to electromagnetic interference. Any system that is in widespread use, especially an AVI system used for weight enforcement or tax administration, will be tampered with and counterfeited and there will be a black market in stolen equipment.

AVI transponders can be linked to onboard computers (e.g., vehicle management systems) or electronic odometers and used to transmit information to or from roadside readers linked with computers. This technology could be used to automate permit and other paperwork clearance at weigh stations, log state line crossings, or report odometer readings at state borders.

Active, infrared (optical) AVI systems are an available and applicable technology that may be appropriate for some HVM functions. Transponders can be mounted on the inside of the cab windshield and connected to a vehicle management system. Signal-to-noise ratios can be very high and data transmission rates are more than adequate for AVI functions. Infrared radiation at the levels used in current equipment (e.g., home television remote control devices) does not pose a known health risk.

Automatic Vehicle Location Technology

For the motor carrier industry, frequent or on-demand communication is of primary importance for fleet management. Vehicle location is of secondary importance and for most long haul operations can be very approximate.

The technology available for automatic vehicle location is changing rapidly. In particular, satellite-based radio location and land mobile communication services look very promising and could significantly improve productivity in some segments of the motor carrier industry; however, neither has yet been fully proven out in commercial service. Current performance specifications and costs are based on estimates and early tests; more time will be needed to evaluate the full impact of these services.

Radio determination satellite service (RDSS) will provide digital communications and automatic vehicle location. If successfully developed, RDSS systems, such as Geostar, are likely to capture a dominant share of the motor carrier market that needs frequent, on-demand communication and vehicle location for fleet management. RDSS will provide AVL and limited two-way digital message communications.

Mobile satellite service (MSS) (a coupling of satellite communications with cellular mobile telephone service) will provide voice communications. Automatic vehicle location can be added to MSS. MSS is still in the early stages of development, but it could be a major competitor to RDSS because it can provide both voice and data communications.

The satellite-based NavStar Global Positioning System (GPS) and the ground-based Loran-C navigation system have a limited market among long distance motor carriers as stand-alone vehicle location systems. But these AVL systems can be combined with conventional mobile communications systems to provide local/metropolitan fleet management services or, eventually, linked with MSS to provide regional and national coverage.

RDSS, MSS, GPS, and Loran-C systems are accurate enough for most motor carrier fleet management functions, but are not accurate enough to distinguish between adjacent trucks and, therefore, may not be acceptable for truck enforcement activities.

A network of AVI sites can be used as a proximity vehicle location system; however, the effectiveness of these systems is limited by the coverage and density of the network.

Vehicle Management Systems (Onboard Computers)

Vehicle management systems (VMS) are an available and applicable technology. VMS are well established as a major tool for vehicle and driver management. Fifteen to 20 percent of heavy trucks are currently equipped with VMS. There are more than a dozen established manufacturers supplying equipment spanning a wide range of sophistication and price. The next generation of heavy trucks will integrate computerized engine and transmission controls with VMS computers. This will make VMS a more useful tool for the motor carrier.

Future vehicle management systems will store, manage, and track much of today's truck paperwork—mileage tax reports, permits, waybills, shipping papers, and operating authorities. Motor carriers with sophisticated fleet management systems will link VMS and fleet communications equipment.

Telecommunication Technology

Virtually all of the anticipated telecommunication needs of a national HVM system can be met with existing technology, whether by dedicated systems (e.g., private microwave in remote areas) or by common carrier services in developed areas.

Computer Technology

The computer technology for large transaction-based data processing systems is available, well established, and appropriate for an HVM system. The cost of designing and maintaining the computer software for a national HVM system will be a major consideration in determining its cost-effectiveness. With proper investment in engineering and design, current microprocessor technology can serve all anticipated onboard vehicle and roadside HVM applications. Available technology should meet all anticipated environmental and durability requirements.

LEGAL IMPLICATIONS

A national HVM system would be a complex sociotechnical system affecting millions of people and many organizations.

In exploring the legal and institutional ramifications of a national HVM system for individual truck drivers, motor carrier firms, government, and the public, there was nothing in the legal literature on heavy-vehicle monitoring systems per se. The discussion that follows, therefore, is based on a review of statutes and case law in the following areas:

- Data confidentiality and privacy.
- Use of beepers and electronic tracking and monitoring devices.
- The law of search and seizure as it pertains to new electronic technologies.
- General protection of privacy, particularly as reflected in certain vehicle controls, such as drunk driving roadblocks.
- Standards of proof which may be applied to WIM and AVI technologies when used in court, as derived from the experience with radar speed enforcement.
- Implications of the Interstate Commerce clause of the U.S.

Constitution and the extent to which states may independently deploy and require AVI technology.

Use of WIM for Weighing and Weight Enforcement

There were no objections to the use of WIM for the collection of truck weight data for weight enforcement and planning purposes. Weighing a truck in motion is a faster and, potentially, less costly means of enforcing weight limitations, but is not substantially different from the weight enforcement done at state weigh stations and ports of entry. For most planning purposes, the identification of particular vehicles is not required. The important elements of highway use data are vehicle type, size, axle weight, and axle spacing. The use of WIM and AVC equipment to collect planning data, stripped of all individual identifiers, would not present a problem.

Under existing statutes, current WIM technology is not accurate enough for enforcement, but could be coupled with AVI to identify and screen overweight trucks for subsequent weighing on static or slow speed WIM scales. While current technology precludes the widespread use of WIM and AVI technology for direct truck weight enforcement, further refinements of WIM technology are likely and may make direct enforcement possible in the future. In that case, the use of WIM and AVI would be analogous to the use of radar for speed enforcement. All major states now take judicial notice of the scientific facts underlying radar measurements and usually require only that the state prove that the enforcement officer was trained and experienced in the use of radar and the particular machine was regularly calibrated according to standard, documented procedures.

Use of AVI for Vehicle Identification

No valid legal objection was found to the use of AVI technology for vehicle identification at given points where the government currently monitors traffic. AVI technology provides an extension of the sensory capabilities and equipment now available to state officials. AVI is an electronic license plate identifying the vehicle through a "characteristic pattern of electromagnetic radiation." The reflected light waves that make an existing license plate visible are also a "characteristic pattern of electromagnetic radiation."

There were no valid legal objections to the use of AVI for the identification and recovery of stolen vehicles. Recovery of stolen vehicles is within the police powers of the state, and the use of AVI to assist this function is no different, legally, from the same activities performed now by a state policeman.

Use of AVI or AVL to Track Vehicles

If participation by the motor carrier is voluntary, the use of AVI or AVL to track trucks for fleet management and administration of weight-distance or other mileage-based taxes is not a legal issue.

Mandatory tracking of trucks for weight enforcement or tax administration would be a major departure from the current practice of random checks and self-reporting and raises in critics the charge that such use would create an element of "Big Brother" surveillance. It is not clear that current statutes and case law would interpret such a system as an impermissible intrusion on protected rights.

Data confidentiality statutes provide limited protection and would not, as currently written, preclude development of mandatory AVI systems. These statutes generally cover only transmission of data between government agencies for uses beyond the original intent; notice to data subjects of requests for such transfers; provisions to prevent unauthorized access to personal databases; and opportunity to inspect and correct personal data files. If the purposes for which an HVM database (built from AVI data) are clearly stated and, if the database is built and managed according to regulations governing such databases, the HVM system would not be subject to attack under most government data privacy statutes.

Under current case law, tracking a vehicle with AVI or AVL would not necessarily infringe upon a truck driver's constitutionally protected rights. No case could be found that equated a vehicle identification number with an individual personal identifier. Moreover, the courts have generally held that a person traveling in a vehicle on a public thoroughfare has no reasonable expectation of privacy in his movements from place to place. There would be no expectation of privacy if the driver knew that the truck was equipped with an AVI transponder.

Some states have explicit constitutional protections of the right of individual privacy, but even these provisions may not necessarily invalidate the vehicle tracking capability of an HVM system because these states do not equate a vehicle with an individual.

The danger to privacy created by an HVM system comes, not from any one observation, but from the assembly of a database of many readings that would enable a government to know where a vehicle has been or to track it at any given time. Drivers who operate trucks on an employment basis for large companies will have little basis to object, but owner-operators are in a position to argue that the location of their truck is the same as their personal location for a large proportion of the time, including extended periods when they are strictly off duty.

It is expected that the privacy issue will be decided on the degree of intrusion created by an HVM system. A thin net of AVI stations capable of collecting information on vehicle movements adequate for audit purposes—in effect, the automation of existing state port-of-entry and weigh-station observations—but incapable of tracking a vehicle, is not likely to be equated by the courts with a continuous surveillance system that threatens an invasion of privacy. A dense or thick net system capable of effectively tracking a vehicle for weight-distance tax administration—or for that matter, fleet management—comes closer to the type of surveillance to which truck drivers object and may be close enough to monitoring to attract judicial sympathy for a constitutional challenge.

Barriers to Interstate Commerce—Consistency of AVI Requirements

Requirements that motor carriers use different AVI transponders from one state to another are likely to be struck down by the courts as interfering with interstate commerce by imposing an unreasonable burden on the carrier. This problem can be avoided by establishing model or advisory AVI standards.

INSTITUTIONAL ISSUES

A national HVM system would create new capabilities and redefine the relationships among motor carriers, government agencies, and shippers/receivers. These relationships are shaped by a complex web of tradition, law, politics, organizational culture, and the attitudes of individual managers and officials. The willingness and ability of managers and officials to accept new capabilities and redefine relationships is crucial to the success of a national HVM system.

The survey conducted during the course of this study in order to define current relationships and attitudes toward change revealed that there is little consensus within the industry on the proper role of a national HVM system and its appropriate functions. There is support for uniform regulation of the motor carrier industry across states and actions that facilitate trucking and the competitive position of the trucking industry, but motor carriers are very concerned about the confidentiality of business information, cost-effectiveness of a national HVM system, and equity of state tax administration. In the survey, interstate motor carriers, in particular, expressed concern that a national HVM system, if deployed only on interstate highways and used primarily for tax administration, might be used to discriminate against them in favor of local and intrastate carriers.

Motor carriers strongly prefer to have a private sector corporation manage a national HVM system. The three clear choices for management of a national system that emerge from the survey of motor carriers are: (1) a private corporation acting under contract to government and industry and providing data services to each; (2) a trucking industry organization; or (3) self-reporting by motor carriers using their own data collection systems.

Strong state support was found for an HVM system that serves highway planning and maintenance functions. Most of the states are actively planning improvements in their current data collection programs using available WIM and AVC technology. Several state DOTs are interested in testing and demonstrating the newest HVM technology, and most of these are actively working to develop cooperative relationships with the motor carrier industry.

There is little state support for an HVM system for expanded tax and weight enforcement programs. The motor carrier industry has expressed great concern that HVM technology will be used to extend weight-distance taxes to other states, but only a very small percentage of states expressed interest in using an HVM system to expand tax and weight enforcement. The states most strongly interested in HVM for weight-distance tax administration were those that already have high weight-distance taxes. They were joined by a very small percentage of motor carriers, principally those in states with high tax evasion rates, who were supportive of government actions to dramatically improve tax compliance and "keep the competition honest."

Only two-thirds of the states have the staff, technical resources and financial capacity to mount an HVM program. It is judged that one-third of the states could develop some form of heavy vehicle monitoring capacity on their own initiative; another one-third might develop systems after others have demonstrated the feasibility of HVM and if funding is available; but the remaining one-third of states lack the resources and political commitment to implement a system until and unless there is a concerted national effort to develop an HVM system that is heavily supported by federal funding.

The initiative in developing a national HVM system is likely to remain with the states. The monitoring of heavy trucks is inextricably bound up with public policy issues, foremost among which are taxation, public safety, and the cost of repairing excessive damage to the highways caused by overweight trucks. In the past, states have treated the taxation and regulation of trucking as states' rights and have jealously and independently protected their ability to set policy in these areas. This attitude probably will influence the states' participation in a national HVM system.

Counterbalancing this pattern is the recent success of the National Governors' Association in shaping a consensus on uniform state approaches to fuel use taxation, retaliatory taxes, vehicle registration fee proration, and other regulatory issues. This success has given the states a positive model to follow and created a framework within which the states can talk to each other. This has aided the HELP Program; HELP's relative success in attracting state participation and funding has created a new framework, albeit contentious and fragile, within which the states can talk to each other and to the motor carriers about HVM.

Nevertheless, experience with the International Registration Plan and other efforts to achieve uniformity in state regulation of the motor carrier industry suggests that consensus on a single, integrated, national HVM system will be slow to develop.

The Federal Government has adopted and is likely to maintain a relatively passive role in the development of a heavy vehicle monitoring system. The Federal Highway Administration has encouraged the HELP Program with direct and indirect funding and has strongly supported other innovative work on WIM and AVC, but has left policy formulation, management, and implementation of the HELP Crescent Demonstration almost entirely to the states and the motor carriers. FHWA adopted the same approach with the National Governors' Association effort—offering encouragement, support, and spurring the states on by hinting that if the state effort failed, the Federal Government might be forced to intervene—but refrained from taking a leadership role. It is believed that FHWA will follow suit on the issue of a national HVM system.

ORGANIZATION AND MANAGEMENT

A national HVM system must be organized and managed so that it successfully addresses the opportunities and constraints posed by the market, technology, and the legal and institutional framework.

The 15 alternative HVM system scenarios that were developed to explore alternative ways of organizing and managing a national HVM system were differentiated by ownership and management (private ownership and management, public sector ownership and management, or joint ownership and management); principal technologies/services (roadside-based—e.g., AVI, AVL using AVI, WIM, and AVC—or satellite-based—e.g., AVL using GPS, Geostar, or mobile satellite cellular telephone services); primary markets (state DOTs, interstate motor carriers, toll road operators); deployment pattern (borders, major truck routes, or network); and participation—whether voluntary or mandatory. Figures 2 and 3 categorize the scenarios by ownership and management approach. The fifteen scenarios are described in Appendix D, Figure D-1.

Those scenarios that were judged to be infeasible or less ef-

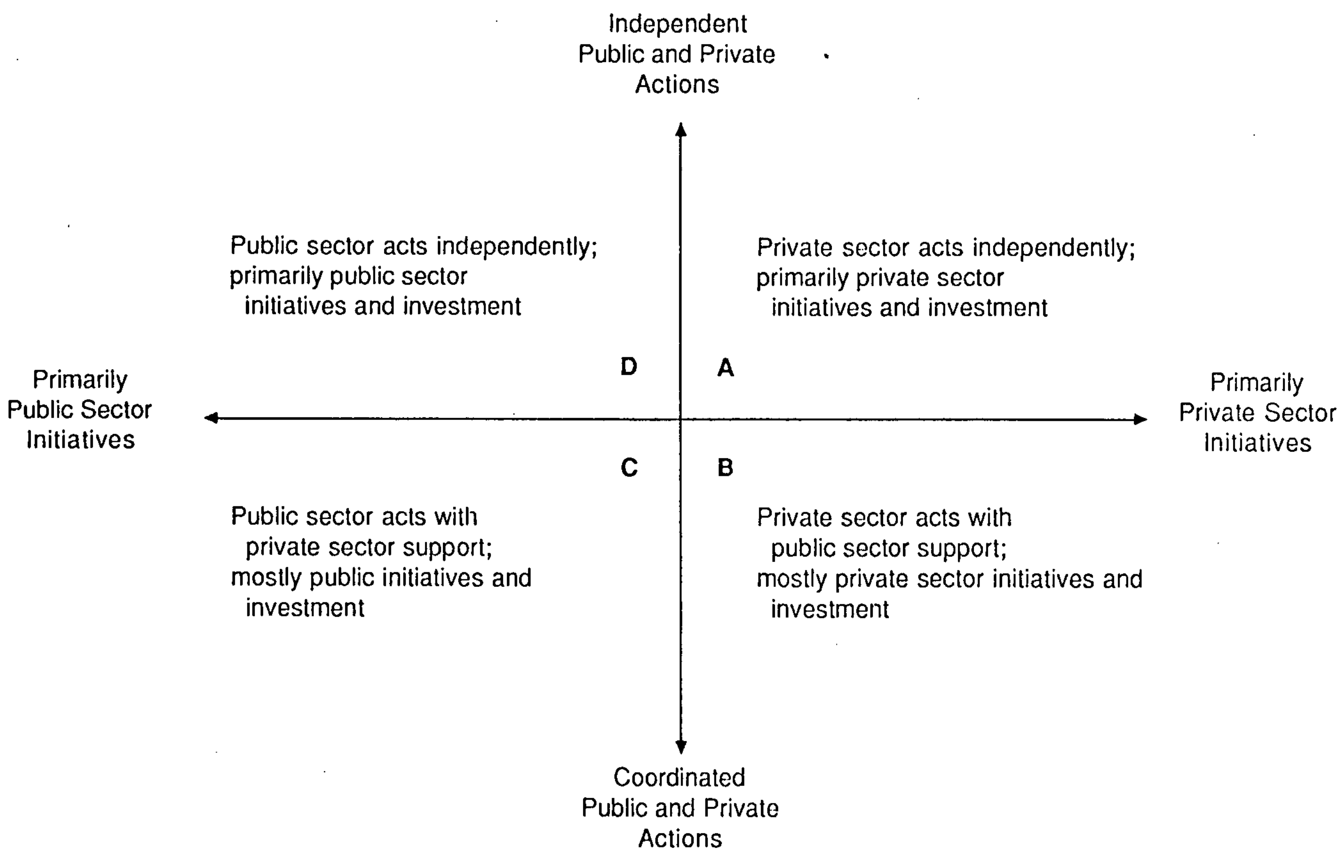


Figure 2. Framework for organization and management of national HVM system scenarios.

fective and more costly than current practices were eliminated. Seven of the scenarios were subsequently developed and assessed in detail:

A1: Fragmented Market (as a base case)
B1: AVI Standardization
B2: Roadside Corporations Voluntary System
B3: Roadside Corporations Mandatory System
B4: Satellite Corporations Voluntary System
C2: State Voluntary Major Routes System
D3: National Mandatory Major Routes System

The assessment criteria included: market penetration (state and motor carrier participation); operational impacts (on fleet management, reliability of HVM information, cost-effectiveness, and on-route delays); economic impacts (on industry concentration and competition, risk and cost of system failure, confidentiality of business and tax data, and tax reporting); and sociopolitical impacts (on individual privacy (e.g., truck drivers), government intrusion, tax equity, and likelihood of achievement).

The assessments are summarized in Appendix D, Figure D-2. The primary findings are discussed in the following.

The three most viable scenarios are: B2: Roadside Corporations Voluntary System, B4: Satellite Corporations Voluntary System, and C2: State Voluntary Major Routes System. The major barriers to the development of these scenarios are political and institutional and arise because of significant differences between the major markets that a national HVM system must serve.

The two major markets are state highway agencies, which need HVM information for highway planning, enforcement, and maintenance functions; and motor carriers, which need HVM information for fleet and driver management. The most appropriate technologies for the state highway market are WIM, AVC, and roadside AVI equipment. These technologies must be installed in the pavement or proximate to the roadway. The fleet management needs of the motor carrier market are most effectively served today by onboard computers, mobile cellular telephones, long-distance telephone/telex/data communication services. These services require equipment onboard the truck, but are increasingly independent of roadside installations.

A national system organized along the lines of scenario C2, State Voluntary Major Routes System, could serve the needs of the state market. Several states and the HELP program have already demonstrated that the public sector has the capability to organize and deploy in-pavement and roadside-based HVM technology and provide HVM information for planning, en-

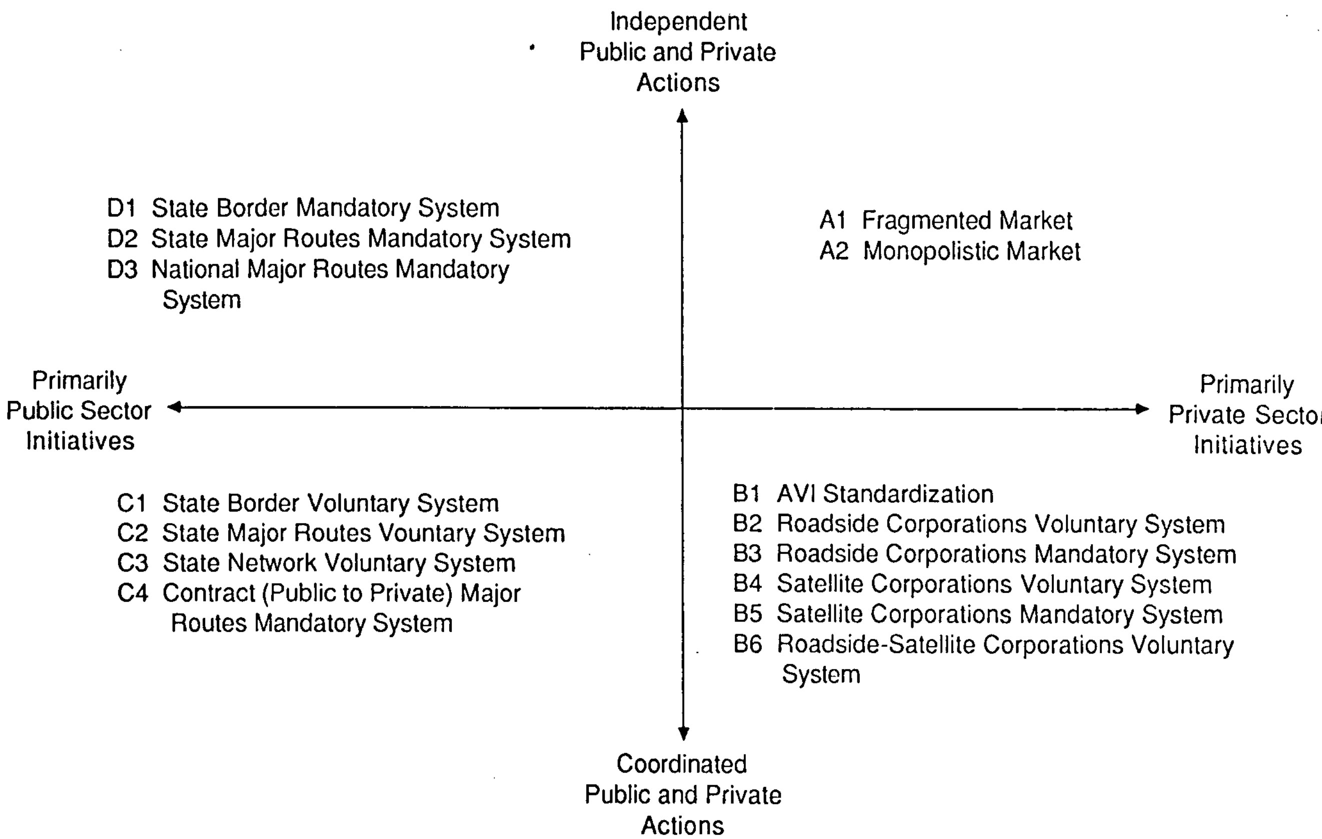


Figure 3. National HVM system scenarios by public-private role in organization and management.

forcement, and maintenance; however, there are significant barriers that would make it difficult for such a system to effectively serve the fleet management needs of the motor carrier industry.

Primary among these is the lack of consensus among states on the need to provide fleet management services to motor carriers, Without that consensus, deployment of a roadside AVI network for fleet communication and location would be very difficult, and the result is likely to be a patchwork of less-than-nationwide coverage. Effective fleet management services could not be provided under these circumstances.

Satellite-based services are the logical solution to the patchwork problem posed by an incomplete roadside AVI network, but there is little likelihood that states will develop satellite services for the motor carrier fleet management market in competition with private sector entrepreneurs. The satellite systems are high-technology, high-cost, and high-risk operations, for which few states are organized or have the resources to undertake. A public sector national HVM system could manage contracted satellite services, but it is not clear from the analysis that this would be a cost-effective arrangement for motor carriers. Federal government mandates and financial participation could overcome both of these barriers, but such action is unlikely, except in the area of WIM/AVC applications for planning and enforcement.

A second, more intractable barrier to the public provision of motor carrier fleet management services is the attitude of motor carriers. Many are anxious about the potential for government intrusion into business operations, and most would strongly prefer to have a private sector corporation provide their fleet management services. In this environment, a public sector national HVM system would have difficulty capturing a significant share of the motor carrier fleet management market against competition from private firms.

A single, national system that is organized within the private sector along the lines of scenarios B2, Roadside Corporations Voluntary System, or B4, Satellite Corporations Voluntary System, would face comparable barriers. It could capture only a portion of the market for HVM services. A private system could install WIM/VAC and AVI equipment and contract with the states to provide highway planning and maintenance data, but the states would be reluctant to relinquish control over WIM/AVC/AVI equipment used for safety, weight, or tax enforcement. And, it is not clear that a private sector national HVM system deploying roadside AVI equipment would be any more successful in providing fleet management services to motor carriers than a public sector national HVM system. A number of private companies now provide nationwide fleet management services including messaging, voice and data communication, and permit and cash transmittal. These companies could install roadside AVI equipment and expand their fleet management services, but they must gain state authorization to install the equipment. Lacking a national consensus, there is no guarantee that all states would participate in the system without federal intervention and, consequently, no guarantee that private operators could provide adequate geographic coverage for roadside AVI fleet management.

Nor is it clear that a private sector national HVM system could integrate roadside and satellite fleet management services within a single organization. These services compete for many of the same motor carrier markets. If they were lodged within the same organization, there would be pressure on management to favor the more profitable of the two services, perhaps to the disadvantage of motor carriers.

For these reasons, it is anticipated that no, single, integrated, national HVM system will emerge; rather, one expects that all three systems—a private sector satellite system, a private sector roadside system, and a state roadside system—will evolve to serve the national HVM markets.

The private sector satellite system will provide high-quality fleet management and communication services to about 30 percent of heavy trucks. There will likely be several competing suppliers employing emerging RDSS and MSS technologies. The satellite system will provide national coverage. With private sector operation, confidentiality will not be a major issue. Successful integration of satellite location and communication equipment into existing fleet operations will be a technical and managerial challenge. The services will be most attractive to special commodity carriers and large firms that can make use of fleet management. The private sector satellite system is unlikely to provide roadside WIM, AVI, AVC technology and services and, therefore, is unlikely to capture the public markets and joint public-private applications, such as weigh station clearance and toll collection.

The roadside-based communication and data collection systems will provide cost-effective communication, data and credit transmission, and limited fleet management services to about 40 percent of heavy trucks. These systems will develop from existing private sector wire transmittal and information services that currently provide permit services, fuel credit checks, and messaging. Service will likely be limited to major truck routes. Some of the roadside systems will contract with state highway agencies to provide data collection services. In general, it is expected that roadside-based services will be priced to handle larger volumes of data at lower costs and on less critical timelines than the satellite systems. Many carriers will use both satellite- and roadside-based services.

The state roadside-based systems for data collection, weight enforcement, and weigh station clearance will be developed in about 15 to 20 states. These systems will primarily serve state markets. Several of these states also will develop tax reporting/audit services for participating carriers.

The nation will realize substantial economic benefits from the development of these systems. Greater benefits can be achieved if the public and private sectors encourage the coordination of these systems in a manner that fosters innovation in the development and delivery of HVM services. The efforts of the public and private sectors should be directed towards identifying overlaps between markets and services where action on common needs will unify and enlarge the markets with payoffs in innovative applications, lower costs, wider acceptance, and greater productivity. There are numerous precedents where industries have developed open coordinated systems that serve many users with differing needs and realize benefits that could not have been achieved without this coordination. Successful examples are the magnetic ink recognition codes on bank checks; the electronic funds transfer system employed by the banking industry; the universal product code developed by the grocery industry; the national airlines reservation systems; protocols used for electronic data interchange; standards developed for vehicle maintenance reporting; and the automatic train control system standards being developed by the railroads.

CHAPTER THREE

FINDINGS—STATE HEAVY-VEHICLE MONITORING APPLICATIONS

WEIGHT ENFORCEMENT

The area of weight enforcement using WIM technology was selected for detailed analysis because of initial research which suggested that this area could achieve potentially the highest net benefits of all the functions and areas to which HVM systems could be applied. Therefore, attention was devoted to refining estimates of all key factors that affect the success of using WIM for weight enforcement, and performing detailed sensitivity analysis of the major factors.

The analysis considers the costs and benefits of deploying WIM as a means of deterring travel by overweight vehicles. The results have been calculated on a large Lotus 1-2-3 spreadsheet, described in more detail in Appendix A. The analysis models nationwide travel by overweight trucks by functional class of road, and estimates the probability that the overweight travel will be affected by enforcement. Travel is modeled by trip length and functional class of highway. It estimates the public costs of overweight travel before and after deployment of weight enforcement teams. It also estimates the costs and benefits to motor carriers of overweight travel based on trip length, functional class of road used, revenue per ton-mile, truck operating costs, fine structures, and the deployment strategies employed by the enforcement agencies.

The spreadsheet modeling procedure can be used on behalf of the entire nation, or a single state, or group of states, to calculate the costs and benefits of weight enforcement efforts under a variety of conditions. Appropriate types and levels of deployment can be determined using data specific to an individual state and road system, such as data on overweight truck travel gathered using unobtrusive WIM equipment. The impacts of many potential policies, such as changes in fines or penalties, off-loading requirements, and new uses of WIM equipment can be modeled prior to major expenditures of time or resources by state personnel. The analysis procedures developed should prove of substantial help to the Federal Government, the states, and toll authorities, in determining appropriate policies for weight enforcement.

Most of the attention in this analysis is devoted to the use of WIM in combination with portable scales, where the WIM would be used as a screening device to select likely overweight vehicles for weighing. Deployments at various levels across the functional classes of highway are assumed to cause overweight travel to be deterred if the likely cost of traveling overweight exceeds the benefit to the motor carrier of traveling overweight on that type of truck trip. The primary findings of the analyses are summarized in the following.

Current weight enforcement efforts are neither equitable nor cost-effective. The states now pursue weight enforcement through the use of fixed weigh stations, ports-of-entry, and portable scales. All trucks, or at least all loaded trucks, approaching these weight enforcement sites are stopped and weighed. However, most illegally loaded trucks avoid enforcement by waiting until they close or by detouring around these sites, whose locations are well known and publicized. As a consequence, the overwhelming majority of trucks that are stopped at weigh stations, ports-of-entry, and even portable scale sites, are operating legally. This imposes a time penalty on legally loaded motor carriers, but does not deter overweight operators. It is estimated that, nationally, current enforcement practices cost the public about $138 million annually. If this level of effort were used instead in a program such as recommended here, it could realize about $302 million in benefits, primarily deterred wear and tear on highway pavements, for a net benefit of about $164 million.

Weigh-in-motion equipment could be used to rectify problems of equity and cost-effectiveness in weight enforcement. WIM can be used by weight enforcement teams to screen approaching trucks so that only those trucks that the WIM screening units indicate are overweight are stopped for static weighing. This would reduce the time penalties imposed on legally loaded motor carriers. And, because WIM equipment promises to be relatively inexpensive compared to current fixed weigh scale technologies, weight enforcement efforts can be increased and teams deployed more widely across highway systems. This would help improve the cost competition among motor carriers by making it more difficult for illegally loaded carriers to detour around weight enforcement sites and significantly increasing the risk and cost of overweight travel.

There are three strategies by which a state might deploy WIM equipment to improve weight enforcement: (1) uniform deployment strategy, where each road segment in a given highway functional class would be given the same probability of enforcement occurring, regardless of the volume of heavy trucks it was carrying; (2) proportional deployment strategy, where enforcement efforts on each functional class and road segment within classes are proportional to its share of the vehicle-miles of travel (VMT) by heavy trucks; and (3) focused deployment strategy, where enforcement would be concentrated on those roadway segments within each functional class of highway that experience the highest vehicle-miles of travel by heavy trucks.

The proportional deployment strategy appears to be the most attractive strategy from the viewpoints of cost-effectiveness, equity, and feasibility. A maximum net benefit of $525 million is attained by investing $342 million annually to obtain a conservative estimate of about $862 million in savings due to deterred overweight travel. This level of effort is within reach; it is about 2.5 times higher than the current annual level of expenditures and would amount to $6.8 million per state compared to a current expenditure of $2.8 million per state.

The focused deployment strategy can generate a slightly higher net benefit than the proportional strategy for the same level of public expenditure. However, because it is highly focused and enforcement would occur repeatedly and predictably along the same road segments, it would suffer the same evasion problems as current enforcement approaches and rapidly be rendered ineffective.

The uniform deployment strategy generates lower net benefits than the proportional deployment strategies.

A highly randomized pattern of enforcement by road segment and time period provides for greater deterrence than a regularized enforcement pattern, which is easily discerned and avoided by operators planning to carry illegal loads. This analysis suggests that it is almost always appropriate to deploy enforcement teams that consist of a primary crew and a wing crew operating in tandem. Because most truck drivers receive timely CB radio communications about enforcement activities, a wing team is necessary to intercept those operators taking detours or stopping to avoid the primary team. A wing team could either operate on a parallel route or along the primary route, coming up on, and weighing trucks stopped upstream of the primary team.

Higher fines are a strong economic deterrent to illegally overweight travel. States could achieve the same level of net benefits with lower levels of deployment by increasing the fines for illegally overweight operations. It is feasible to increase current average fine schedules and greatly improve the cost-effectiveness of most state enforcement efforts.

The cost-benefit model developed for this research project can be applied to a single state using state-specific data on truck travel, deployment of enforcement teams, operating costs, and pavement conditions. The factors influencing the costs and benefits of deploying WIM for weight enforcement are each discussed below, after a brief discussion of the overall structure of the weight enforcement analysis.

Framework of Analysis

The analysis has considered all the factors that will influence the costs and benefits of enforcing weight limits with the assistance of WIM. The analysis has been divided into a number of modules because of the great complexity of the calculations necessary to arrive at the determination of costs and benefits, given any particular input parameters and deployment strategy.

Briefly, the relative costs and benefits of overweight travel to operators and to highway agencies are determined by the following factors:

- The distribution of heavy truck travel and of overweight truck travel by functional class of road, by road segment, and by time period.
- Truck trip lengths, and the proportion of vehicle-miles of each trip which occurs on the various functional classes of highway.
- The benefits of overweight travel to the shipper or truck operator, in terms of increased revenue for the overweight trip.
- The costs of overweight travel to the motor carrier, in terms of the costs of expected fines and off-loading, and the costs of detouring or stopping to avoid weight enforcement activities.
- The costs to public agencies of overweight travel, principally the costs of pavement damage due to excess axle weights, and the fines collected from enforcement efforts.
- The level of fines and penalties assessed for overweight violations, and the requirements for off-loading imposed on overweight vehicles.
- The distribution and amount of excess weights on each axle, which determine pavement damage.
- The deployment strategy and density of deployment of truck weight enforcement efforts using WIM to screen vehicles.
- The cost to enforcement agencies of deploying WIM and enforcement teams.

Each of the important factors affecting the costs and benefits of weight enforcement using WIM is discussed briefly below, and in more detail in Appendix A. The discussion is followed by the results of the analysis, which include the costs and benefits of using WIM for weight enforcement under base case values and under variations in the important factors affecting the benefits and costs.

Discussion of Transportation and Cost Elements Affecting Weight Enforcement

VMT Distribution by Functional Class.—The distribution of heavy truck VMT by functional class of highway is an important determinant of how enforcement efforts should be deployed. A disaggregation of vehicle traffic by roadway class for 1982 was prepared by Oak Ridge National Laboratory under contract to FHWA. The disaggregation developed estimates of VMT by vehicle type, state, and functional class from 1982 estimates of VMT by FHWA as contained in *Highway Statistics.* Tables VM-1 and VM-2, and in Truck Weight Study (TWS) counts by individual states. The data sources were factored together until an internally consistent estimate of VMT by state, vehicle type, and functional class was obtained.

Because there are very large differences in heavy truck VMT on various roads and road segments within each functional class, deployment strategies should take advantage of these variations. Therefore, VMT density distributions within functional classes have been estimated as well as VMT density distributions among functional classes. This has been done by dividing each functional class into segments and time periods as described below, and grouping those segments and time periods with similar heavy truck traffic densities.

Distributions of Trip Lengths and VMT by Time Period and Segment.—Truck trips vary substantially in terms of trip length. Little comprehensive data exist on the distribution of truck trip lengths themselves, as opposed to the wealth of data on how far commodities are shipped (which can include one or many individual truck trips). An ICC report, *Empty/Loaded Truck Miles on Interstate Highways During 1976,* was used to develop a breakdown of truck trip lengths for trucks which use the rural Interstate System for portions of their trips.

The deployment strategies recommended are also based on the observation that truck VMT varies significantly by time of day, day of the week, and highway segment. Thus, deployment strategies focusing on selected time periods and segments are able to monitor and potentially to deter a higher share of total truck VMT.

For the purposes of this analysis, traffic on each of the major road classifications was divided into five segment/time period categories. These categories correspond to one-fifth of the total number of time periods (8-hour shifts/7 days per week/365 days per year) times the number of segments, each for various classes of roads. The major analytical problem was determining the portion of total truck VMT that occurred in each segment/time-period category, which was addressed by using ICC survey data.

A second important analytical problem was determining the distribution of VMT by trip length. The ICC study involved the compilation of trip distance for a systematic one-twentieth subsample of the 13,165 trips. The probability that a truck would be selected in the ICC study is the same as the sum of the probabilities that it would have been included in each of the ICC checkpoints it passed. This fact provided the basis for estimating the actual trip length distribution from the distribution reported in the ICC tabulations.

Percentage of VMT Which Is Overweight.—Information from several states was used to define the estimated range of expected overweight travel in the absence of enforcement. In one state, observations by unobtrusive WIM at sites on the rural Interstate System ranged from 13 percent to 59 percent overweight, and at only two sites on rural arterials ranged from 19 percent to 24 percent overweight. In another state, data from two sites on the rural Interstate System indicated 35 percent to 57 percent overweight at times when weigh stations were not in operation. At eight sites on the rural Interstate System in two other states, an average of 21 percent overweight heavy trucks was measured. These included axle weight violations as well as gross weight violations. Based on these data, a conservative estimate of 15 percent overweight was selected as a base case, intended to be representative of what happens on road systems in the absence of enforcement. Higher and lower values were tested in the sensitivity analysis. Data from a state measured at fixed scales indicated axle weight violations on 6 percent of heavy trucks. This was taken as the absolute (and obviously unrealistic) minimum of overweight vehicles to be expected without enforcement. The 59 percent observation would be a theoretical maximum, given that some trucks will be empty and some will have low density products that cause them to be full prior to reaching the legal weight limit (also referred to as "cubed out" or having all their cubic space filled).

All trucks do not travel overweight by the same amount, and the pavement damage which they inflict varies with the axle weights of the overweight vehicles. WIM data were used from Arizona, which gave axle weight distributions for overweight vehicles, to develop a breakdown of excess axle weights for the overweight trucks. The excess weight categories used were 2.5 tons overweight, 7.5 tons overweight, and 12.5 tons overweight.

Although this analysis presumes only 3S2 vehicles, this is considered to be a good approximation for all heavy trucks because 3S2s are responsible for such a large majority of the ton-miles and equivalent single axle loads (ESALs).

Cost per Mile of Overweight Travel.—Excess equivalent single axle loads (ESALs) were estimated for each category of overweight travel, based on the assumptions made above about the distribution of the excess loads. ESALs were estimated from tables used by the State of Florida to calculate ESALs associated with truck counts in that state.

Costs per ESAL-mile have been estimated in a variety of studies of pavement damage and highway cost allocation. For pavement damage alone, cost estimates per ESAL-mile vary across a wide range for studies conducted by responsible researchers. A recent TRB report (*Twin Trailer Trucks*) was used as the basic source for the various estimates that have recently been made of pavement costs per ESAL-mile of travel.

Costs to States of Deployments.—The costs to states of deploying enforcement teams which use WIM to screen trucks for weighing include much more than the costs of WIM itself. Most costs will be for personnel when WIM is used as a screening device to pick out the likely offenders. Estimates of the costs of equipment, the numbers of personnel, and the costs of personnel could vary by wide amounts because of the very substantial variations that are possible in future costs of technologies and in future personnel costs that may be encountered by various states.

For the base case used in this study, primary enforcement teams on the high VMT portions of the rural Interstate System, the urban Interstate System, and the urban freeway and expressway system are assumed to consist of two persons per direction of travel, for a total of four persons on each primary enforcement team. For nonlimited access highways, the primary team was assumed to consist of two persons.

Each primary team (the four-person team on the limited access highways and the two-person team on the other highways) would be associated with a team on the so-called "wing," meaning on a parallel route that is likely to be used as a detour around an enforcement team on the other road. Two or more wing teams could also be used. The wing team was assumed to alternate among the parallel detour routes and the segments of road upstream from the primary team, where trucks that were overweight might stop to avoid going through the primary enforcement site.

Costs of Enforcement Teams.—Forty-three agencies including states, Canadian Provinces, and the Port Authority of New York and New Jersey provided information on the costs and personnel levels for their weight enforcement efforts. The average cost of the enforcement efforts was $2.725 million per year, and the average number of personnel reported was 93.1.

The average cost per enforcement person is $29,300 per year. This number is considered to be relatively low as a total cost per person average, because all the states are not likely to have included annualized costs of capital equipment or complete overhead in these figures.

Teams on undivided highways were assumed to have one-half the resource requirements as teams on divided highways, except that they would also use two sets of WIM equipment (one each just up the traffic stream in each direction from an enforcement location). For the base case, four-person teams were estimated to cost $226,000 per year and two-person teams $118,000 per year.

Calculation of Enforcement Teams Required.—The number of enforcement teams required is calculated in relation to the desired deployment level on each of the roadway functional classes on which enforcement teams were assumed to be deployed. No deployment was assumed on the collector and local systems in this analysis.

The number of segments on each functional class depends on the total mileage and the number of interchanges and intersections along that mileage. For the various functional classes, it is estimated that the base case number of segments is as follows on a national basis (with the average state having one-fiftieth the number of segments in the nation):

Functional Class	Mileage	Miles/ Segment	Number of Segments
Rural Interstate	32,879	5	6,576
Rural Principal Arterial	81,018	2	40,509
Rural Arterial	148,879	2	74,440
Urban Interstate	9,581	2	4,791
Urban Expressway	7,010	2	3,505
Urban Arterial	112,779	1	112,779

Each deployment strategy is expressed in terms of the probability that a team is operating on a given segment. Calculations are made for all functional classes to determine the total numbers and costs of teams required for a given deployment strategy across all the functional classes. The sum of the costs for each functional class yields the total cost of the overall deployment.

Cost of Evasive Action for Overweight Trucks.—In every part of the country, there are only a small number of bypass routes that a truck driver would consider to avoid a citation or off-loading while still continuing on his way at a reasonable speed. In order to determine how much an average detour would add in terms of miles and travel times, typical detours available on an atlas were measured, and they were related to the average segment lengths on the system on which the truck would be operating.

On the basis of those measurements, it is estimated that if a truck operator chooses from among the two shortest detours, the average detour mileage added will be about 2.4 times the segment length. If four detours are considered, the average would be 3.6 times the segment length. The segment length is the average distance between interchanges or intersections on the particular road system.

These detour mileages represent additional miles that are estimated to cost an average of $1.03 per mile, based on ICC data. It is assumed that longer distance operators would consider an average of about four detours. The cost of detouring is thus the segment length times 3.6 times $1.03 for the longer distance trucks. For trucks making the shortest trips, only two detours would be considered, and the cost of an average detour would thus be 2.4 times the segment length times $1.03.

The determination of the costs of the strategy of stopping in order to avoid detection by an enforcement team is based on an estimate of the operating costs per hour times the expected number of hours the driver will stop in order to avoid detection, which was estimated to be half the length of the enforcement session, or four hours.

Costs of Off-Loading.—If a driver has to off-load his overweight load, the carrier will have to dispatch another vehicle to the site of the citation and either bring the freight back to the origin terminal or deliver it to the destination terminal. Obviously, the costs of off-loading are significant. For the purposes of this analysis, these costs are estimated at $1.03 per mile times the trip distance.

A tough policy on off-loading is very cost-effective because increasing the likelihood of off-loading increases the expected cost to the truck operator of traveling overweight, without a proportional increase in enforcement costs.

Revenue per Ton-Mile.—Explicit estimates have been made of the benefits to carriers of overweight travel by trip length and amount overweight for each overweight truck trip, in terms of increased revenues from each type of overweight trip. The assessment of the benefits to carriers of overweight operations depends on an evaluation of the potential revenue gain from the additional freight. The potential revenue gain is the product of the carrier's revenue per ton-mile times the added ton-miles from the overweight operations. The ton-miles are a combination of the amount overweight times the distance of the trip. An ATA analysis of motor carrier annual reports shows that specialized carriers nationwide had an average revenue of 9.87 cents per ton-mile. A value of nine cents was used for the base case analysis for the least overweight trips. For trips that are more overweight, average revenue per ton-mile is lower because these include very low value goods.

Cost of Fines.—The average cost of fines for overweight travel at 2.5, 7.5, and 12.5 tons was interpolated from median data on the states' fines for overweight travel compiled in a 1985 FHWA Report, *Overweight Vehicles—Penalties and Permits: An Inventory of State Practices.* The medians for each overweight amount were selected as the base value of fines. The median values are given in the following table:

Amount Overweight	Median Fine
2.5 tons	$181.00
7.5 tons	$740.00
12.5 tons	$1,238.00

Module to Calculate Overweight Cost Compared to Revenue.—The determination of the impact of various enforcement strategies on truck driver behavior depends on a comparison of the potential benefits to the truck operator of his overweight travel versus the expected cost of being caught for overweight operation and being fined, forced to off-load, or detouring or stopping.

The determination of the truck operators' benefit from overweight operations is dependent on the amount of overloading, the revenue per ton-mile, and the trip distance.

The costs associated with the overweight operations are a combination of the costs and probabilities associated with being caught and fined, stopping to avoid detection, and detouring to avoid detection. These costs and probabilities vary according to the trip length and the various deployment strategies used on the different highway classes. The model computes for each trip length and general highway class (rural Interstate and nonrural Interstate), an expected cost of the overweight operations.

The direct comparison of trip benefits from overweight operation and expected costs of overweight operations is assumed to be the determining factor in a decision on whether the overweight trip is deterred or whether it will continue. If the benefits exceed the expected costs, the trip is recorded as an undeterred overweight trip. If, however, the costs exceed the benefits, the trip is recorded as a deterred trip.

Implications for Changes in Current Enforcement Practices

The research findings suggest that higher levels of weight enforcement effort than current average efforts may be appropriate, based on the potential benefits from reducing and then controlling the pavement damage associated with overweight truck travel. The use of WIM for screening trucks for enforcement purposes can make higher levels of enforcement politically acceptable to the trucking industry, because very few trucks not traveling overweight would be stopped and weighed.

A highly randomized pattern of enforcement by road segment and time period provides for greater deterrence than a regularized enforcement pattern. Those who desire to travel overweight can easily plan routes and schedules to avoid weight enforcement activities that are fixed in time and location.

The findings suggest that it is almost always cost-effective to deploy enforcement teams that consist of a primary crew and a wing crew operating together. Because most truck operators receive timely communications about enforcement activities, a wing team is necessary to intercept those taking detours or stopping to avoid the primary team. A wing team could either operate on a parallel route, or could operate along the primary route, coming up on, and weighing trucks stopped upstream of the primary team. (Overweight vehicles can be assumed to be much more likely than others to take a "timely" rest break when they know about enforcement ahead of them.)

The switch to more random deployment does not mean that current fixed weigh stations would be abandoned. In most instances, they are already located at high volume locations that are difficult to avoid. The use of wing teams when those stations are opened can greatly enhance the effectiveness of the station as an element in a strategy for deterring overweight travel. Wherever cost-effective, WIM should be used to screen trucks for weighing at fixed stations as well as at portable scales.

Information gathered on overweight truck travel when using WIM for data collection can be very useful for maximizing the benefits of deploying WIM-assisted weight enforcement teams. The WIM used for data collection will provide information on where overweight travel is occurring. The benefits of deploying weight enforcement teams on a particular road segment are directly proportional to the amount of overweight travel occurring on that segment.

Findings from Application of Model

The analysis model was used to examine the impacts of several specific kinds of public policy actions to improve weight enforcement: proportional deployments of WIM-assisted enforcement teams on different functional classes, based on relative truck VMT; focused deployment of WIM-assisted enforcement teams on various segments within a functional class with higher or lower truck VMT; and setting of alternative fines and penalties for overweight travel.

Deployment of Weight Enforcement Teams.—The benefits of deploying a weight enforcement crew are directly proportional to the amount of overweight truck VMT which is using (or would otherwise use at some point in its trip) the road segment on which the crew is deployed. "Optimal" deployment, if it could ever be practically achieved, would occur when there are no net public benefits (pavement damage savings minus enforcement costs) from deploying an additional crew or from deploying crews in a different manner. The "optimal deployment level" in terms of numbers of crews occurs for each specified fine level. (Higher fines mean "optimal deployment" will occur at a lower public cost, as discussed later.)

For reasons explained later, deployments that might be "optimal" in an economic sense would not necessarily involve attention to all functional classes of highway or road segments. However, an "optimal" deployment strategy as defined in narrow benefit-cost terms might be biased against interstate operations and provide no enforcement for local operations. An equally important criterion for any enforcement program should be equitable application of the law among all types of operations. Therefore, the analysis focused on "proportional" deployment strategies. The proportional strategy provides that enforcement efforts on each functional class and road segment within that functional class are proportional to the relative heavy truck VMT on that segment. The proportional strategy thus assures that weight enforcement resources are relatively assigned to where they will have the most impact, but that there is some probability of enforcement on each segment.

Table 4 shows what the impacts would be of proportional deployment at current average levels of fines ($181 for 2.5 tons overweight, $740 for 7.5 tons, and $1,238 for 12.5 tons) and at current average expenditures per state for enforcement ($2.7 million). The proportional deployment makes the probability of enforcement proportional to the heavy truck VMT on each road segment. The percentage of overweight travel assumed for this base case analysis is 15 percent, and the assumed pavement damage cost per ESAL-mile is 4.8 cents. Assumed revenue per ton-mile for overweight travel is nine cents for those traveling 2.5 tons overweight, four cents for those traveling 7.5 tons overweight, and two cents for those traveling 12.5 tons overweight. Net public benefits are the amount by which the pavement damages are reduced ($302 million), less the costs of the deployment ($138 million). As will be shown below, the net public benefit of $164 million is relatively low reflecting the fact that not very much overweight travel is deterred at this level of enforcement.

Table 4 also shows that significant amounts of fines would be collected ($1,042 million). (Although the amount of fines collected is critical to the success of the enforcement program and may be an important source of state revenue, this amount is not included in the calculation of net benefits because it is not a true public benefit. Economists consider this a "transfer payment" that should not be included in benefit-cost analyses.) The analysis also shows that the trucking industry would incur significant additional operating costs (total of $1,442 million) due to detouring and stopping to avoid enforcement, and the need for added travel to carry the same ton-miles.

The level of deployment pictured in Table 4 thus generates substantial disbenefits for overweight truck operations, but not enough to deter a significant proportion of that segment of the industry traveling overweight. The estimate of benefits given in Table 4 is probably conservative. Many, of course, are deterred from traveling overweight for noneconomic reasons. Some respond to enforcement for fear of being caught, even though they may not lose economically. Others prefer to operate within applicable laws and regulations, regardless of the fear of being caught or the economics of overweight operation. Only those who fall in the category of responding because of fear of being caught are a source of error in terms of the model underestimating benefits. This error tends to be offset by the model's failure to recognize that some will try to operate overweight regardless of the economics involved.

Table 4. Base case: proportional deployment at current levels.

OVERALL PARAMETERS AND IMPACTS	VALUES
Overweight VMT %	
RI	15
Non-RI	15
Cost per ESAL ($)	0.048
Number of Crews	418
Public Cost for Deployment Strategy (in millions $)	138
Savings due to Deterred Overweight Travel (in millions $)	302
Net Benefit	164
Fines ($)	
2.5 tons overweight	181
7.5 tons overweight	740
12.5 tons overweight	1238
Fines Collected from Continuing Overweight Travel (in millions $)	
RI	633.4
Non-RI	408.9
Total	1042.3
TRUCKING INDUSTRY PARAMETERS AND IMPACTS	
Revenue Per Ton-Mile ($)	
2.5 Tons Overweight	0.09
7.5 Tons Overweight	0.04
12.5 Tons Overweight	0.02
Carrier Operating Cost Per Mile ($)	1.025
Operating Cost of Stopping ($)	138.6
Probability of Being Caught While Stopping	
RI	0.2
Non-RI	0.2
Probability of Being Caught While Detouring	
RI	0.2
Non-RI	0.2
Incremental Trucking Industry Cost from Deterred Overweight Travel (in millions $)	
RI	198.4
Non-RI	292.5
Total	490.9
Trucking Industry Cost from Undeterred Overweight Travel Stopping Costs (in millions $)	
RI	30.9
Non-RI	184.7
Total	215.6
Detour Costs (in millions $)	
RI	525.5
Non-RI	209.7
Total	735.2
Total Industry Costs Costs from Deterred and Undeterred Travel (in millions $)	1441.7
VMT IMPACTS	
Deterred Overweight VMT (in millions)	
RI	769
Non-RI	1145
Total	1914
Deterred Cost (in millions $)	
RI	118
Non-RI	184
Total	302
Undeterred Overweight VMT (in millions)	
RI	5616
Non-RI	3371
Total	8987
Undeterred Cost (in millions $)	
RI	364
Non-RI	200
Total	564

Table 4. Continued

DEPLOYMENT LEVELS

(Proportion of Segment-Time Period Quintiles with Deployment)

Rural Interstate	
Segment 1	0.008
Segment 2	0.004
Segment 3	0.003
Segment 4	0.002
Segment 5	0.001
No. of Crews	118
Urban Interstate	
Segment 1	0.019
Segment 2	0.01
Segment 3	0.007
Segment 4	0.004
Segment 5	0.001
No. of Crews	195
Rural Principal Arterial	
Segment 1	0.0003
Segment 2	0.0001
Segment 3	0.0001
Segment 4	0.0001
Segment 5	0
No of Crews	24
Rural Arterial	
Segment 1	0.0001
Segment 2	0
Segment 3	0
Segment 4	0
Segment 5	0
No. of Crews	11
Urban Arterial	
Segment 1	0.0001
Segment 2	0
Segment 3	0
Segment 4	0
Segment 5	0
No. of Crews	15
Urban Expressways	
Segment 1	0.0074
Segment 2	0.0039
Segment 3	0.0025
Segment 4	0.0015
Segment 5	0.0006
No. of Crews	55

Table 5. Relationship between increases in proportional deployment and net benefits. All overweight VMT are deterred at stage 6; no further public cost is warranted. Maximum net benefits are achieved with given levels of nondeployment parameters stated in Table 4. Note: The base case proportional deployments on all highway segments were increased successively by approximately 20% across all segment-time period quintiles. This table shows the impact on deployment costs, savings due to deterred overweight travel, and net benefits. The proportional deployment with the maximum net benefit is selected as a best case deployment and is presented in Table 6 in detail.

STRATEGY	PUBLIC COST	SAVINGS DUE TO DETERRED OVERWEIGHT TRAVEL	NET BENEFITS
	(in millions)		
1 (Base Case as shown in Table 4)	$138	$302	$164
2	$165	$673	$508
3	$198	$673	$475
4	$238	$673	$435
5	$285	$729	$444
6	$342	$867	$525

Table 5 shows how the net benefits change as enforcement levels increase, using the same proportional deployment strategy and the same fine structure as in Table 4. When the density of the deployment is increased, the net public benefits increase, but then they begin to decrease again. Later, they increase again. The highest net public benefits from applying this proportional deployment strategy occur at an enforcement cost of $342 million, about 2.5 times the current average level of state enforcement efforts. The finding that the net benefits are not monotonically increasing is partly an artifact of the categories of overweight travel (2.5 tons, 7.5 tons, and 12.5 tons) and their revenues per ton-mile. A continuous function for revenue per ton-mile in relation to the amount overweight would not have points at which the next group of carriers were not yet deterred in spite of the increased deployment (and higher deployment costs). This would probably result in a single high point in the net benefits curve, which would more clearly define the optimal enforcement level under this strategy.

Table 6 gives additional detail on the proportional deployment program of Table 5 which has the highest estimated net benefit to the public (all other facts being assumed equal to those assumed for Table 4). A comparison of Tables 4 and 6 provides a detailed analysis of the shifts that occur in enforcement levels on each functional class and the resulting impact on overweight operators.

The trucking industry also incurs stopping and detouring costs for those segments that continue to travel overweight. The cost of lost revenue from the deterred overweight travel is $2,519 million. This revenue is assumed to accrue, however, to the same carriers operating within weight limits, or to other segments of the trucking industry, or to other modes of freight transportation. Therefore, these losses are considered to be transfer payments, and are not included in the benefit-cost analysis.

Table 7 gives a comparison between the proportional strategy in Table 6, a uniform strategy of deployment within each functional class, and two strategies of deployment which focus on

Table 6. Proportional deployment strategy with highest net benefit.

OVERALL PARAMETERS AND IMPACTS	VALUES
Overweight VMT %	
RI	15
Non-RI	15
Cost per ESAL ($)	0.048
Number of Crews	1037
Public Cost for Deployment Strategy (in millions $)	342
Savings due to Deterred Overweight Travel (in millions $)	867
Net Benefit	525
Fines ($)	
2.5 tons overweight	181
7.5 tons overweight	740
12.5 tons overweight	1238
Fines Collected from Continuing Overweight Travel (in millions $)	
RI	0
Non-RI	0
Total	0

TRUCKING INDUSTRY PARAMETERS AND IMPACTS	
Revenue Per Ton-Mile ($)	
2.5 Tons Overweight	0.09
7.5 Tons Overweight	0.04
12.5 Tons Overweight	0.02
Carrier Operating Cost Per Mile ($)	1.025
Operating Cost of Stopping ($)	138.6
Probability of Being Caught While Stopping	
RI	0.2
Non-RI	0.2
Probability of Being Caught While Detouring	
RI	0.2
Non-RI	0.2
Incremental Trucking Industry Cost from Deterred Overweight Travel (in millions $)	
RI	1474.6
Non-RI	1044.8
Total	2519.4
Trucking Industry Cost from Undeterred Overweight Travel	
Stopping Costs (in millions $)	
RI	0
Non-RI	0
Total	0
Detour Costs (in millions $)	
RI	0
Non-RI	0
Total	0
Total Industry Costs	
Costs from Deterred and Undeterred Travel (in millions $)	2519.4

VMT IMPACTS	
Deterred Overweight VMT (in millions)	
RI	6386.1
Non-RI	4516.5
Total	10902.6
Deterred Cost (in millions $)	
RI	482.8
Non-RI	384.4
Total	867.2
Undeterred Overweight VMT (in millions)	
RI	0
Non-RI	0
Total	0
Undeterred Cost (in millions $)	
RI	0
Non-RI	0
Total	0

DEPLOYMENT LEVELS

(Proportion of Segment-Time Period Quintiles with Deployment)

Rural Interstate	
Segment 1	0.021
Segment 2	0.011
Segment 3	0.007
Segment 4	0.004
Segment 5	0.002
No. of Crews	294
Urban Interstate	
Segment 1	0.047
Segment 2	0.025
Segment 3	0.016
Segment 4	0.01
Segment 5	0.004
No. of Crews	485
Rural Principal Arterial	
Segment 1	0.0007
Segment 2	0.0004
Segment 3	0.0002
Segment 4	0.0001
Segment 5	0.0001
No. of Crews	60
Rural Arterial	
Segment 1	0.0002
Segment 2	0.0001
Segment 3	0.0001
Segment 4	0
Segment 5	0
No. of Crews	24
Urban Arterial	
Segment 1	0.0002
Segment 2	0.0001
Segment 3	0.0001
Segment 4	0
Segment 5	0
No. of Crews	36
Urban Expressways	
Segment 1	0.0184
Segment 2	0.0097
Segment 3	0.0063
Segment 4	0.0038
Segment 5	0.0014
No. of Crews	138

the road segments with the highest truck volumes—one which focuses on the two highest segment-time periods within each functional class and one which focuses on the ten segment-time period quintiles with the highest share of truck VMT. As would be expected, net public benefits decline when enforcement efforts are uniform among all segments within each functional class, rather than proportional to heavy truck VMT, and net public benefits are greater when enforcement efforts are more highly concentrated on the segments of the road systems with the highest truck volumes.

Thus, there are some obvious losses in cost-effectiveness from "uniform" deployment—where each road segment within each functional class would be given the same probability of enforcement occurring, regardless of the volume of heavy trucks it was carrying. Extending uniformity of deployment by making it similar across functional classes would reduce public benefits much more, and is clearly not a reasonable approach.

Table 7. Proportional strategy with highest net benefit compared with alternative deployment strategies.

PARAMETERS	DEPLOYMENT STRATEGIES: Proportional with Highest Net Benefit	Uniform	Focused within All Classes[1]	Focused among Selected Classes[2]
OVERALL PARAMETERS AND IMPACTS				
Overweight VMT %				
RI	15	15	15	15
Non-RI	15	15	15	15
Cost per ESAL ($)	0.048	0.048	0.048	0.048
Number of Crews	1037	1033	735	806
Public Cost for Deployment Strategy (in millions $)	342	342	243	305
Savings due to Deterred Overweight Travel (in millions $)	867	674	806	867
Net Benefit	525	332	563	562
Fines ($)				
2.5 tons overweight	181	181	181	181
7.5 tons overweight	740	740	740	740
12.5 tons overweight	1238	1238	1238	1238
Fines Collected from Continuing Overweight Travel (millions $)				
RI	0	309	154	0
Non-RI	0	243	61	0
Total	0	552	215	0
TRUCKING INDUSTRY PARAMETERS AND IMPACTS				
Revenue Per Ton-Mile ($)				
2.5 Tons Overweight	0.09	0.09	0.09	0.09
7.5 Tons Overweight	0.04	0.04	0.04	0.04
12.5 Tons Overweight	0.02	0.02	0.02	0.02
Carrier Operating Cost Per Mile ($)	1.025	1.025	1.025	1.025
Operating Cost of Stopping ($)	138.6	138.6	138.6	138.6
Probability of Being Caught While Stopping				
RI	0.2	0.2	0.2	0.2
Non-RI	0.2	0.2	0.2	0.2
Probability of Being Caught While Detouring				
RI	0.2	0.2	0.2	0.2
Non-RI	0.2	0.2	0.2	0.2
Incremental Trucking Industry Cost from Deterred Overweight Travel (in millions $)				
RI	1475	754	1188	1475
Non-RI	1045	571	954	1045
Total	2520	1325	2142	2520
Trucking Industry Cost from Undeterred Overweight Travel				
Stopping Costs (in millions $)				
RI	0	50	0	0
Non-RI	0	174	37	0
Total	0	224	37	0
Detour Costs (in millions $)				
RI	0	296	179	0
Non-RI	0	134	45	0
Total	0	430	224	0
Total Industry Costs				
Costs from Deterred and Undeterred Travel (in millions $)	2520	1979	2403	2520
VMT IMPACTS				
Deterred VMT (in millions)				
RI	6386	2826	4968	6386
Non-RI	4517	2174	4065	4517
Total	10903	5000	9033	10903
Deterred Cost (in millions $)				
RI	483	366	436	483
Non-RI	384	307	370	384
Total	867	673	806	867
Undeterred VMT (in millions)				
RI	0	3560	1418	0
Non-RI	0	2342	451	0
Total	0	5902	1869	0
Undeterred Cost (in millions $)				
RI	0	117	46	0
Non-RI	0	76	15	0
Total	0	193	61	0
DEPLOYMENT LEVELS				
(Proportion of Segment-Time Period Quintiles with Deployment)				
Rural Interstate				
Segment 1	0.021	0.009	0.021	0.022
Segment 2	0.011	0.009	0.011	0.011
Segment 3	0.007	0.009	0	0.007
Segment 4	0.004	0.009	0	0.004
Segment 5	0.002	0.009	0	0
No. of Crews	294	294	208	296
Urban Interstate				
Segment 1	0.047	0.02	0.047	0.049
Segment 2	0.025	0.02	0.025	0.026
Segment 3	0.016	0.02	0	0.017
Segment 4	0.01	0.02	0	0.010
Segment 5	0.004	0.02	0	0
No. of Crews	485	485	344	488
Rural Principal Arterial				
Segment 1	0.0007	0.0003	0.0007	0
Segment 2	0.0004	0.0003	0.0004	0
Segment 3	0.0002	0.0003	0	0
Segment 4	0.0001	0.0003	0	0
Segment 5	0.0001	0.0003	0	0
No of Crews	60	60	42	0
Rural Arterial				
Segment 1	0.0002	0.0001	0.0002	0
Segment 2	0.0001	0.0001	0.0001	0
Segment 3	0.0001	0.0001	0	0
Segment 4	0	0.0001	0	0
Segment 5	0	0.0001	0	0
No. of Crews	24	22	17	0
Urban Arterial				
Segment 1	0.0002	0.0001	0.0002	0
Segment 2	0.0001	0.0001	0.0001	0
Segment 3	0.0001	0.0001	0	0
Segment 4	0	0.0001	0	0
Segment 5	0	0.0001	0	0
No. of Crews	36	34	26	0
Urban Expressways				
Segment 1	0.0184	0.0079	0.0184	0.0192
Segment 2	0.0097	0.0079	0.0097	0.0101
Segment 3	0.0063	0.0079	0	0
Segment 4	0.0038	0.0079	0	0
Segment 5	0.0014	0.0079	0	0
No. of Crews	138	138	98	102

[1] Focused within All Classes---All deployment on Segment-Time Period Quintiles 3, 4, and 5 within all functional highway classes is removed. Deployment on Quintiles 1 and 2 is the same as shown in the Proportional Strategy

[2] Focused within Selected Classes--All deployment put on the 10 Segment-Time Period Quintiles with the highest share of Truck VMT. Deployment on these 10 segments was proportional to the amount of truck VMT in each segment. Overall deployment was set at a level needed to achieve savings of $867 million in pavement damage, which occurs when all overweight travel is deterred.

The "focused" deployment indicates that net benefits can be increased by concentrating enforcement on the highest VMT segment-time periods within each functional class. This raises the issue of whether an attempt should be made to optimize net benefits by concentrating enforcement efforts on only the highest volume segment-time periods.

This analysis indicates that only about a 7 percent increase occurs in net benefits as a result of either of the two focused strategies, while losing substantially in terms of equity of the enforcement program. There is also the danger that more focused strategies will distort trucking operations as the strategy becomes known and result in a loss of effectiveness of the program. "Optimal" deployment in narrow benefit-cost terms would result in a very high concentration of enforcement efforts on high truck volume functional classes and segments. However, if enforcement efforts are applied only to particular roadway types and segments the portion of the trucking industry which travels overweight can learn where the "safe" routes are and, ultimately, defeat a strategy that concentrates enforcement on too few road segments and time periods.

The compilation of WIM data collected for planning purposes can help to provide an up-to-date picture of where overweight truck travel is occurring, and states can revise their deployment strategies to take account of this new information.

Another problem with the high concentration of deployments that may be optimal in terms of crew costs vs. reduced pavement damage is that overweight truck trips on some routes are much more likely to be subject to enforcement than on other routes. In effect, the states would be discouraging and penalizing overweight travel by some operators to a much greater degree than others. This again raises the issue of fairness. The situation is analogous to that in auditing of some motor carrier taxes. Some larger firms complain that they may be audited by several governmental agencies, whereas smaller firms are never audited. This means that the large firms must play by the rules, but that the smaller firms will not be subject to careful scrutiny. The auditors, of course, can assess much larger additional fees for the same reporting problem they might find at a large firm compared to the smaller firm, and thus an "optimal" audit strategy focuses on the larger firms.

In weight enforcement, it would be inappropriate to ignore equity concerns, because the government has an interest in even application of rules and regulations. Thus, in practice, a strategy of weight enforcement that is optimal in the narrow economic sense may not be selected in comparison to a strategy that gives balanced consideration to equity in enforcement in terms of functional classes and relative density of traffic within functional class.

Fines and Penalties.—Because higher fines can provide more deterrence than lower fines at a given level of deployment, or because higher fines with lower cost levels of deployment can achieve the same deterrence as lower fines with higher cost levels of deployment, the "optimal" fine structure from the public agency's point of view is the highest fine structure that the courts will enforce.

Table 8 shows the relationship between increases in fines and the changes in net benefits, using a proportional deployment strategy in which the costs of the deployment have been held constant. As fines go up, additional overweight travel is deterred. The fines increase in increments of 25 percent in Table 8. Table 9 shows that as fines are increased, net benefits can be further increased by decreasing deployment levels and public costs. In Table 9, the fines and deployments are always set so that all overweight travel is deterred. The net benefits increase from $525 million to $767 million as fines are increased in $100 increments above current average fines.

These results show that it is clearly cost-effective for public agencies to use higher fine levels as part of their weight enforcement strategy. Nonetheless, it is unrealistic to believe that judges would enforce clearly draconian fines for offenses such as traveling overweight by a modest amount. In addition, considerations of fairness throughout society dictate that fines or penalties be consistent with the relative seriousness of the offense. The maximum practicable fines are probably around the range of two times the average fines assessed by the states today for traveling overweight by a certain amount. The results given in the last column of Table 9 show that the gains in net benefits drop off quite sharply after a doubling or so of fines.

Applicability of Results to a Single State or Region.—The model for weight enforcement was developed and applied at a national level. Within the structure of the model it was assumed that all states are applying weight enforcement efforts in roughly the same manner; however, it was not required to assume that equal efforts are made by all the states or even by adjoining states in order for the model to yield reasonable results.

The model can also be applied to a single state, using state-specific data about travel on its roadways. However, one major difference which occurs is that some of the benefits of a state's enforcement efforts accrue because pavement damage is reduced in other states. Thus, if one hypothesizes only one state enforcing weight limits, there will still be deterred overweight travel, but some of the deterred overweight travel benefits adjacent states rather than the state doing the enforcement.

To estimate the proportion of the benefits of reduced overweight travel that stays within a state, the state needs to calculate the percentage of in-state heavy truck VMT in comparison to the total VMT by all heavy truck trips that travel on the state's roads for at least a portion of their trips. This percentage is not readily available from any existing data source. Motor carriers report the percentage of their total fleet VMT that occurs in each state for the purposes of apportioning their mileage under the International Registration Plan (IRP) and for fuel use taxation. However, the fleet's percentage of miles within the state is not equivalent to the percentage of miles within the state for only those trips by the fleet which go through the state. Therefore, an approximate, judgmental estimate must always be made in order to analyze the impacts of a single state acting in isolation from other states.

Potential Use of WIM in Combination with AVC and AVI

Additional applications of WIM for weight enforcement could be undertaken in combination with either AVC or AVI technologies. The use of AVC in combination with WIM could potentially allow for more sophisticated attention to bridge formula enforcement. The impacts on bridges have not been treated in detail in the weight enforcement because of the overwhelming importance of the pavement damage costs.

AVI used with WIM offers extraordinary opportunities for weight enforcement, but only with a mandatory AVI system which would allow records to be kept of chronic violators. States could then assess high fines or threaten the registrations of those who were found to be in consistent violation of weight limits.

Table 8. Relationship between increases in fines and changes in net benefits for base case strategy.

Fine Structure (2.5 tons overweight, 7.5 tons overweight, & 12.5 tons overweight	Public Deployment Cost (millions)	Savings Due to Deterred Overweight VMT (millions)	Net Benefit (millions)	Incremental Increase in Net Benefits (millions)
$145,$512,$990	138	141	-3	
				167
$181,$740,$1238	138	302	164	
				371
$226,$925,$1548	138	673	535	
				0
$283,$1156,$1935	138	673	535	
				0
$354,$1445,$2418	138	673	535	
				0
$443,$1806,$3023	138	673	535	
				93
$554,$2258,$3779	138	758	628	
				101
$693,$2822,$4723	138	867	729	

All Overweight VMT is deterred at the last fine level shown in the Table.

Source: Spreadsheet model developed by Sydec, Inc.

Note: Starting with the Base Case Strategy identified in Table 1, fine levels were initially decreased, then increased, with each increase being 25 percent for each level of fine. Table 5 shows the impact of changing fines on net benefits, with an unchanged base case deployment.

A voluntary AVI system is not expected to be very valuable for weight enforcement, inasmuch as those carriers operating at illegal weights would very likely decline to participate.

Findings from Sensitivity Analysis

Extensive sensitivity analyses were conducted, because the net benefits of a weight enforcement program were found to be very sensitive to a number of factors: percent of trucks traveling overweight, pavement damage associated with overweight travel, revenue from overweight operations, and likelihood of successfully avoiding an enforcement team. The sensitivity of the results to varying values of each of these important factors is discussed in Appendix A. A qualitative summary for each factor is provided here.

There are also other practical considerations. Some deployments considered theoretically in the preceding tables may have to be modified because of various constraints on enforcement. For example, lower deployments are likely on the urban Interstate and urban Expressway systems because of the constraint that trucks could not be safely weighed on many highway segments. The highest deployment levels considered for urban Interstates was only one out of 20 segments, however.

Percent Traveling Overweight.—The benefits of enforcement vary linearly with the percentage of trucks traveling overweight. Estimates of the proportion of trucks traveling overweight have been made in several states recently, using unobtrusive and calibrated WIM measuring devices. Observations of up to 59 percent overweight have been reported for specific sites. Sensitivity analyses have been made in this study for ranges of 6 percent to 36 percent overweight. Six percent is believed to be a reasonable minimum assumption and 36 percent a reasonable maximum, because some trucks are traveling empty and some are carrying low density cargo. However, this does not mean that in specific instances, such as roads used near extraction industries, the percentage could not be higher. The higher the percentage of overweight trucks, the greater the benefits that can be achieved.

ESAL Damage Costs.—As expected, the findings were that net benefits from weight enforcement increases as the estimated cost per ESAL-mile of pavement damage increases. The very substantial variations in costs of pavement damage per ESAL-mile by responsible researchers indicate that states should take great care in estimating their own relevant pavement costs per ESAL-mile of travel, and use these estimates in developing weight enforcement strategies (as well as in developing fine structures).

Revenue from Overweight Operations.—The revenue received from overweight operations has an important impact on whether or not a given deployment strategy and fine structure will deter a truck trip that would otherwise travel overweight. It was

Table 9. Relationship between increases in fines, decreases in deployment, and changes in net benefits.

Fine Structure (2.5 tons overweight, 7.5 tons overweight, & 12.5 tons overweight	Public Deployment Cost (millions)	Savings Due to Deterred Overweight VMT (millions)	Net Benefit (millions)	Incremental Increase in Net Benefits (millions)
$181, $740, $1238	$342	$867	$525	
$281, $840, $1338	$249	$867	$618	$93
$381, $940, $1448	$224	$867	$643	25
$481, $1040, $1548	$182	$867	$685	42
$581, $1140, $1648	$163	$867	$704	19
$681, $1240, $1748	$138	$867	$729	25
$781, $1340, $1848	$124	$867	$743	14
$881, $1440, $1948	$111	$867	$756	13
$981, $1540, $2048	$100	$867	$767	11

Source: Spreadsheet model developed by Sydec, Inc.

Note: Starting with the Deployment Strategy Identified in Table 3 as an optimal strategy (i.e. the one with the highest net benefits), fine levels were increased in increments of $100. Deployment was reduced proportionally across all highway classes and segment-time periods for each fine increment as long as savings did not decline. Minimum deployment at each level of fines is reported in Table 6.

assumed in this study that the segment of the industry that would choose to travel overweight receives more revenue, on average, from traveling overweight than the costs of overweight travel (in potential fines, off-loading costs, detour costs, and stopping costs). Those operators that have very high increments of revenue for overweight travel will continue their overweight travel even under high enforcement efforts.

Likelihood of Successfully Avoiding an Enforcement Effort.— Less overweight travel will be deterred if overweight truck operators develop successful strategies for avoiding primary and wing teams. For example, trucking operators may try to keep each other well informed of where they think all enforcement teams are currently operating. Any decrease in the likelihood of success per team deployed for enforcement increases the cost of achieving a given level of deterrence of overweight travel.

DATA COLLECTION FOR PLANNING, DESIGN, AND RESEARCH

Most states are actively involved in improving their data collection programs relating to heavy vehicle use of highways. The Highway Performance Monitoring System (HPMS) has been implemented as planned in almost all states, and is providing count data on a good statistical basis for all functional classes (except local streets and roads). The majority of states are now regularly using automatic vehicle classification systems and are involved in some phase of implementing weighing-in-motion systems.

The states are likely to take widely different approaches, at least in the early period of implementing WIM systems, until more expertise is gained and shared among the states. Many states expect to follow the Federal Highway Administration's *Traffic Monitoring Guide* (TMG), but many other states have widely varying views on different approaches to the deployment of WIM for planning data collection and related purposes.

The schedule for SHRP's long-term pavement monitoring program has fallen behind, but is now moving forward with approved funding. More SHRP staff have been recruited and are working closely with all the states in an effort to complete the site selection process by spring of 1988. By then, an average state is expected to have some 30 continuing monitoring sites selected through SHRP, which will be concentrated on the rural Interstate System.

Many states are currently holding back on making decisions on the type of WIM equipment to purchase until the results of the HELP and other research and testing programs are completed. They are also looking for further guidance from various sources on how best to approach the task of deploying equipment and manpower to satisfy several related program requirements.

A review of the TMG in relation to the needs for planning data leads one to conclude that it provides very useful guidance, but that it does not provide the best possible program for utilizing the capabilities of WIM systems. The costs of WIM are decreasing significantly and the potential benefits of better data collection are increasing relative to expectations of just a very few years ago, thus resulting in a warrant for substantially greater deployment levels from a benefit-cost standpoint.

A Lotus 1-2-3 computer spreadsheet program has been developed and used to perform extensive cost-effectiveness analyses of different strategies for deploying WIM equipment for planning data collection purposes. The results reveal the following:

- The number of data collection sessions recommended by the TMG meets the specified criterion of precision (plus or minus 10 percent of the estimate with 95 percent confidence) only if equipment precision is ignored and concern is limited to 3S2s.
- The use of permanent WIM data collection sites rather than 48-hour data collection sessions using portable equipment can substantially increase precision. Using the recommendations of the TMG to determine the number of permanent WIM sites results in achieving the specified criterion (referred to as 95-10 in the TMG) *for all vehicles as a whole* rather than just 3S2s, if equipment precision is ignored.
- The specified criterion for 3S2s (95-10) can be achieved by the use of as few as 18 permanent WIM sites, with 6 on the Interstate System and 12 on other roads, if equipment precision is ignored, compared with 30 (10 + 20) recommended by the TMG.
- In order to achieve the 95-10 criterion for all vehicles as a whole using 48-hour data collection sessions, the number of sessions should be increased to about 58 (18 + 40), if equipment precision is ignored.
- The 95-10 criterion can be met for all vehicles as a whole with 30 (10 + 20) permanent WIM data collection sites, the number recommended by the TMG, if equipment precision is ignored.
- When equipment precision is taken into account, a substantially larger data collection program is necessary to achieve the 95-10 criterion. The size of the required program depends on the precision level that can be achieved by the WIM equipment, which is not well known yet. If permanently installed WIM equipment can achieve 95-5 precision, 43 sites can achieve the 95-10 combined precision criterion for all vehicles as a whole.
- If portable WIM equipment is being used, the cost-effectiveness of increasing the duration of sessions from 24 to 48 hours compares favorably under most assumptions with the cost-effectiveness of increasing the number of sessions in the vicinity of the number of sessions recommended by the TMG.

Discussion of Data Collection Needs

Results of the State Survey.—In April 1986, a written survey questionnaire was distributed to the states to provide a basis for understanding the state government markets for heavy vehicle monitoring system information.

The survey questions were distributed to the principal highway or transportation departments of all states and the District of Columbia, most Canadian provinces, various toll authorities, and others.

The agencies surveyed included: (1) highway or transportation departments; (2) state police, highway patrol, or enforcement units of DOTs; and (3) motor vehicle and revenue agencies.

The first set of questions requested of the state highway agencies information on the equipment used and level of effort devoted to HVM functions. Responses indicate that the states have: WIM (51 roadway units in 29 states and provinces, and 27 bridge units in 13 states and provinces); AVC (1,781 units in 34 states and provinces); and AVI (5 roadside interrogator units—Oregon 4 and Alberta 1). In addition, 46 states and provinces have plans to increase their AVC and WIM operations. Alberta plans to install a second AVI test site, and Arkansas is conducting bar code research. Undoubtedly, most of these numbers have increased since the time of the survey.

Table 10 summarizes the amount of effort that states were devoting to heavy vehicle data collection programs for highway planning, design, and needs study purposes. In the top half of the table, the states and provinces are listed in the order of the amount of their annual budget.

The second set of questions requested of the state highway agencies information on the adequacy of current heavy vehicle data collection programs and the importance of improvements to them. Table 11 summarizes the states' evaluation of the

Table 10. Summary of state budgets and manpower for heavy vehicle data collection programs.

Annual Budget for Data Collection 1/	Number of States and Provinces (listed by size of budget)	
$1 - $5 million	4	(CA, FL, OR, IA)
$750,000 - $999,999	7	(TX, PA, WY, MD, ID, VA, AL)
$500,000 - $749,999	9	(CN, IN, MN, HI, KY, AZ, NV, KS, RI)
$250,000 - $499,999	8	(ONT, IL, SD, LA, MI, MT, NH, TN)
$100,000 - $249,999	15	(NS, DE, GA, WI, MS, AR, MO, NY, OK, UT, WA, NC, ND, AK, OH)
0 - $99,999	6	(ALTA, CO, SASK, VT, NE, DC)
Total $25,219,000	49	
Average $ 514,700		

Person-Years in Budget for Current Fiscal Year	Average 2/	Total
Traffic and classification counts 3/	11.0	529
Truck Weight Study	1.8	88
Other special studies 4/	0.5	26
All programs	13.4	643

1/ Current fiscal year capital and operating budget. Includes some funds for WIM research, testing, and implementation; and joint budget with law enforcement for TWS and planning data collection in one state (Wyoming).

2/ Averages for all 48 responses which included quantitative data.

3/ Includes TWS manpower in at least one state (Colorado).

4/ Includes WIM, special surveys of commodity flows and weight, HELP, and SHRP.

Table 11. Summary evaluation of the adequacy of current data and the importance of improvements for highway planning, design, and needs studies.

	Adequacy of Current Data 1/					Importance of Improvements 1/				
	Inadequate				Adequate	Not Important				Very Important
Heavy Vehicle Classification Data	1	2	3	4	5	1	2	3	4	5
Classification locations (right locations?)	5	16	15	11	5	4	4	6	21	16
Classification frequency (times per year)	9	11	8	14	9	4	3	14	17	13
Classification duration (hours, days)	6	12	13	12	9	6	3	8	20	14
Classification coverage (truck classes)	2	2	11	12	24	9	4	14	12	10
Accuracy of classification counts	2	2	15	20	12	5	3	13	13	16
Heavy Vehicle Weight Data										
Weighing locations (right locations?)	9	15	13	9	4	2	3	9	15	21
Weighing frequency (times per year)	12	15	6	13	5	2	5	12	19	12
Weighing duration (hours, days)	11	11	15	6	8	6	5	4	20	15
Weighing coverage (truck classes)	6	5	13	12	15	6	9	11	16	8
WIM data collected at fixed mainline highway locations	20	3	7	6	5	5	2	11	10	13
WIM data collected at random locations	20	6	4	5	2	5	1	7	10	24

1/ Each entry in the table is the number of states or provinces that responded on the five-point scale with the stated response at the top of each column for each aspect of data collection programs listed on the left.

adequacy of current heavy vehicle data collection programs for highway planning, design, and needs studies, and the importance of potential improvements to classification and weight data collection programs. The items that stand out in this table indicate that the greatest inadequacies with current programs are the lack of WIM data collected at both fixed and random locations. The greatest improvements are expected from WIM data collected at random locations. The second greatest improvements can be achieved by better location of weighing locations. The least important areas in terms of improvement needs are classification coverage (truck classes), accuracy of classification counts, and weighing coverage (truck classes).

In all of the other categories, the states have a wide distribution of views regarding current data accuracy. Many states see important opportunities for improvements, even in areas judged relatively adequate.

States' Plans for Data Collection Programs.—The third set of questions requested of the state highway agencies information on states' plans for improvements in heavy vehicle data collection programs. Table 12 summarizes state plans for improvement of heavy vehicle data collection programs. The returns from 51 states and provinces were categorized based on the descriptive answers provided to the open-ended question regarding their plans. A total of 85 responses is tabulated because many states reported plans involving more than one type of improvement. Most of the values in the exhibit probably would be larger if the survey were repeated today.

Almost half of all the responses deal with states' plans for WIM systems. About half of all the states and provinces have specific plans to acquire new WIM equipment or add additional WIM sites. Another quarter of them have plans to test or evaluate WIM systems, or are actively involved in studying, planning, or recommending WIM systems. Only the remaining one quarter of the states and provinces report no activities regarding WIM systems.

The second most active area of state planning for improvements in heavy vehicle data collection programs relates to AVC systems. About one-quarter of the states have plans for acquiring

AVC equipment, adding sites, or testing and evaluating AVC systems.

The next most frequently reported type of plan is implementation of the FHWA's *Traffic Monitoring Guide* (eight states). These plans most commonly involve the acquisition of WIM systems and the development of additional heavy vehicle monitoring sites with WIM and AVC systems as part of a statewide monitoring system. Many of the states that gave this response are the ones that could probably be added to the number of states planning to implement improvements in WIM and AVC systems, although most of them did not explicitly state this.

States' Strategies for Deploying WIM.—In the fourth set of questions, states were asked to evaluate strategies that have been identified for deploying and using various configurations of HVM systems. Table 13 summarizes the evaluation by states and provinces of the cost-effectiveness of several strategies presented in the questionnaire. The evaluation process used in the survey consisted of several questions. Of these, the question that provides the basis for the single most complete summary evaluation of the relative merits of the several strategies is the evaluation of the cost-effectiveness of the alternative strategies on a five-point scale.

The first six of the strategies evaluated involved single specific approaches for the deployment of WIM, AVC, and (in one strategy) AVI. Most of the states and provinces evaluated these strategies (more than 40 in each case). The seventh was the respondent's choice of a mix of the above strategies, as specified by the respondent. About half of the states and provinces performed an evaluation of a specific mix of deployment strategies. The eighth strategy was some approach specified by the respondent other than those specified in the first six strategies or in a mix of them. About one quarter of the states and provinces identified and evaluated such a strategy, although these tended to be variations on the initial six, or combinations thereof.

The first column of Table 13 presents the average responses on the five-point scale, where 1 is defined as "not cost-effective" and 5 is defined as "very cost-effective." An average score of 3 can be interpreted as the approximate breakpoint between a positive and a negative collective judgment by the respondents as to the merits of pursuing a given strategy. The first column presents the averages for all states and provinces evaluating each strategy. The last two columns show the number of states or provinces that evaluated each strategy at either extreme (1 or 5), "not cost-effective" or "very cost-effective."

Among the six strategies specified in the questionnaire, the strategy evaluated most favorably is the second. This is a strategy analogous to the well-accepted approach now used for expanding and adjusting traffic counts for a statewide system. A relatively small number of sites would be used as permanent recording stations to obtain seasonal and weekly factors, and a much larger number of other sites would be used for short-term classification and weight surveys, providing the basis for expansion and adjustment to average annual weight distribution estimates. This strategy was evaluated as superior to the deployment strategy recommended by FHWA in the *Traffic Monitoring Guide.* FHWA's guide received the third highest average evaluation by all respondents and had the same number of states rating it very cost-effective as did strategy number 2. However, among the states involved in the HELP Program (which are generally further along in their planning) FHWA's guide is in the "also ran" category, along with the four other strategies.

Table 12. Summary of state plans for improvement of heavy vehicle data collection programs.

WIM Plans	Number of States
Acquire equipment; add sites	26
Bridge WIM implementation	1
Test, evaluate	3
Develop system plan	2
Use WIM to locate sites	1
Recommend WIM; possible WIM	2
Study alternatives	3
Automatic replacing manual	1
Subtotal	(39)
AVC Plans:	
Acquire equipment; add sites	11
Test, evaluate	2
Traffic Monitoring Guide Implementation	8
SHRP Site Implementation	2
Install Permanent Loops, Telemetry	7
Automate Port Operation, Data Collection	2
Piezo Cable Testing	3
Test AVI, Add Sites	2
Planning; Reviewing Needs; Increasing Budget	4
No Plans	5
Total	85

Table 13. Summary evaluation of strategies for deploying equipment for planning and design data collection.

	Cost Effectiveness Evaluations		
		Number Rating Strategy:	
Strategy	Average Score 1/	Not Cost Effective	Very Cost Effective
1. Fixed location, mainline WIM to collect year-round data	2.6	8	7
2. WIM as permanent recording stations, plus AVC and short weight surveys for expansion to annual	3.6	2	7
3. RWIM at random locations and hours of operation	3.5	3	5
4. FHWA's Traffic Monitoring Guide	3.3	6	7
5. WIM on mainline lanes to collect data for enforcement strategies	2.7	8	0
6. Use AVI in sample of vehicles to establish weight distribution	2.5	9	1
7. States' mixture of above strategies	3.8	0	5
8. Other strategies than above	4.6	0	9

1/Average score of states' evaluation of the strategies on a five-point scale where "1" is "not cost effective" and "5" is "very cost effective."

Table 14. Multiple strategies favored by the states.[1]

	Fixed Location WIM	Permanent stations/ expansion factors	Random location & hours	Traffic Monitoring Guide	Data for enforcement strategies	AVI in sample of vehicles
Alberta		1		3		2
Arkansas	4	3	1	2	5	6
California		1		2		
Colorado		3		1	2	4
Delaware	1	3	2		4	
Idaho	3	1	2			
Illinois	2			1		
Kansas	4	2	3	1		
Louisiana			2	1		
Maryland		1		2	3	
Michigan	5	2	3	1	4	6
Minnesota		1				2
Missouri			1			
Mississippi		1	2	3		
Nebraska	4	2	1	3	5	6
Nevada		1				2
North Carolina			2	1		
Ohio	1	3	5	2	4	6
Oregon			1			2
Pennsylvania	4	1	3	5	2	6
Saskatchewan	1				2	3
South Dakota	3	6	2	1	5	4
Tennessee	5	3	1	2	4	6
Utah	1	2	5	6	4	3
Vermont		2	1		3	
Washington		2		1		
Wisconsin	3	5	6	1	4	2
Wyoming	3	1	2	4	5	6

1/Numbers in the table indicate the first, second, third, etc. listed choices of the states and provinces.

Table 14 further demonstrates the diversity of the respondents' assessment of the different strategies. Four out of the six specified alternative strategies were listed first by several states as part of their preferred mixture of deployment strategies, and all of the six were included by several states in their preferred mixture of strategies. Almost no two respondents specified the same mix of strategies.

This analysis suggests that the states are likely to take widely different approaches, at least in the early period of implementation of HVM systems for highway planning purposes, until more expertise is gained and shared among the states. To date, virtually no quantitative analysis has been conducted to provide guidance. Moreover, the choice of deployment strategy for highway planning, design, and needs study applications is closely related to the choice of deployment strategies for other purposes, and these interrelationships have previously been given almost no attention.

Status of The Strategic Highway Research Program.—SHRP's long-term pavement monitoring program has grown from an 8-state program started in 1981 to a 50-state program. The original plans for the expanded program called for pavement performance monitoring at 1,560 sites to be selected by January 1987, involving continuous counts, quarterly (eventually continuous) classification counts, and annual (perhaps eventually continuous) weighing (*2*).

Because of delays in funding and difficulties in the site selection process, the schedule for implementation of SHRP has slipped significantly. After the initial candidate sites had been submitted by the states, only about 15 percent of the targeted number of cells in the experimental design had been satisfactorily filled. The SHRP staff have been attempting to get four candidate sites for each cell of the 1,560 site experimental design so that they can select final sites randomly from the candidate list.

The second round of site selection has been underway since early 1987, and staff are optimistic that they will be able to find a minimum of two candidates for most of the cells and make the final selections in 1988.

About 46 states had submitted candidate sites in the first round. Of these, about 70 percent were on the Interstate System. The rest were all on primary routes—probably almost all on principal arterials. About 90 percent are in rural areas.

Current plans are for all sites to have permanent traffic counters, and for AVC classification counts to be obtained for 48-hour periods once each season. WIM data are to be collected initially on an annual basis and eventually on a seasonal basis, also for 48 hours per session.

Thus, by some time in 1988 an average state may have 20 to 30 continuing monitoring sites selected through SHRP, most of which will be concentrated on the rural Interstate System, and the rest primarily on rural principal arterials. Many of these sites are likely to be in locations that are satisfactory for other planning and design purposes, in accordance with the *Traffic Monitoring Guide* and other requirements, although some will undoubtedly not be very useful for planning purposes because they are duplicative of other sites.

For the average state then, a substantial proportion of the truck weighing recommendations of the TMG might be satisfied for rural Interstates (30 sessions of 48 hours each over a 3-year period), *if* the candidate sites were picked in accord with the TMG. The weighing recommendations for rural Interstates are likely to be fully satisfied, or substantially so, for many states. The weighing recommendations for urban Interstates and other, lower functional classes are not likely to be satisfied to any significant extent, however, and recommendations for classification counts will not be satisfied to any substantial extent (300 classification count sessions of 48 hours over a 3-year period for the total of all functional classes).

Other Recent WIM Research and Testing.—Recent testing of WIM high-speed systems and ongoing projects in several states are providing useful, up-to-date data and experience for this NCHRP project.

Arizona has provided some approximate cost data and reported experience with portable capacitance pad systems. The pads have worked well, although some problems with the electronics have had to be overcome, with considerable effort from the supplier.

Florida has also provided some approximate cost data and reported experience with portable capacitance pad systems. FDOT staff have had continuing problems with the electronics over a 2-year period, but are now achieving acceptable performance with some of the equipment. Accuracy levels are less than advertised.

Florida has also had continuing problems with its old Radian permanent installations, largely because the supplier has left the field. FDOT has recently contracted with a German firm, PAT, for installation of new permanent WIM systems at 19 sites.

Oregon has recently published a report documenting several years of testing of WIM, AVC, and AVI systems, including permanent WIM systems and a portable bridge WIM system (*3*). Experience with the WIM systems has been generally satisfactory after solving some initial problems.

Maine has been performing comparative evaluations of two different portable pad systems and three permanent systems, and has provided cost data and some results of preliminary testing. All systems have worked with reasonable satisfaction, to a greater or lesser extent.

Minnesota and Iowa have been involved in coordinated testing of low-cost piezoelectric systems. Both DOTs expect performance and cost criteria to be met, although Minnesota has had substantial problems with electronics.

Maryland is probably the only state that is currently using high speed WIM to identify potential weight limit violators for enforcement purposes. MDOT has supplied data on approximate costs of operation of its bridge system and on experience, which has been generally satisfactory.

California recently found that the competitive bid price per unit for permanent WIM installations was on the order of half of what had been anticipated because of the size of the order (20 scales) and the growing competition among suppliers in this rapidly expanding market.

A recent NCHRP draft interim report on low cost bridge WIM reached positive conclusions about the feasibility of developing and producing a system for less than $10,000 (exclusive of warranty and sales cost).

Over the last couple of years a substantial amount of data has become available from high-speed WIM tests on the main lanes of highways in a few states—widely scattered throughout the country. These data consistently show a much higher percentage of trucks violating weight limits than has been documented in any previous research. Violations of tandem axle weight limits typically range between 20 and 50 percent of all heavy trucks, and bridge formula violations typically are between 40 and 60 percent. These findings have not been fully documented because of their tentative nature and because of their controversial implications. Nonetheless, sufficient evidence has been arising from so many sources that the need for much greater weight enforcement activity has been clearly demonstrated.

Table 15. Number of major segments on Interstate System in selected states.

State	Number of Major Segments[1]	Number of HPMS Sections[2]
California	77	327
Iowa	21	388
Maine	7	131
Massachusetts	39	274
Minnesota	21	131
Ohio	79	389
Oregon	7	186
Rhode Island	5	43
Texas	61	254
Virginia	31	228
Wyoming	8	117
Average of Above States	32	224
Average of All States & D.C.	N.A.	172

[1]A major segment is defined as a portion of an Interstate highway between two interchanges with other Interstate routes, a state border, or a terminus of an Interstate route.

[2]From TMG, Exhibit 3-3-3.

Transportation planners have in the past often sought to separate truck weight study data collection from weight enforcement activities in order to obtain more accurate data for realistic planning purposes. Recent facts show that this has not been achieved successfully. Moreover, the analysis, reported later in this section, convinces one that the public benefits to be gained from improved weight enforcement are greater by an order of magnitude than the potential losses in accuracy that might be achieved by a much more integrated approach to the planning of weight enforcement efforts and data collection for planning and related purposes.

Discussion of Traffic Monitoring Guide's Recommendations for WIM

The TMG recommends that truck weight data be collected for 48-hour sessions with the following number of sessions and resulting precision:

STRATA	Number of Measurements (3-year)	Annual Measurements	Expected Precision of 3S2 ESAL System Estimates (3-year Cycle)*
Interstate	30	10	95-10
Other Roads	60	20	95-10 to 20

* 95-10 is a short form for the recommended criterion of being able to estimate equivalent single axle loads (ESALs) for 3S2s on the Interstate System or on other roads as a whole within plus or minus 10 percent of the true value with 95 percent confidence. A range of 10 to 20 percent is stated as being acceptable for other roads.

Each of the sites for the data collection sessions is recommended to be selected randomly from among the state's sample of highway data collection sections used in the Highway Performance Monitoring System (HPMS sections).

One problem with this recommendation is the inefficiency caused by assuming that small segments of highways are independent of each other in terms of ESALs (or vehicle classification). As is to be expected, there is a high correlation in traffic characteristics from section to section over long segments of highway, particularly for the Interstate System. Thus, it is far more efficient statistically to sample from longer highway segments that are more independent of each other in terms of traffic characteristics.

Table 15 provides a tabulation of the number of HPMS sections on the Interstate Systems in selected states, along with an estimate taken from a recent atlas of the number of major Interstate segments in those same states. As defined in the footnote in the table, these Interstate segments are probably about the longest practical segments that could be defined by the use of a simple criterion that would result in more independent segments in terms of traffic characteristics. More sophisticated criteria could be developed using traffic volume and vehicle classification data. In many states there probably are fairly obvious interchanges with other major non-Interstate routes where some of these long segments have large changes in volume or vehicle mixes, particularly in western states with very long segments.

The states selected for Table 15 are not intended to be a random sample. Rather they were selected to cover a range of network characteristics by covering a range of sizes, regions, and other characteristics, with a bias toward representing both large and small states and states with both many and few urban areas.

Note that most of the states have a number of major segments that fall in the range between the number of annual measurements recommended by the TMG (30) and the number of measurements recommended for a 3-year cycle (90), and none has more than the latter. This suggests that states might easily develop a more efficient data collection program by selecting WIM data collection sites that are representative of longer segments. The longer segments to be used could either be the longer segments tabulated in Table 15 or subsegments of them, using sufficient divisions of segments to yield either 30, 60, or 90 sites (accepting for the moment the recommended number of sites of the TMG). This will be discussed further below and in Chapter Four, Recommendations.

A second problem with the TMG recommendation is the use of higher standards for the Interstate System. Not only is the criterion apparently higher (95-10 vs. 95-10 to 20), but all other functional classes are grouped into a single category. The TMG does not attempt to explain why this is done in contrast to recommendations for volume counts and classification counts, wherein the same criterion is used for each functional class (except local streets and roads). In explaining why only two strata (Interstate and all other roads) are used, the TMG (page 5-2-3) indicates that this is done to reduce the sample size required. Other types of stratification are likely to result in increased sample sizes. Large states may opt to expand the stratification to increase reliability or provide more information. For example, separating the Interstate into rural and urban portions would require 60 measurements, 30 in the rural and 30 in the urban strata, to approximately achieve the precision levels in both strata.

The issue of the number of measurements that would be required for consistent application of a criterion for all functional classes needs to be addressed further in the analysis of strategies for deployment of WIM systems.

A third basic issue is raised by further consideration of the foregoing arguments in the TMG. Why does the precision level have to remain at 95-10 for the Interstate System? If this criterion cannot be met for each functional class because of costs, why not reduce the requirement uniformly (e.g., to 95-20 or 95-30)? This issue also needs to be addressed in the analysis.

Another closely related issue is that the specified precision level is only for a single vehicle class, 3S2s. For most uses of weight data, there is no need to know the axle loads for any individual vehicle class. However, for most, if not all purposes, there is a need to know axle loads of all vehicles as a whole. The sample size and cost implications of this need to be addressed.

A final issue regarding the precision recommendations of the TMG is the effect of equipment error on the sample size requirements and cost of meeting the criterion. Or put another way, what effect does equipment precision have on the resulting overall precision level for any given level of deployment?

Finally, the TMG's recommendation that all data collection sessions be 48 hours should be analyzed. The TMG considers the tradeoff between precision and length of session, but does not explicitly consider either cost considerations, tradeoffs between length of sessions and number of sessions, or how these relationships might be affected by the type of equipment used (e.g., portable vs. permanent WIM installations).

All of these issues are considered further in the next section and in Chapter Four.

Cost-Effectiveness Analysis for WIM Data Collection

Development of the Model.—A cost-effectiveness analysis has been performed to evaluate alternative strategies and levels of effort for deploying WIM systems to collect data for planning, design, and research purposes. The basic analytical approach is a spreadsheet computer program prepared using Lotus 1-2-3, Release 2.01. The alternatives that the program is designed to evaluate include five strategies based on those described at the beginning of this section and used in the survey of the states. The five strategies are:

1. Fixed location, continuous data collection at permanent WIM sites, using sensors installed either in pavements or on bridges, and with telemetry for transmission of data to a centralized computer facility.
2. Fixed location, continuous data collection at permanent WIM sites, plus portable WIM equipment at other sites using mats or other sensors permanently imbedded in pavements or on bridges, along with electronics that are transportable in vans.
3. Fixed location, continuous data collection at permanent WIM sites, plus portable automatic vehicle classification (AVC) equipment (using appropriate average axle weight statistics to convert vehicle classification counts into estimates of axle loads).
4. Portable WIM mats used at random locations and hours (i.e., without permanently installed sensors).
5. Portable WIM electronics used at permanent sites with sensors imbedded in pavements or on bridges (referred to as the Traffic Monitoring Guide program because this type of system is designed for regularly repeated data collection sessions at fixed locations as recommended by the TMG).

The spreadsheet program develops cost estimates for all aspects of a state's WIM data collection program, together with estimates of the level of statistical precision for the program. Each program to be evaluated must be specified in terms of the number and types of equipment, the number of sites, the number of sessions, the length of data collection sessions, the number of permanent sites with and without telemetry and the number with portable and fixed electronics. An effort has been made to generalize the inputs for each alternative strategy being evaluated so that the user can compare different approaches at a general level without having to specify all input values. Default values have been prepared for all the unit cost estimates, including equipment, installation, maintenance, field crews, travel, overhead, and replacement costs based on expected life. All default values are approximate national averages based on data obtained from the states wherever available. Costs are estimated by the model for each year over a 20-year program, as well as in equivalent annual cost terms (using a 10 percent discount rate).

The cost elements include: (1) purchase prices for WIM equipment and electronics, vans, AVC equipment, etc.; (2) installation, site preparation, telemetry, and power hook up; (3) initial calibration; (4) replacement costs over the 20-year period; (5) annual operating cost (set-up and monitoring of data collection); and (6) annual maintenance cost.

Table 16. Choice of general deployment strategy, number of sites, and number of sessions initial base case for comparison purposes.

Deployment Strategy	Number of Sites			Number of Data Collection Sessions[2]	
	IS	Non-IS	Total	Standard[3]	Continuous
1. Fixed location, continuous data collection	10	20	30	0	30
2. Fixed location plus portable WIM					
Permanent WIM sites	3	6	9	0	9
Portable WIM sites	7	14	21	21	0
3. Fixed location plus portable AVC					
Permanent WIM sites	5	10	15	0	15
Portable AVC sites[1]	33	67	100	100	0
4. Random locations and hours					
Portable WIM sites[1]	10	20	30	30	0
5. Traffic Monitoring Guide program					
Portable WIM sites	10	20	30	30	0

[1] Additional sites without permanent loops in the pavement should be used as appropriate.

[2] Assumes that sessions are either continuous (i.e., for substantial portions of the year), or are of a standard length as recommended by the Traffic Monitoring Guide).

[3] Standard length sessions are assumed to be spread proportionately among all types of sites shown in Table 2 if the number of sessions is greater than the number of sites shown in Table 1.

Some of the default values included in the model are very approximate because of the lack of data from actual experience by the states. These include WIM maintenance and calibration costs, training, office manpower, and other overhead costs. Better data are available on most of the initial capital cost items and field operating costs.

Estimates of precision levels for each program are based primarily on data and relationships developed in the process of preparing the TMG, supplemented by a limited amount of additional data on equipment precision obtained from the states and other sources during this project.

The spreadsheet program has been prepared so that it can be used by a state analyst who is familiar with Lotus 1-2-3 and has general knowledge of WIM systems. Sufficient documentation is provided in the spreadsheet and in Appendix B of this report so that a state analyst should be able to learn to use the program within a few hours.

Results of Model Application.—Tables 16, 17, and 18 provide summaries of the major inputs and outputs of a base case application of the cost-effectiveness model. As Table 16 shows, this base case follows the recommendations of the TMG, insofar as applicable to the five strategies defined in the preceding subsection, regarding the number of data collection sessions or sites on the Interstate System and other roads.

Strategy 5 is a precise application of the TMG recommendations with a total of 30 standard length WIM data collection sessions per year at fixed locations using piezoelectric cable sensors imbedded in the pavement at each site and portable electronics. Strategy 4 involves the same data collection program, but using capacitive mats at random locations. Strategy 1 involves the same number of sites (30) but at permanent data collection sites using piezoelectric sensors, permanently installed electronics, and telemetry. Strategy 2 involves a mix of permanent and portable WIM equipment at a total of 30 sites, all using piezoelectric cable. And strategy 3 involves a mix of permanent WIM sites and portable AVC equipment in the only deployment that differs in terms of number of sites from the TMG recommendations—the number of WIM sites is half of the recommendation, but this is supplemented by 100 AVC sites (the TMG recommendation for vehicle classification sessions) providing estimates of axle loads using appropriate average axle weight statistics to convert classification counts into estimates of axle loads.

Table 17 presents cost estimates for each of these five strategies for the base case deployments defined in Table 16. Tables in Appendix B provide details on the unit costs and other parameters used in these base case cost estimates. Among the more important assumptions affecting the cost estimates in Table 17 are that all standard length data collection sessions would be 48 hours (as recommended by the TMG), that two persons would be required to be on duty on the average throughout the data collection sessions, that the average wage rate for all personnel involved would be $12 per hour, that the overhead rate covering training, fringe benefits, and all support services and facilities would be 100 percent of direct labor and expenses for field operations, and that the total initial cost of piezoelectric

Table 17. Summary of cost estimates for base case.

	DEPLOYMENT STRATEGY				
CAPITAL COSTS	1. Fixed Location Year Around Data Collection	2. Fixed Location Plus Portable WIM	3. Fixed Location Plus Portable AVC	4. Random Location and Hours	5. Traffic Monitoring Guide Program
WIM Equipment Cost	315	133	158	48	48
Other Equipment Costs (vans, AVC, etc.)	120	66	190	30	33
WIM Installation Costs	195	59	98	0	0
Other Equipment Installation Costs (telemetry, etc.)	210	66	114	3	18
Initial Calibration Costs	105	38	73	9	9
Total Initial Costs	945	362	633	90	108
Replacement Costs over 20 Year Period	945	439	792	180	234
Total Capital Cost over 20 Year Period	1890	801	1425	270	342
Equivalent Annual Capital Cost, Undiscounted	95	40	71	14	17
Discounted (@10%) Present Value of 20 Year Capital Requirements	1010	412	728	125	159
Equivalent Annual Discounted Capital Costs	51	21	36	6	8
ANNUAL COST					
Operating Cost	23	63	39	79	82
Maintenance Cost for WIM Equipment	105	38	53	9	9
Maintenance Cost for Other Equipment	30	14	40	5	20
Total Annual O&M Cost	158	115	132	93	111
TOTAL EQUIVALENT ANNUAL COST					
Total Using Undiscounted Capital Cost	253	155	203	107	128
Total Using Discounted Capital Cost	209	135	168	100	119

cable installations would be $19 and $22 thousand, for two-lane and four-lane systems respectively, including equipment, installation, and initial calibration.

The cost estimates in Table 17 suggest that strategies 4 and 5 are probably less costly in terms of equivalent annual costs than the other strategies for these base case levels of deployment and assumptions regarding unit costs and other parameters. The random location strategy (4) appears to be slightly less costly than the TMG strategy (5) primarily because of maintenance costs for the permanent loops in the pavement. The maintenance cost of WIM equipment appears to be a major factor in the apparently higher costs of the other two pure WIM strategies (1 and 2). Although strategy 3 (permanent WIM sites plus portable AVC) also appears to be substantially higher than strategies 4 and 5, it is estimated to be very close to them in equivalent annual cost terms if only WIM costs are included ($105 thousand per year), recognizing that the costs of the recommended level of AVC deployment would presumably be the same under all strategies.

Also note that in these base case comparisons, capital costs do not play a dominant role in the cost comparisons when considered in discounted equivalent annual cost terms.

These cost comparisons must be considered very tentative because of the lack of any empirical data from U.S. experience on many of the unit cost factors, most notably maintenance costs of piezoelectric systems.

Table 18 presents the base case comparisons of precision estimates for the five strategies. In this standard output format from the model, the left column shows an estimate of the level of equipment precision for each strategy and major component thereof. In this base case set of assumptions, all equipment specified (piezoelectric and mats) is assumed to meet a 95-10 criterion. However, if equipment with different levels of precision were specified, the model would compute a statistically weighted precision level. The next three columns present the estimated statistical measures of precision for the levels of deployment for the Interstates, non-Interstates, and combined—all ignoring equipment precision. The final three columns present estimates of combined precision for the highway systems, taking into account both equipment precision and statistical precision based on the level of deployment of the equipment.

In each column except the first, precision levels are estimated first for 3S2s, then for all vehicles as a whole. For example, the statistical measure of precision (ignoring equipment precision) at the recommended level of ten data collection sessions per year for 3S2s using the TMG strategy (5) for Interstate routes is plus or minus 10.7 percent with 95 percent confidence, and for all vehicles as a whole is 13.1 percent. When equipment precision is taken into account, these ten data collection sessions on the Interstate System yield an estimated precision level of plus or minus 14.7 percent for 3S2s and 16.5 percent for all vehicles, with 95 percent confidence.

Table 18. Precision estimates based on equipment capability, sampling variability of the deployment, and a combination of the two for base case.[1]

Deployment Strategy	Equipment Precision[2]	Precision of Deployment[3]			Combined Precision[4]		
		IS	Non-IS	Combined	IS	Non-IS	Combined
1. Fixed location, continuous data collection	10.0%	7.9%	7.4%	7.5%	12.7%	12.4%	12.5%
		9.7	10.2	10.0	13.9	14.3	14.2
2. Fixed location plus portable WIM:							
Permanent WIM sites	10.0	14.3	13.4	13.7	17.5	16.7	17.0
		17.7	18.6	18.3	20.3	21.1	20.9
Portable WIM sites	10.0	12.8	12.0	12.3	16.3	15.6	15.8
		15.7	16.6	16.3	18.6	19.4	19.1
Combined	10.0	9.9	9.2	9.5	12.4	12.9	12.7
		12.1	12.8	12.6	14.2	16.1	15.5
3. Fixed location plus portable AVC							
Permanent WIM sites	10.0	11.1	10.4	10.6	14.9	14.4	14.6
		13.7	14.4	14.2	16.9	17.6	17.4
Portable AVC sites[1]	10.0	20.5	17.9	18.8	22.8	20.5	21.3
		149.4	299.0	259.4	149.7	299.2	259.6
Combined	10.0	17.1	15.0	15.7	19.2	18.7	18.9
		121.5	243.4	211.0	122.2	268.8	230.9
4. Random locations and hours							
Portable WIM sites[1]	10.0	10.7	10.0	10.3	14.7	14.2	14.3
		13.1	13.9	13.6	16.5	17.1	16.9
5. Traffic Monitoring Guide program							
Portable WIM sites	10.0	10.7	10.0	10.3	14.7	14.2	14.3
		13.1	13.9	13.6	16.5	17.1	16.9

[1]All estimates are 95 percent confidence limits expressed as percentages of the estimated equivalent single axle loads (ESALs) or percentages of the estimated vehicle classification.

[2]Weighted average precision of equipment under average conditions. Precision level is assumed to be the same for the Interstate system and for other roads. Portable WIM sites are assumed to be either all mats or all fixed location WIM equipment with transportable electronics, but not a mix of the two types; the equipment precision estimate will be the unweighted sum of error of the two types if they are mixed.

[3]Ignores equipment error. All values are expressed in terms of percent of ESAL estimates including estimates based on AVC data. First values are for 3S2s; second values are for all vehicles.

[4]Estimated precision taking into account both equipment precision and sampling variability of deployment. First values are for 3S2s; second values are for all vehicles.

Because the results presented in Table 18 are based on the same data and have been developed starting with the same basic approach, one would expect the values to be in agreement with the 95-10 precision estimates stated in the TMG, and this is confirmed by the 3S2 values for strategy 5 in columns two through four (10.7, 10.0, and 10.3 percent). The same values are shown for strategy 4 because the model does not reflect any potential statistical advantage that could be gained by a purely random deployment (or more accurately, it does not reflect any loss in precision due to a fixed set of measurement sites rather than a random selection of sites).

Note that strategy 1 yields a substantially better level of precision with 30 permanent WIM installations and continuous data collection. Most importantly, it achieves the 95-10 criterion for all vehicles (ignoring equipment precision), which is believed to be the most significant measure of precision as stated previously. By comparison, strategy 5 yields an estimated 13.6 percent precision for all vehicles for the combined highway systems measure (which is a statistically weighted measure for the two strata, Interstate, and non-Interstate).

Strategy 2 provides a statistically combined level of precision that is intermediate between strategies 1 and 4, as should be expected because it combines parts of both. However, strategy 3 appears to offer no promise that the use of AVC can provide acceptable estimates of precision, particularly for all vehicles. The data used in developing the TMG show that the variability in vehicle classification percentages is very high for the various functional classes. When these high variability measures are combined statistically with measures of variability for axle weight statistics, the resulting relationship requires very high sample sizes to achieve reasonable precision levels.

Note that when equipment precision is taken into account all of the strategies result in much poorer precision—typically about 40 percent greater variability than when equipment precision is ignored in those cases that are approximately achieving the 95-10 criterion.

The foregoing results do not provide a very good basis for comparing the strategies because they achieve substantially different levels of precision at substantially different costs. Tables 19 and 20 provide one basis for comparison, using the TMG criterion of 95-10 for 3S2s. Table 19 provides data on equipment deployment and costs comparable to the first two tables of the base case, but in a more summary form; and Table 20 provides precision estimates in the same form as before—as a direct output of the model. These results were produced by holding all inputs the same as for the base case except the number of permanent sites or standard sessions. These were varied upward or downward for each strategy until the 95-10 criterion for 3S2s was achieved within roundoff error for each of the two highway strata, as can be seen in the first row of values in columns 2 to 4 of Table 20 for each strategy, or for the "combined" precision in the case of strategies 2 and 3.

Table 19. Number of sites required and annual cost estimates to achieve desired precision levels for 3S2s ignoring equipment precision.

Deployment Strategy	Number of Sites: Interstate	Non-interstate	Total	Total Equivalent Annual Cost (Thousands)
1. Fixed location, continuous data collection	6	12	18	$125
2. Fixed location plus portable WIM				
Permanent WIM sites	3	6	9	122
Portable WIM sites	6	10	16	
3. Fixed location plus portable AVC				
Permanent AVC sites	6	10	16	220[1]
Portable AVC sites	70	100	170	
4. Random locations and hours	11	20	31	102
5. Traffic Monitoring Guide program	11	20	31	122

[1] WIM costs are estimated to be about $111 and AVC costs about $109.

This comparison shows that the number of permanent WIM sites can be cut back to about 60 percent (18/31) of the number of standard 48-hour sessions required, reducing equivalent annual costs to a level quite comparable with costs for the TMG approach. In fact, all of the strategies appear to be quite comparable in cost terms—easily within the margin of error for the unit cost factors—if one considers only WIM costs. Strategy 4 again appears to have the lowest equivalent annual costs, for reasons discussed previously, but this margin is considered to be quite uncertain. All of the strategies produce roughly comparable levels of precision for all vehicles as a whole (about 13 percent) except for strategy 3, which produces unacceptable results for reasons discussed before.

As argued previously, the most appropriate criterion governing precision should deal with estimation of axle loads for all vehicles as a whole rather than just for 3S2s. Accordingly, the cost-effectiveness model was used in iterative fashion to develop deployments that would satisfy this criterion for all strategies at the 95 − 10 level, within roundoff error, to the extent feasible, again ignoring equipment precision. Tables 21 and 22 show these results in the same format as for the last set of results. Again, base case values have been held constant for all unit costs and other factors except the levels of deployment.

In this series of runs, it was found that it was not economically feasible to achieve the stated criterion for strategy 3 with the base case assumptions. Unlike what was shown for the previous set of results, the use of AVC does not appear to be able to reduce the cost of achieving the specified precision criterion for all vehicles as a whole. As illustrated by the results given in Tables 21 and 22, successive iterations of the model led to the conclusion that even very high levels of deployment of AVC equipment could not bring precision levels down to the stated criterion for all vehicles unless the number of WIM sites was also raised above what was needed to meet the criterion using WIM equipment alone. Note that strategy 3, as shown in the tables, involves twice the recommended level of deployment of AVC and almost double the cost of the other strategies, while coming nowhere close to achieving the stated criterion for all vehicles. Within the limitations of available data, it is, therefore, concluded that the use of AVC data does not appear to be a cost-effective mechanism for achieving desired levels of precision for all vehicles as a whole. However, AVC can be used as an effective means to estimate axle loads for project planning purposes at locations not covered by WIM equipment.

As shown in Tables 21 and 22, the other four strategies appear to require levels of deployment that cost approximately the same amounts in equivalent annual terms. Of particular interest, however, strategy 2, involving the use of mixed permanent and portable WIM equipment, now appears to have a slight edge in cost over either strategy 1 or 5. This is of interest because some benefits to a mixed strategy can be seen that are not reflected in the values in these tables (e.g., ability to monitor seasonal and other trends while retaining flexibility to monitor new locations when desired).

Much confidence is not placed in these small cost differences, given the very approximate nature of the unit cost factors. Nonetheless, most errors in the unit cost factors would have similar effects on the levels of costs for either permanent or portable WIM, or more likely for both. More importantly, most errors in unit cost factors would probably not affect the con-

Table 20. Precision estimates based on equipment capability, sampling variability of the deployment, and a combination of the two for programs meeting precision criterion for 3S2s ignoring equipment selection.[1]

Deployment Strategy	Equipment Precision[2]	Precision of Deployment[3] IS	Non-IS	Combined	Combined Precision[4] IS	Non-IS	Combined
1. Fixed location, continuous data collection	10.0%	10.1%	9.5%	9.7%	14.2%	13.8%	13.9%
		12.5	13.2	12.9	16.0	16.5	16.4
2. Fixed location plus portable WIM							
Permanent WIM sites	10.0	14.3	13.4	13.7	17.5	16.7	17.0
		17.7	18.6	18.3	20.3	21.1	20.9
Portable WIM sites	10.0	13.9	14.2	14.1	17.1	17.4	17.3
		16.9	19.7	18.7	19.7	22.1	21.2
Combined	10.0	10.3	10.1	10.2	12.5	13.7	13.3
		12.6	14.0	13.5	14.5	17.4	16.4
3. Fixed location plus portable AVC							
Permanent WIM sites	10.0	10.1	10.4	10.3	14.2	14.4	14.4
		12.5	14.4	13.7	16.0	17.6	17.0
Portable AVC sites[1]	10.0	14.0	14.7	14.4	17.2	17.8	17.6
		102.6	244.8	198.9	103.0	245.0	199.2
Combined	10.0	12.6	13.0	12.9	15.4	16.7	16.2
		90.9	212.5	173.5	90.4	228.8	185.2
4. Random locations and hours							
Portable WIM sites[1]	10.0	10.2	10.0	10.1	14.3	14.2	14.2
		12.5	13.9	13.4	16.0	17.1	16.7
5. Traffic Monitoring Guide program							
Portable WIM sites	10.0	10.2	10.0	10.1	14.3	14.2	14.2
		12.5	13.9	13.4	16.0	17.1	16.7

[1] All estimates are 95 percent confidence limits expressed as percentages of the estimated equivalent single axle loads (ESALs) or percentages of the estimated vehicle classification.

[2] Weighted average precision of equipment under average conditions. Precision level is assumed to be the same for the Interstate system and for other roads. Portable WIM sites are assumed to be either all mats or all fixed location WIM equipment with transportable electronics, but not a mix of the two types; the equipment precision estimate will be the unweighted sum of error of the two types if they are mixed.

[3] Ignores equipment error. All values are expressed in terms of percent of ESAL estimates including estimates based on AVC data. First values are for 3S2s; second values are for all vehicles.

[4] Estimated precision taking into account both equipment precision and sampling variability of deployment. First values are for 3S2s; second values are for all vehicles.

clusion that at some point as the precision criterion is tightened, the cost advantage should logically be expected to shift to the use of permanent WIM installations. A mixed strategy, such as 2, may be the most cost-effective strategy when other factors such as flexibility are considered.

Shifting attention to the effects of equipment precision will, of course, increase the requirements for deployment of WIM. Tables 23 and 24 show the results of attempts to meet the 95-10 criterion taking into account equipment precision. In order to achieve this criterion, WIM equipment itself must have the capability of exceeding the 95-10 criterion. For all previous runs of the model, it was assumed that all WIM and AVC equipment could just meet this precision level, but, for the results reported in Table 24, the assumption was made that piezoelectric systems could achieve 95-5 while portable mats and AVC systems remain at the 95-10 level. This level of precision does appear to be achievable based on recent research and testing, although it is probably not presently achievable under a realistic range of pavement and other conditions. It is judged to be a fairly optimistic scenario for piezoelectric systems at this time, although perhaps not unrealistic for bending plate or load cell systems (at somewhat higher costs as shown by the cost data reported in Appendix B).

These tables show that the 95-10 criterion can be achieved for all vehicles as a whole, taking into account equipment precision, using 43 permanent piezoelectric WIM installations if the equipment can achieve 95-5 precision. However, as should be expected, none of the other strategies can achieve, or even come very close to the 95-10 criterion of all vehicles within a reasonable level of deployment and cost compared to strategy 1, unless portable equipment is used that can also achieve precision levels substantially better than 95-10. This can probably be done with bending plate or load cell systems with portable electronics, and the model can be used to evaluate such systems. If piezoelectric systems with portable electronics could achieve equipment precision of 95-5, about 72 sessions of 48 hours would be required to achieve a combined precision criterion of 95-10 for all vehicles (not shown in the tables), at a total equivalent annual cost of about $668 thousand. Appendix B shows the default values for the unit cost factors built into the model for such systems, as well as for bending plate or load cell and bridge WIM systems.

Table 21. Number of sites required and annual cost estimates to achieve desired precision levels for all vehicles ignoring equipment precision.

Deployment Strategy	Number of Sites: Interstate	Non-interstate	Total	Total Equivalent Annual Cost (Thousands)
1. Fixed location, continuous data collection	10	20	30	$209
2. Fixed location plus portable WIM				
Permanent WIM sites	4	10	14	198
Portable WIM sites	10	20	30	
3. Fixed location plus portable AVC				
Permanent AVC sites	12	24	36	379
Portable AVC sites	67	133	200	
4. Random locations and hours	18	40	58	193
5. Traffic Monitoring Guide program	18	40	58	229

Table 22. Precision estimates based on equipment capability, sampling variability of the deployment, and a combination of the two for programs meeting precision criterion for all vehicles ignoring equipment precision.[1]

Deployment Strategy	Equipment Precision[2]	Precision of Deployment[3]: IS	Non-IS	Combined	Combined Precision[4]: IS	Non-IS	Combined
1. Fixed location, continuous data collection	10.0%	7.9%	7.4%	7.5%	12.7%	12.4%	12.5%
		9.7	10.2	10.0	13.9	14.3	14.2
2. Fixed location plus portable WIM							
Permanent WIM sites	10.0	12.4	11.6	11.9	15.9	15.3	15.5
		15.3	16.1	15.9	18.3	19.0	18.7
Portable WIM sites	10.0	10.7	10.0	10.3	14.7	14.2	14.3
		13.1	13.9	13.6	16.5	17.1	16.9
Combined	10.0	8.4	7.5	7.8	11.1	11.5	11.4
		10.3	10.3	10.3	12.6	14.0	13.5
3. Fixed location plus portable AVC							
Permanent WIM sites	10.0	7.2	6.7	6.9	12.3	12.0	12.1
		8.8	9.3	9.2	13.3	13.7	13.6
Portable AVC sites[1]	10.0	14.4	12.7	13.3	17.5	16.2	16.6
		104.8	212.2	183.4	105.3	212.5	183.7
Combined	10.0	11.6	10.3	10.8	14.4	14.5	14.5
		82.4	166.0	143.6	83.0	187.0	159.9
4. Random locations and hours							
Portable WIM sites[1]	10.0	8.0	7.1	7.4	12.8	12.3	12.4
		9.8	9.8	9.8	14.0	14.0	14.0
5. Traffic Monitoring Guide program							
Portable WIM sites	10.0	8.0	7.1	7.4	12.8	12.3	12.4
		9.8	9.8	9.8	14.0	14.0	14.0

[1]All estimates are 95 percent confidence limits expressed as percentages of the estimated equivalent single axle loads (ESALs) or percentages of the estimated vehicle classification.

[2]Weighted average precision of equipment under average conditions. Precision level is assumed to be the same for the Interstate system and for other roads. Portable WIM sites are assumed to be either all mats or all fixed location WIM equipment with transportable electronics, but not a mix of the two types; the equipment precision estimate will be the unweighted sum of error of the two types if they are mixed.

[3]Ignores equipment error. All values are expressed in terms of percent of ESAL estimates including estimates based on AVC data. First values are for 3S2s; second values are for all vehicles.

[4]Estimated precision taking into account both equipment precision and sampling variability of deployment. First values are for 3S2s; second values are for all vehicles.

Table 23. Number of sites required and annual cost estimates to achieve desired precision levels for all vehicles taking into account equipment precision.

Deployment Strategy	Number of Sites: Interstate	Non-interstate	Total	Total Equivalent Annual Cost (Thousands)
1. Fixed location, continuous data collection	13	30	43	$298
2. Fixed location plus portable WIM				
Permanent WIM sites	8	16	24	370
Portable WIM sites	20	40	60	
3. Fixed location plus portable AVC				
Permanent AVC sites	24	48	72	632
Portable AVC sites	67	133	200	
4. Random locations and hours	36	80	116	377
5. Traffic Monitoring Guide program	36	80	116	450

Table 24. Precision estimates based on equipment capability, sampling variability of the deployment, and a combination of the two for programs meeting precision criterion for all vehicles taking into account equipment precision.[1]

Deployment Strategy	Equipment Precision[2]	Precision of Deployment[3]: IS	Non-IS	Combined	Combined Precision[4]: IS	Non-IS	Combined
1. Fixed location, continuous data collection	5.0%	6.9%	6.0%	6.3%	8.5%	7.8%	8.0%
		8.5	8.3	8.4	9.9	9.7	9.8
2. Fixed location plus portable WIM							
Permanent WIM sites	5.0	8.8	8.2	8.4	10.1	9.6	9.8
		10.8	11.4	11.2	11.9	12.5	12.3
Portable WIM sites	10.0	7.6	7.1	7.3	12.6	12.3	12.4
		9.3	9.8	9.7	13.6	14.0	13.9
Combined	8.9	5.9	5.5	5.7	9.6	10.2	10.0
		7.2	7.7	7.5	10.5	11.7	11.3
3. Fixed location plus portable AVC							
Permanent WIM sites	5.0	5.1	4.7	4.9	7.1	6.9	7.0
		6.2	6.6	6.5	8.0	8.3	8.2
Portable AVC sites[1]	10.0	14.4	12.7	13.3	17.5	16.2	16.6
		104.8	212.2	183.4	105.3	212.5	183.7
Combined	6.4	9.8	8.7	9.0	12.6	13.3	13.0
		67.1	134.6	116.4	68.0	166.5	141.4
4. Random locations and hours							
Portable WIM sites[1]	10.0	5.7	5.0	5.2	11.5	11.2	11.3
		6.9	7.0	6.9	12.2	12.2	12.2
5. Traffic Monitoring Guide program							
Portable WIM sites	10.0	5.7	5.0	5.2	11.5	11.2	11.3
		6.9	7.0	6.9	12.2	12.2	12.2

[1] All estimates are 95 percent confidence limits expressed as percentages of the estimated equivalent single axle loads (ESALs) or percentages of the estimated vehicle classification.

[2] Weighted average precision of equipment under average conditions. Precision level is assumed to be the same for the Interstate system and for other roads. Portable WIM sites are assumed to be either all mats or all fixed location WIM equipment with transportable electronics, but not a mix of the two types; the equipment precision estimate will be the unweighted sum of error of the two types if they are mixed.

[3] Ignores equipment error. All values are expressed in terms of percent of ESAL estimates including estimates based on AVC data. First values are for 3S2s; second values are for all vehicles.

[4] Estimated precision taking into account both equipment precision and sampling variability of deployment. First values are for 3S2s; second values are for all vehicles.

The cost-effectiveness model has also been used to evaluate the tradeoffs involved between increasing the lengths of standard data collection sessions and increasing the number of standard length sessions. Table 25 shows the effects of increasing the duration of sessions progressively from 1 to 5 days. The annual cost per 1 percent decrease in level of precision increases from $12 thousand, for increases in session lengths from 1 to 2 days, to $117 thousand, for increases from 4 to 5 days. This compares with a cost of $29 thousand per 1 percent decrease in level of precision for increasing the number of standard sessions from 30 (see Tables 17 and 18) to 58 (see Tables 21 and 22).

This comparison tends to confirm the recommendation of a 48-hour data collection as a standard, using the base case assumptions involved in this analysis, if portable equipment are being used. However, as discussed earlier, the use of permanently installed WIM equipment may be warranted for at least a portion of a state's truck weight data collection program, and this drastically reduces the cost of continuous data collection.

Level of Deployment on Interstate and Other Functional Classes

As noted previously, the TMG addresses the question of how much deployment there should be on the several functional classes of highways. However, by comparison with its recommendation for traffic counting and classification programs, the TMG is heavily biased toward the Interstate System. The "recommended procedure allocates the sample to type of area, functional class, and volume groups based on the proportion of AVMT those systems carry (HPMS AVMT) relative to other systems" (*Traffic Monitoring Guide,* FHWA, Page 5-2-3). This recommendation needs to be viewed in the present context in which truck weight data collection is overwhelmingly concentrated on the rural Interstate System because of the almost prohibitively high costs of building and operating fixed weigh stations. WIM technology is rapidly changing this context.

Within this changing context, a completely satisfactory assessment of the appropriate level of deployment on different functional classes would include a comprehensive benefit-cost analysis of deployment strategies. Unfortunately, however, the benefits side of this calculus is almost intractable because it depends on estimates of the costs of errors of many kinds that are exceedingly difficult to define, let alone predict with accuracy. These include such items as the costs of building pavements too thick or too thin, the costs of over- or under-designing bridges, and improperly allocating highway costs among vehicle classes for the purpose of developing equitable highway user taxation. Therefore, the relative value of any given level of precision on the several functional classes must remain judgmental.

One aspect of this judgment is the distribution of heavy vehicle traffic among functional classes. Table 26 provides an estimate of this distribution from the best known source. This table shows that the proportion of traffic that is on the Interstate System is about 20 percent for all vehicles, 52 percent for 3S2s, and 43 percent for all trucks with three or more axles. The proportion of ESALs that is on the Interstate System is probably closest to the last of these three percentages. Using this as a guide, one might argue for even a higher percentage of data collection on the Interstate System than recommended by the TMG. However, this ignores several factors that should be considered relating to the benefits and costs of improved weight data.

An argument could be made that weighing activity should be approximately distributed among highway systems in proportion to expenditures. On this basis, the TMG recommendation of one-third of the total weighing sessions on Interstates is right on target—total state and federal expenditures on the Interstate System for 1985 were 34 percent of total expenditures for all functional classes, excluding local streets and roads

Table 25. Comparison of costs and precision levels for data collection sessions of varying duration.

Duration of Session (Hours)	Total Equivalent Annual Cost (Thousands)[1]	Precision of Deployment[2]			Annual Cost per One Percent Decrease (Thousands)
		Interstate	Non-Interstate	Combined	
24	$ 84	15.9%	16.8%	16.5%	
48	119	13.1	13.9	13.6	$ 12
72	160	12.0	12.8	12.5	37
96	195	11.5	12.2	11.9	58
120	230	11.1	11.8	11.6	117

[1] Based on deployment of WIM equipment following Strategy 5, using portable WIM electronics at fixed locations.

[2] Ignores equipment error. All values are expressed in terms of percent of ESAL estimates for all vehicles.

(FHWA; *Highway Statistics 1985;* Table SF-12, pages 78–80). However, the distribution of expenditures for pavements is far more relevant than the distribution of total expenditures because pavements is the one category of expenditures most directly related to axle weights. The proportion of total Interstate capital expenditures that is expended for pavements is probably only about one-third of that for other highways. (Interstate pavement costs were estimated to be 16.1 percent of total estimated costs for remaining Interstate construction, as compared to 43.7 percent for all future Federal-aid highway costs, according to FHWA's Final Report on the Federal Highway Cost Allocation Study, May 1982, pages IV-12 and IV-15.) On this basis then, the recommended level of weighing effort on non-Interstate systems should be increased about three-fold, to about six times the level recommended for the Interstate System.

Second, the value of having weight data for non-Interstate highways is currently much greater than for Interstates simply because one knows so little about truck weights on non-Interstate highways. Truck Weight Study data have been overwhelmingly concentrated on rural Interstates. Very little also is known about truck trip patterns among the various functional classes. (Research on truck trip patterns could facilitate both weight enforcement planning and data collection for planning purposes. We need to know how truck trips of various lengths are distributed among the various functional classes.)

Third, there is no reason to think that truck weights are lower for the same class of truck off the Interstate System. In fact, there is some reason to believe that illegally overweight trucks may avoid the Interstate System because of the greater enforcement effort. Also, a high proportion of the heaviest axle weights occur with short-haul trucks carrying specialized cargoes that have a lower percent of their miles on Interstates (e.g., dump trucks, garbage trucks, loggers, grain carriers, coal haulers).

Fourth, related to the above point, it is expected that there is far more variation in weight distributions on lower functional classes in most states because of the greater variation in the weight of products related to the local economy. Local products being carried are going to vary considerably throughout many states, and will vary by season to a greater extent.

Fifth, truck trips are much longer on the average on the Interstate System, so there will be less variability over a segment of any given length than for lower functional class highways.

Sixth, an increase in deployment of WIM on lower functional classes is also consistent with the need for a nondiscriminatory weight enforcement policy. Representatives of interstate trucking have argued that increased weight enforcement efforts should not be biased toward long-haul routes. A strategy that attempts to place an equal probability of being monitored on truck trips of all lengths would result in substantially greater concentration on lower functional classes compared with the TMG recommendations.

Seventh, a higher concentration on lower functional classes may be warranted, all other things being equal, because WIM data collection may be less expensive on the average. Lower traffic volumes and fewer lanes will reduce equipment, and possibly manpower needs depending on the type of equipment and other factors. This, of course, will be offset by the decreased amount of data collected per unit of time.

An eighth argument for greater emphasis on non-Interstate roads is the fact that their pavements are generally designed to lower standards so that the cost of pavement damage due to ESALs is higher. Greater concentration of data collection on lower functional classes is required in order to provide a better basis for pavement design, planning of maintenance programs, and improving the effectiveness of weight enforcement efforts.

A ninth and final argument in favor of a shift in emphasis of data collection programs is to improve consistency with other parts of the TMG. Table 27 gives the sample sizes that would be required to achieve the 95-10 criterion, ignoring equipment precision, for 3S2s and for all vehicles, for each of the major functional classes used in other parts of the TMG. The Interstate and other road totals shown directly below the requirements for the individual functional classes are simply the sums of the numbers above. The values shown below that are the requirements when the criterion is applied to each of only two strata rather than to each of the several road classes.

The values shown at the bottom of the first column of Table 27 are essentially the same as those recommended in the TMG. Applying the TMG criterion of 95-10 for 3S2s to each highway class would approximately double the Interstate requirement (as noted in the TMG), but would lead to about a 14-fold increase for other roads. The proportion required on other roads would increase from 64 to 92 percent. If, instead, the 95-10 criterion is applied to two strata of highways for all vehicles as a whole (the values at the bottom of the second column), the requirements for data collection on the Interstate System combined would increase about 50 percent (from 35 to 52 sessions) and on other roads combined would almost double (from 61 to 116 sessions). The most extreme change would occur, of course, if both changes were made (applying the criterion to all vehicles as a whole and to each major functional class), leading to about a three-fold increase for the Interstate System and about a 17-fold increase for other roads.

Table 26. Distribution of vehicle-miles of travel by functional class of highway for all vehicles, 3S2s, and 3 or more axle trucks.

	All Vehicles	3S2s	All 3 or More Axle Trucks
Rural Interstate	142,186 (8.9%)	16,742 (36.2%)	21,287 (29.3%)
Rural Principal Arterial	137,214 (8.6%)	7,471 (16.1%)	10,718 (14.8%)
Rural Arterial	132,844 (8.3%)	5,049 (10.9%)	7,942 (10.9%)
Rural Collector and Local	278,441 (17.5%)	3,599 (7.8%)	7,908 (10.9%)
Urban Interstate	175,459 (11.0%)	7,267 (15.7%)	10,245 (14.1%)
Urban Expressway	91,054 (5.7%)	986 (2.1%)	2,134 (2.9%)
Urban Arterial	414,597 (26.0%)	3,988 (8.6%)	8,892 (12.2%)
Urban Collector and Local	220,686 (13.9%)	1,177 (2.5%)	3,559 (4.9%)
All Functional Classes	1,592,480 (100%)	46,279 (100%)	72,684 (100%)

Source: FHWA, Highway Statistics, 1982; Peterson, Bruce E. and Frank Southworth, "Disaggregation of Highway Traffic by Vehicle Type," May 1984.

Table 27. Sample sizes required to achieve desired precision levels for truck weight data collection over three years on each functional class of highway and for combined functional classes ignoring equipment precision.

Functional Class	Sample Sizes Required to Achieve Precision Levels for: 3S2s	All Vehicles
Rural		
Interstate	24	42
Principal Arterial	65	100
Minor Arterial	100	148
Collector	55	116
Subtotal	(244)	(406)
Urban		
Interstate and Other Freeway and Expressways	47	64
Principal Arterial	53	112
Minor Arterial	284	271
Collector	284	276
Subtotal	(668)	(723)
Interstate Total[1]	71 (8%)	106 (9%)
Other Roads Total[1]	841 (92%)	1,023 (91%)
Grand Total[1]	912	1,129
Interstate Combined[2]	35 (36%)	52 (31%)
Other Roads Combined[2]	61 (64%)	116 (69%)
Total for Two Combined Categories[2]	96	168

[1] Total samples required are sums of the samples for the individual functional classes required to meet precision levels for each functional class.

[2] Combined samples required are samples required to meet precision levels for combined functional classes.

AUTOMATIC CLEARANCE AT PORTS-OF-ENTRY AND WEIGH STATIONS

State DOTs and motor carriers have a common interest in improving and speeding up clearance procedures at weigh stations, ports-of-entry, and roadside inspection sites. It is estimated that, initially, 15 percent of the states and 15 to 30 percent of trucks would participate in a program for automated weigh station clearance. Motor carrier and state interest in automated clearance is low to moderate, except in a few of the western states; however, interest will increase as the number of states adopting and implementing the National Governors' Association's recommendations for uniform truck regulation increases.

There are three general strategies the states could adopt for automated clearance: "sample," "sort," and "preclear and bypass." The objectives of strategy 1, "Sample," are to reduce queuing delays by managing the flow of trucks entering stations and improve paperwork screening by equipping stations with a microcomputer database and telecommunication capabilities. The objective of strategy 2, "Sort," is to increase the throughput at ports-of-entry where all trucks must be weighed and their paperwork cleared. The objective of strategy 3, "Preclear and Bypass," is to reduce the volume of trucks weighing through the station by allowing preregistered carriers to completely bypass the weigh station. The common elements among these strategies are the use of AVI/AVC/WIM technology and microcomputer-based motor carrier records.

States could automate paperwork clearance at ports-of-entry and weigh stations as an initial step toward an automatic clearance program or as an independent program to improve the quality and comprehensiveness of paperwork screening. As a minimum configuration, stations would be equipped with a standard microcomputer and a database containing truck identification numbers, general status indicators, such as "clear" or "hold," and special permit information. The station computer or a secondary terminal would be linked to a central computer(s) from which the weigh station officer could extract more detailed motor carrier record information. Common transactions, such as the preparation of permits and citations, would be automated through the station computer and printed on-site.

To realize an automatic clearance program, participating states and motor carriers must adopt standards for automatic vehicle identification and electronic data interchange (EDI). Motor carriers will realize significant benefits if several states participate in automated clearance programs, but not if each state requires a separate transponder technology or a unique identification number.

Automation of port-of-entry and weigh station clearance will have little effect on illegal truck operations, such as tax evasion and intentional overloading. Most of the citations issued at ports-of-entry and weigh stations are for paperwork violations (e.g., expired permits) or modest weight violations of the "bridge formula," the result of poorly distributed loads or misestimated loads. Chronic violators avoid the ports-of-entry and weigh stations. Any automated clearance program should be married to a state-wide, mobile-enforcement program along the lines described in the preceding section. The primary benefits of automatic clearance will accrue to legal operators.

The potential for evasion and fraud in an automated clearance program is a major concern of state police and DOT enforcement officers. Abuses under an automated clearance program are expected to be no worse than abuses of the current system; however, practical solutions must be developed and demonstrated before these programs will be widely accepted.

The clearance functions at ports-of-entry and weigh stations and the several strategies proposed for automation of these functions are described next. The results of an analytical model that calculates the costs and benefits of automation for state DOTs and motor carriers follow that discussion.

Clearance Operations, Issues, and Concepts

Clearance Operations.—Ports-of-entry and weigh stations are usually located on rural interstates or rural principal arterials and are similar in physical layout and general operation. The typical facility consists of a deceleration lane leading from the highway to one or more weigh scales, a station office, a truck parking lot, and an acceleration lane leading back to the highway.

When the facility is open, a sign directs all approaching trucks to weigh at the station. For an 18-wheel tractor-semitrailer (3S2), separate weighings are taken for the steering axle, the tandem drive axles, and the tandem semitrailer axles and then cumulated to determine the gross vehicle weight and check compliance with the bridge formula. Some facilities are equipped with a three-section platform scale that can accommodate the entire truck at once. More common are single platform scales. With these the station officer weighs the steering axle, the drive axles, and the trailer axles separately as the truck driver rolls across the scales at 1 to 3 mph. Trucks loaded at or above the maximum allowable weights are stopped on the scales for more accurate readings.

As a truck moves through a facility it may be inspected for compliance with the state's size, weight, safety, and economic regulations. Port-of-entry and weigh station officers do this by scanning externally displayed indicia, such as registration plates and fuel tax stickers, or by inspecting the paperwork carried by the driver in the tractor cab. An inspection could comprise:

1. Size and weight inspection (overall length, height, and width; gross vehicle weight; axle weight (single and tandem); bridge formula (spacing and distribution of weight among axles); oversize/overweight permits; data collection for highway planning and design).
2. Paperwork—authorizations and permits—inspection (truck and trailer registration; operating authority; temporary trip permits, the "average" state issues 40,000 permits annually; registration for fuel use taxation; fuel use tax permits; certification of current tax payments; registration for other mileage-based taxes, such as weight-distance taxes and ton-mile taxes; driver's license; insurance; waybills, manifests).
3. Safety inspection (tires, brakes, air-brake lines; lights, mudflaps; hazardous material placards).
4. Agricultural inspections.

In terms of operation and inspection techniques, ports-of-entry and weigh stations are similar; they differ mainly in their role in motor carrier taxation and, as a consequence, their deployment. Port-of-entry facilities are used primarily in states that tax motor carriers directly on the basis of weight carried (variously defined) and distance traveled in the state. The ports are usually located near state borders and most are operated around the clock to intercept all truck traffic entering or exiting the state. A log is kept of trucks clearing through the ports, and weight and odometer readings are recorded to administer and audit motor carrier tax reporting.

Weigh stations can serve as ports-of-entry, but in most states their primary function is the enforcement of weight and safety regulations. External indicia (external plates and stickers) are checked to ensure that the motor carrier is complying with registration and fuel tax requirements, but except when a violation is apparent, paperwork is not regularly inspected and no recording is made of weight and odometer readings.

There are 773 ports-of-entry and permanent weigh stations in the United States (see Appendix C, Table C-2; counts are based on 1986 data; no facility counts were available for New York State). They are distributed among 43 states with the "average" state operating 18 facilities. The 43 states can be broken down into three groups:

1. *States with ports-of-entry and permanent weigh stations.* There are 7 states in this group operating a total of 63 ports-of-entry and 167 permanent weigh stations. The "average" state in this group operates 9 ports-of-entry and 24 permanent weigh stations. The variation among the states is considerable; Oregon operates the largest total number of facilities (72) and Colorado, the smallest (10). Mississippi and Arkansas operate the largest number of ports-of-entry (16) and Oregon operates the largest number of permanent weigh stations (66).
2. *States with ports-of-entry only.* The 6 states in the group operate a total of 99 ports-of-entry. The "average" state in this group operates 17 ports-of-entry. Idaho and Wyoming operate 28 and 27 facilities, respectively; South Dakota operates 5 ports.
3. *States with permanent weigh stations only.* The 30 states in this group operate a total of 444 weigh stations. The "average" state in this group operates 15 weigh stations. Again, the variation among the states is considerable: California operates 57 weigh stations; Delaware and Virginia report only 1 facility each.

In addition to the ports-of-entry and permanent weigh stations, all states own and operate portable weigh scales. It is estimated that the "average" state operates 5 temporary weigh stations using portable scales.

To operate these facilities, the "average" state employs a staff of 93 people (74 officers and 19 clerks or about 2 officers per facility) and spends $2.725 million per year. The 43 states responding to the survey (see Interim Report Appendixes, p. A2–20) reported that they budgeted a total of 4,650 person-years and $117.2 million for weight enforcement programs during the 1986 fiscal year. About 30 percent of these funds were spent for the operation of ports-of-entry or paperwork inspections near state borders. Annual expenditures per state ranged from a low of $100 thousand to a high of over $10 million.

The "average" state undertook 1.93 million truck-weighings in FY 1984. This represents slightly over 7 weighings each of 269,000 heavy trucks. There are 1.9 million heavy trucks in service in the continental United States, or about 39,000 per "average" state. Because the "average" heavy truck is registered in 12 states, there may be as many as 465,000 trucks operating (or intending to operate) in the "average" state during a year—39,000 of which are based, for registration purposes, in that state and 426,000 of which are based in other states. Of these 465,000 trucks, 269,000 or about 58 percent are in long-haul service and constitute the majority of the trucks exposed to ports-of-entry and weigh stations. (The other 42 percent of heavy trucks include municipal refuse trucks, heavy construction, agricultural, mining, and off-road vehicles, which are seldom exposed to weigh stations.)

From these numbers, long-haul trucks can be expected to be weighed an average of 7.2 times in each of 12 states or a total of 86 times per year. These averages mask considerable variation. The actual exposure rates for long-haul, special commodity carriers and carriers operating in western states, where ports-of-entry and weigh stations are more prevalent, are probably several times the "average" rate.

Clearance Issues.—State DOT and motor carrier concerns about port-of-entry and weigh station operations center around four issues: (1) congestion and delay, (2) state budget and staffing constraints, (3) need to maintain state revenues, and (4) equity and cost effectiveness.

Motor carriers believe that the costs of congestion and delay at weigh stations are increasing, while other costs in the industry are dropping, and this imposes an unnecessary burden on the industry and shippers.

At a low volume weigh station in good weather, it takes 3 to 5 min for an 18-wheel tractor-semitrailer to decelerate from 55 mph, weigh through a static platform scale, and accelerate back up to highway speed. At congested stations in poor weather, the average delay may fluctuate between 15 and 30 min. At an operating cost of $0.58 per min (research team estimate based on $34.66 per hour operating cost; this figure represents the mid-point of the range of operating cost estimates provided by agencies, carriers, and researchers), the cost of a weigh station stop can range from $1.74 for 3 min to $17.50 for 30 min. If the "average" long-haul carrier is weighed 86 times per year, the total cost can range from a modest $150 per year to a more significant $1,500 per year.

Most motor carriers regard weigh station delays as a necessary cost of doing business and, in general, support state DOT enforcement operations because they "keep the competition honest" and uphold minimum safety standards, but many believe that congestion and delay have increased in recent years. They believe that the states bear the blame for this situation because the states have not increased their weigh station capacity to keep pace with increases in truck traffic brought about by deregulation of the motor carrier industry and economic growth. There is a general sense that weigh station operations and technology are lagging well behind motor carrier technology. Carriers point out that a mechanic can now obtain and analyze a truck's entire trip record from an onboard computer in a fraction of the time it takes a state DOT officer to ascertain a truck's registration status and weight.

They are concerned that weigh station delays will push operating costs up at a time when other costs in the industry are dropping. They believe that this imposes an unnecessary burden on the industry and their shippers at a time when competition with other motor carriers and the railroads is reducing profits and forcing motor carriers out of business.

Their concerns about weigh station delays are aggravated by their general frustration at the lack of uniformity in motor carrier regulation. Weigh stations, as visible symbols of state bureaucracy, are a reminder to motor carriers of all they dislike about state regulation and taxation of the industry.

State DOT officials echo the concerns of motor carriers about increases in weigh station delays, but point to budget and staffing constraints that prevent them from expanding enforcement programs.

Current clearance procedures in most states are labor-intensive and inefficient. Weigh station officers must visually scan each truck for registration and tax indicia and must stop trucks to examine cab cards, oversize/overweight permits, and other paperwork carried in the driver's notebook. Full paperwork checks are seldom done and are usually limited to egregious or chronic offenders. In most states, verification of permit information (other than driver's licenses) from the field, even at permanent weigh stations, requires a telephone call and the assistance of a central office clerk. State officials estimate that, on average, a limited paperwork inspection or a simple citation ties up a weigh station officer and truck driver for 15 to 30 min.

Efforts to expand the budgets and staffing for weigh station operations have had limited success at the state level. In the face of mounting costs for pavement and bridge rehabilitation, most states have capped enforcement budgets and staffing levels in order to fund maintenance and reconstruction projects. Federal funding for motor carrier safety and weight enforcement programs has grown steadily in recent years and has offset some of the state budget shortfalls, but there is a general consensus among state DOT officials that investments in enforcement programs and weigh station operations have fallen behind needs and new initiatives are necessary.

The same pressures that have led states to cap the budgets for weigh station operations have also made it imperative for the states to protect and increase the revenues collected at weigh stations. Weigh station operations are a substantial revenue generator for the states. A National Governors' Association draft report on the "Feasibility of a Uniform Administrative Approach and Automated Data Processing Alternatives" (No. 16/18, September 1986, p. 9) reported that state receipts for highways in FY 1984 totaled $26.5 billion of which they estimated that slightly over 10 percent or $2.8 billion were paid by interstate motor carriers. Of this $2.8 billion, they further estimated that $265 to $270 million or about 10 percent was accounted for by the overweight fines and other fees collected at ports-of-entry and weigh stations. State DOTs officials have shown renewed interest in protecting and enhancing this yield.

Motor carriers question the equity and cost-effectiveness of weigh station-based enforcement and safety programs. State police and DOT motor carrier safety officers maintain that they are vital because they are a visible symbol of the state's commitment to safety and weight enforcement.

Critics argue that permanent weigh stations are not cost-effective and only marginally deter tax evasion and overweight operations. Most of the citations issued at ports-of-entry and weigh stations are for paperwork violations (e.g., expired permits) or modest overweight violations—the result of poorly distributed loads or misestimated loads. Chronic violators easily avoid ports-of-entry and permanent weigh stations because published information of the location of ports-of-entry and weigh stations is readily available and details about hours of operation are relayed from trucker to trucker over CB radios. Critics argue that the states should put more effort into mobile patrols and temporary weigh stations and focus their efforts on the bypass routes used by motor carriers that knowingly carry illegal loads and avoid taxes. By concentrating enforcement efforts at ports-of-entry and weigh stations, critics charge, the states are wasting their time inspecting legal carriers and imposing an inequitable burden on interstate carriers.

State police and DOT motor carrier safety officers reject these arguments. Port-of-entry and weigh stations provide DOT motor carrier safety officers with a platform to inspect large numbers of trucks. While safety inspections are not restricted to ports-of-entry and weigh stations (most states operate mobile patrols and have established terminal inspection programs with major motor carriers), state police and DOT motor carrier safety officers believe that ports-of-entry and weigh stations are an important cornerstone of their enforcement programs because of the volume of trucks that can be screened and because the stations are a concrete and very visible symbol of the state's commitment to these programs. Safety officials are reluctant to abandon these platforms or allow motor carriers to clear through weigh stations without a visual screening.

Automatic Clearance Concepts.—A number of concepts have been advanced to improve port-of-entry and weigh station operations. These concepts include, among others, paperless borders, transparent borders, deregulation, and regional permits. These concepts can be categorized as follows.

Strategies for reducing the scope of motor carrier inspections—included in this group are proposals for further deregulation of the motor carrier industry. These proposals seek to eliminate certain regulatory requirements and, thereby, reduce the amount of paperwork and the subsequent need to inspect that paperwork. For example, deregulation of the motor carrier industry and expansion of the International Registration Plan has prompted some states to eliminate state economic regulation of motor carriers or reduce the paperwork and subsequent inspection of state operating authority documents.

Strategies for reducing the frequency of motor carrier inspections—included in this group are proposals for regional permits, corridor permits, and transparent borders. For interstate motor carriers, frequency of inspection is directly correlated with the number of states through which the carrier travels, because each state has the right to inspect the motor carrier's paperwork for compliance with its particular regulations. For example, aggregating states into regions or corridors that recognize a common permit effectively reduces the number of jurisdictions with unique regulations. This lessens the need for each jurisdiction to make its own inspection and reduces the frequency of inspections.

The Commercial Vehicle Safety Alliance inspection and sticker program is an example of this strategy. After a truck is inspected, a time-dated sticker is placed in the truck's windshield. This indicates to participating states that the truck has been inspected to a common set of standards and need not be reinspected until the sticker date has lapsed. Another example is the New England Consortium's proposed oversize/overweight permit. Maine, New Hampshire, Vermont, Massachusetts, and Rhode Island have agreed in principle to develop an oversize/overweight permit that would be recognized by all five states. Several western states have made similar proposals for a regional permit for longer combination vehicles (LCVs).

Strategies for reducing the time required to complete motor vehicle inspections—included in this group are strategies for uniform port-of-entry and weigh station operations, paperless border clearance, and non-stop border clearance. The common element in these strategies is the application of technology—optical bar code readers, WIM, AVI transponders, onboard computers—to automate and speed up inspection procedures. Examples of these strategies include Arkansas' experiments with optical bar codes, Arizona's use of magnetic credit cards and dip-type readers at ports-of-entry, and Oregon's proposed demonstration of AVI transponders for port-of-entry paperwork clearance.

Alternative Deployment and Operational Strategies.—The investigation, conducted in this study, of automatic clearance programs for ports-of-entry and weigh stations focused on this third group—strategies that would reduce the time required to complete motor vehicle inspections working within existing stations and station layouts.

Strategy 1, "sample"—the objectives of this strategy are to reduce queuing delays by managing the flow of trucks entering stations and improve paperwork screening by equipping stations with a microcomputer database and telecommunication capabilities. This strategy is a variant of programs being tested by Arkansas DOT for weigh operations and suggested by others for safety inspections.

Under this strategy, motor carriers would purchase a low-cost AVI tag (e.g., retroreflective bar code) and register the identification number with the state(s). The state would install automatic vehicle classification (AVC) equipment in the mainline travel lane(s) approaching existing weigh stations and AVI readers at the scales. For a more sophisticated system, the state would add low-cost weigh-in-motion (WIM) equipment to the mainline installation.

All trucks approaching the station would be classified (and if the equipment is available, weighed-in-motion). A variable message sign alongside the mainline travel lane would direct a sample of these trucks (e.g., a platoon of 3 to 10 trucks) to weigh through the station. During peak hours, the size of the sample would be determined by the station's service rate and queuing space, which for most stations is constrained by the length of the deceleration ramp. When the queue in the station approached the maximum safe length, the variable message sign would direct approaching trucks to bypass the station. As the queue reduced, the sign would direct additional platoons of trucks to weigh through the station.

With moderate or low truck flows, systematic sampling approaches could be implemented. Randomly selected platoons of trucks, particular classes of trucks, trucks within preset weight ranges, or every nth truck would be diverted from the approaching stream of truck traffic into the station. The sampling approaches would be determined by the volume of trucks approaching the station and weather conditions.

Stations would be equipped with a standard microcomputer (e.g., PC AT or portable with mass storage capability) linked to the AVI reader. When an AVI-equipped truck is identified at the scale, the station computer would check the truck's identification against the motor carrier's records stored in the station computer database. For non-AVI trucks the weigh station officer would manually punch in a truck plate number and enter the weight reading to screen the truck against the station's computer records.

The initial database would be limited to an identification number, a general status indicator, such as "clear" or "hold," and special permit information. The station computer or a secondary terminal would be linked by dedicated line or dial-up value added network to a central computer(s) from which the weigh station officer could extract more detailed motor carrier record information. Common transactions, such as the preparation of permits and citations, would be automated through the station computer and printed on-site.

This strategy is most applicable to weigh stations and represents a direct extension of current weigh station practices. It provides an entry-level investment that could subsequently be expanded into a full-blown "sort" (strategy 2) or "preclear and bypass" (strategy 3) program. The system would make use of available, off-the-shelf technology (e.g., AVC, optical AVI systems, standard microcomputers); it could be implemented quickly and at a modest cost. Other than capital equipment, the major investment would be in development of a database suitable for station use.

An optical bar-code AVI system is proposed for the "sample" strategy because (1) the technology is readily available and most motor carriers are familiar with it; (2) the cost to the motor carrier is modest (e.g., plasticized-paper bar-code stickers can be used); and (3) the stickers cannot (as yet) be read surreptitiously at highway speeds—thus, their use would allay motor carriers' fears that "Big Brother" might be monitoring their movements at locations other than weigh stations. This approach might make it somewhat easier to invite motor carrier participation in a weigh station clearance program. The optical system is not a high-speed system and is not suitable for a "sort" or "preclear and bypass" strategy; it would operate under controlled conditions (e.g., the truck will be stopped on the weight scale or moving at a crawl past the reader). There is, of course, no reason why the "sample" strategy could not start up with an RF or microwave AVI system.

The "sample" strategy would not speed up the weigh station processing, since AVI-equipped vehicles would not be processed perceptibly faster than non-AVI-equipped vehicles. The benefits of this strategy would accrue primarily to the state in the form of increased fees and fines from quicker, more comprehensive paperwork screening.

The use of a sampling approach to select trucks for inspection would be a significant change from current policy in most states. State police and weigh station officials prefer a "catch all as catch can" approach and are reluctant to use sampling approaches for enforcement and inspection; however, "sampling by platoon" (e.g., three to ten trucks at a time) is no different from what is done today: when the queue builds up, the weigh station officer simply flips off the WEIGHT STATION OPEN—ALL TRUCKS WEIGH sign and then turns it back on when the queue has dissipated and the station is ready for the next batch of trucks. Manufacturing industry experience with quality control inspection procedures and service industry experience with queue control strongly suggests that such sampling techniques can be developed for weigh station operations and would likely be more cost-effective than current practice.

By sampling trucks and systematically minimizing queues, the state would reduce delays at the weigh station. This would generate modest time savings and benefits for some motor carriers. The use of a low-cost AVI system (e.g., optical bar code technology) would minimize the cost to the motor carrier and would encourage motor carrier participation in the program, but there would be no strong economic incentive driving carrier participation.

Strategy 2, "sort"—the objective of this strategy is to increase the throughput at ports-of-entry where all trucks must be weighed and their paperwork cleared. This strategy is a variant of a clearance demonstration proposed by Oregon DOT for its ports-of-entry.

Under this strategy, motor carriers would purchase an AVI tag and register the identification number with the state. The state would install AVI readers, weigh-in-motion equipment, and automatic vehicle classification equipment in the entrance/deceleration ramp approaching the port-of-entry.

All trucks approaching the port-of-entry would be directed to weigh through the station. As the queue of trucks passed down the entrance/deceleration lane at 30 to 40 mph, each truck would be classified and weighed-in-motion. AVI-equipped trucks would be interrogated for their identification number.

Stations would be equipped with a computer linked to the AVI reader(s). When an AVI-equipped truck was identified, the station computer would check the truck's weight and identification against the motor carrier's records stored in the station computer database. If the truck's weight and paperwork complied with state regulations and the carrier's permits, a variable message sign would direct the AVI-equipped truck to a bypass lane. The AVI-equipped truck would continue at 30 to 40 mph directly to the exit/acceleration ramp.

Non-AVI trucks and any AVI-equipped trucks that fail to pass the paperwork screening would be directed to a static scale. At the scale, the weigh station officer would manually punch in a truck plate number or PUC number and enter the weight reading to screen non-AVI trucks. Transactions, such as the preparation of permits and citations, would be automated through the station computer and printed on-site. During peak periods, a "sample" strategy, similar to that proposed above, could be applied to non-AVI trucks to further reduce the number of trucks queuing at the static scales.

The implementation cost of this strategy depends on the configuration of the individual ports-of-entry. The strategy is most appropriate for a large port-of-entry that has space for an internal bypass road that can safely handle truck traffic moving at 30 to 40 mph, several weigh scale lanes, and adequate reservoir space for queues. Construction of internal bypass lanes at smaller stations would add substantially to the initial capital costs of this strategy.

Smooth operation of the sorting process would require fast processing of AVI, AVC, and WIM data and efficient algorithms for searching the database. Of the three strategies, this approach would require the most sophisticated integration of hardware and software. Provision of backup capabilities and soft failure modes would be important.

The Oregon demonstration has proposed the use of a large microcomputer or a small minicomputer at each port-of-entry to handle all computations, database searches, and transactions. The minicomputer would maintain full or condensed copies of all motor carrier records. Transaction processing would be done on the station computer and uploaded to the state computer during offpeak hours. An alternative scheme would employ standard microcomputers and a simpler database (e.g., an identification number, a general status indicator, such as "clear" or "hold," and special permit information) for screening. To support port-of-entry operations, the station computer or a secondary terminal would be linked by dedicated line or dial-up value added network to a central computer(s) from which the weigh station officer could extract more detailed motor carrier record information. Common transactions, such as the preparation of permits and citations, would be automated through the station computer and printed on site.

State benefits would derive from the deferral of capital and labor costs that would otherwise be incurred in expanding ports-of-entry and adding staff. These savings could be substantial. Some additional, but modest, benefits would derive from more accurate and comprehensive paperwork screening.

Motor carrier costs, primarily for the AVI transponders, would be greater than those in the "sampling" strategy (strategy 1) because the "sort" strategy would require a high performance RF or microwave AVI system. The time savings benefits for AVI-equipped motor carriers would be modest.

Strategy 3, "preclear and bypass"—the objective of this strategy is to reduce the volume of trucks weighing through the station by allowing preregistered carriers to completely bypass the port-of-entry or weigh station. This strategy has been suggested as a concept for a cross-country "clear corridor." A cost-benefit analysis model for this strategy is described in the next section.

Under this strategy, motor carriers would purchase an AVI tag and register the identification number with the state(s). The state would install AVI readers, weigh-in-motion (WIM) equipment, and automatic vehicle classification equipment in the *mainline travel lane(s)* near existing weigh stations.

AVI-equipped trucks would be directed to cross the WIM/AVC/AVI installation in the *mainline travel lane(s)*. The truck would cross the installation at 55 mph, bypassing the station without slowing or stopping. The installation computer would record the truck's passage, weight, and identification for comparison against the state's motor carrier records. The screening could be done at the time of the truck's passage or at a later time. If the truck's weight and paperwork met state regulations and complied with the carrier's permits, the observation would be erased or stripped of identifiers and saved as planning data. If the truck did not meet weight or paperwork requirements (e.g., an expired permit), the motor carrier would be notified by telephone or mail and asked to rectify the problem or pay an administrative fine.

Non-AVI trucks would be directed to weigh through the station. Stations would be equipped with a standard microcomputer (e.g., PC AT or portable with mass storage capability). The weigh station officer would manually punch in a truck plate number and enter the weight reading to screen the truck against the station's computer records.

The initial database for AVI and non-AVI trucks could be limited to an identification number, a general status indicator such as "clear" or "hold," and special permit information. The station computer or a secondary terminal would be linked by dedicated line or dial-up value added network to a central computer(s) from which the weigh station officer could extract more detailed motor carrier record information. Common transactions, such as the preparation of permits and citations, would be automated through the station computer and printed on-site. During peak periods, a "sample" or "sort" strategy, as described previously, could be applied to the non-AVI trucks to further reduce or control queuing and congestion at the station.

This strategy appears to hold the greatest benefits for state DOTs and participating motor carriers. By removing preregistered carriers from weigh station queues, the state can choose to reduce staffing at weigh stations or maintain the same level of effort and screen additional non-AVI trucks that are now waved off at congested stations. The first option would free staff for reallocation to temporary weigh stations. The analysis of weight enforcement programs suggests that the use of roving enforcement teams on Interstates, principal arterials, and other lower classification roads would be a cost-effective way to improve statewide compliance with weight regulations. The latter option—to screen additional trucks at the permanent weigh stations—would generate increased revenues at those facilities.

For participating motor carriers, this strategy would eliminate weigh station stops altogether. For long-haul carriers, particularly less-than-truckload (LTL) carriers that seldom approach or exceed maximum weight limits, and carriers that are regularly exposed to weigh stations, the cumulative time savings from this clearance strategy would be significant.

In this strategy there would be two types of violators: for example, AVI-equipped trucks that are overweight or have expired permits and non-AVI-equipped trucks that evade the weigh station (e.g., they ignore the ALL TRUCKS WEIGH sign or pretend that they are AVI-equipped). A detailed set of enforcement strategies has not been developed in this study but these problems have been discussed with state enforcement offices. Possible enforcement strategies are outlined in the following.

To deal with overweight AVI-equipped carriers, be very selective about accepting motor carriers when the weigh station clearance program is first introduced. Preclear and approve AVI transponders only for those motor carriers that have good compliance records. States could, for example, limit the initial stages of the program to LTL carriers or special commodity carriers, such as tankers, which cannot physically carry more than their legal load. This approach would effectively eliminate the need for weight enforcement among the AVI-equipped carriers during the early stages of the program.

Also, treat the application for an AVI-number and preclearance as a special permit application. Stipulate, as a condition of the permit, that any AVI-equipped carrier that registers overweight on the WIM system would be liable to revocation of the permit or an audit of paperwork for that trip. It is clear that this would be an imperfect tool given the limited accuracy of the current generation of WIM equipment. However, it should be possible to examine the normal variance in WIM observations and set an enforcement threshold high enough to screen out misreads caused by the dynamic effects of pavement roughness and suspension condition and other sources of error. One would expect this threshold to be quite high initially. As WIM technology and the statistical database improved, one would expect to lower (i.e., tighten) the threshold. Where there was a dispute, the motor carrier's paperwork for the trip could be audited. Several states have statutes in place that let them levy overweight fines on the basis of a post facto audit of bills of lading and other such evidence. These statutes could be used as a model for the AVI enforcement activities. Overall, it is expected that overweight violations by AVI-equipped carriers would be minimal. A carrier that consistently runs overweight would not volunteer for an AVI program that regularly exposes it to enforcement and audit actions.

To deal with non-AVI carriers that run the station, use a chase car to apprehend them and apply a schedule of stiff fines to discourage future evasion. This is the method currently used by enforcement teams when carriers run a weigh station, a fairly frequent occurrence in some areas. To make the violation stick, the weigh station and the AVI/WIM bypass lane must be well marked and the program publicized before implementation. It has been suggested that allowing any trucks to bypass the station encourages others to follow them and permits truckers to plead ignorance or confusion. There is a risk of this in the initial stages of a preclearance program, but the practice of allowing certain trucks to bypass weigh stations is not new. Many enforcement teams have an unwritten policy that allows empty trucks to bypass a weigh station without being fined. Abuses under a "preclear and bypass" program are expected to be no worse than abuses of the current system.

Use videotape technology to photograph and identify violators. The tape unit can be tied to the WIM/AVI unit and triggered only when a truck without an AVI unit passes. This is a high-tech solution for the problem and probably is not for full-time enforcement, but could be used as one of a palette of enforcement techniques. The equipment is available; it is used by some toll authorities for enforcement and by many traffic engineers to sample and record traffic flows. The "preclear and bypass" strategy assumes that only AVI-equipped trucks will bypass the weigh station; all other trucks (e.g., non-AVI-equipped trucks) would be directed to be weighed.

The "preclear and bypass" strategy would not be effective where agricultural inspections are required at state borders, because inspectors are looking for illegal shipments and evidence of specific diseases, neither of which could be ascertained from the AVI data even if an AVI transponder were programmed to show the type of commodity being carried. Selective screening (e.g., bypassing AVI-equipped trucks that cannot or do not carry agricultural products, such as chemical tankers, and inspecting only agricultural haulers) may be desirable.

The cost-benefit analysis of the "bypass" strategy indicates that it would be a cost-effective investment in the "average" state for the state DOT and participating motor carriers (see Table 28). Over a 20-year period, the net present (discounted) value of a bypass program would range from $6 thousand with 10 percent of trucks equipped with AVI to $28.7 million with 30 percent of trucks equipped with AVI.

Table 28. Summary of costs and benefits of a preclear and bypass strategy for an "average" state.

INPUT VALUES:				
V/C Ratio	0.75		Truck Fleet	50,000
Citation Rate A	0.67%		AVI	10%
Citation Rate B	0.70%		Operating Cost	$0.58
Fine	$50			

DESCRIPTION OF STATIONS	Ports-Of-Entry High Volume	Ports-Of-Entry Medium Volume	Permanent Weigh Stations High Volume	Permanent Weigh Stations Medium Volume	Permanent Weigh Stations Low Volume	Temporary Weigh Site Low Volume
Number of Stations	3	1	4	8	4	5
Shifts/Day	3	3	1	1	1	1
Screening Hours/Shift	8	8	6	6	6	6
Screening Hours/Day	24	24	6	6	6	6
Operating Days/Year	363	300	260	130	52	52
Service Lanes/Station	2	1	1	1	1	1
Service Rate/Static Scale	100	100	100	75	75	50
Station AVI Mulitiplier	1.50	1.25	1.50	1.00	0.75	0.50
Station Citation Multiplier	2.00	2.00	2.00	2.00	2.00	20.00
Station Citation Revenue Multiplier	1.00	1.00	1.00	1.00	1.00	1.00
Trucks Approaching Station (ADTT)	3000	2000	2500	1500	700	400

NET PRESENT (DISCOUNTED) COSTS AND BENEFITS: SUMMATION

	AVI PARTICIPATION RATE 10%	15%	20%	30%
STATE				
Benefits	$3,617,000	$4,113,000	$4,608,000	$5,564,000
Costs	$3,377,000	$3,377,000	$3,377,000	$3,377,000
Net	$240,000	$736,000	$1,231,000	$2,187,000
AVI MOTOR CARRIERS				
Benefits	$17,680,000	$26,520,000	$35,360,000	$53,041,000
Costs	$1,227,000	$1,840,000	$2,454,000	$3,681,000
Net	$16,453,000	$24,680,000	$32,906,000	$49,360,000
NON-AVI MOTOR CARRIERS				
Benefits	$847,000	$4,284,000	$5,990,000	$7,024,000
Costs	$17,534,000	$20,447,000	$23,580,000	$29,820,000
Net	($16,687,000)	($16,163,000)	($17,590,000)	($22,796,000)
NET PRESENT VALUE	$6,000	$9,253,000	$16,547,000	$28,751,000

With 10 percent of trucks equipped with AVI transponders, the state DOT would incur net present benefits (primarily increased fees and fines) of $3.6 million and net present costs (primarily capital and operating expenses) of $3.4 million. Participating motor carriers would incur net present benefits (primarily operating time savings) of $17.7 million and net present costs (primarily for the AVI transponders and their maintenance) of $1.2 million.

Nonparticipating motor carriers would incur significant losses. By removing AVI-equipped trucks from queues, the state would gain the capacity to screen non-AVI trucks that are now waved off at congested stations. These non-AVI trucks would incur net present costs (primarily from lost operating time, fees, and fines) of $17.7 million, a small fraction of which would be offset by net present benefits (primarily from reduced queue times at low volume stations) of $0.8 million.

This analysis is for a national "average state" that issues citations to 67 out of every 10,000 trucks it weighs and collects $50 in fines for each citation. The "average state" operates 4 ports-of-entry, 16 permanent weigh stations, and 5 temporary weigh sites. Because 38 out of the 52 states and jurisdictions operate only weigh stations, the costs and benefits have been calculated for a national "average weigh-station state." The "average weigh-station state" operates 20 permanent stations and 5 temporary weigh sites, but these are usually concentrated on medium volume highways and operate fewer hours and days per year compared to a port-of-entry. As a result, the benefits to state DOTs and motor carriers are lower. With 10 percent of trucks equipped with AVI transponders, the "average weigh-station state" DOT would incur net present loss of $1.3 million, AVI-equipped motor carriers would realize a net gain of $6.1 million, and nonparticipating carriers would incur a net loss of $9.2 million (see Table 29).

Table 29. Summary of costs and benefits of a preclear and bypass strategy for an "average" weigh station state.

INPUT VALUES:				
V/C Ratio	0.75		Truck Fleet	50,000
Citation Rate A	0.82%		AVI	10%
Citation Rate B	0.86%		Operating Cost	$0.58
Fine	$50			

DESCRIPTION OF STATIONS	Ports-Of-Entry High Volume	Ports-Of-Entry Medium Volume	Permanent Weigh Stations High Volume	Permanent Weigh Stations Medium Volume	Permanent Weigh Stations Low Volume	Temporary Weigh Site Low Volume
Number of Stations	0	0	6	12	2	5
Shifts/Day	3	3	1	1	1	1
Screening Hours/Shift	8	8	6	6	6	6
Screening Hours/Day	24	24	6	6	6	6
Operating Days/Year	363	300	260	130	52	52
Service Lanes/Station	2	1	1	1	1	1
Service Rate/Static Scale	100	100	100	75	75	50
Station AVI Mulitiplier	1.50	1.25	1.50	1.00	0.75	0.50
Station Citation Multiplier	2.00	2.00	2.00	2.00	2.00	20.00
Station Citation Revenue Multiplier	1.00	1.00	1.00	1.00	1.00	1.00
Trucks Approaching Station (ADTT)	3000	2000	2500	1500	700	400

NET PRESENT (DISCOUNTED) COSTS AND BENEFITS: SUMMATION

	AVI PARTICIPATION RATE 10%	15%	20%	30%
STATE				
Benefits	$2,051,000	$2,850,000	$3,649,000	$5,248,000
Costs	$3,312,000	$3,312,000	$3,312,000	$3,312,000
Net	($1,261,000)	($462,000)	$337,000	$1,936,000
AVI MOTOR CARRIERS				
Benefits	$7,291,000	$10,937,000	$14,582,000	$21,873,000
Costs	$1,227,000	$1,840,000	$2,454,000	$3,681,000
Net	$6,064,000	$9,097,000	$12,128,000	$18,192,000
NON-AVI MOTOR CARRIERS				
Benefits	$26,000	$37,000	$46,000	$62,000
Costs	$9,257,000	$13,660,000	$18,062,000	$26,867,000
Net	($9,231,000)	($13,623,000)	($18,016,000)	($26,805,000)
NET PRESENT VALUE	($4,428,000)	($4,988,000)	($5,551,000)	($6,677,000)

The state DOT would break even if motor carrier participation in the program rises to 20 percent or if the state increases its citation rate to 2.5 percent (see Table 30). A combination of a 15 percent motor carrier participation rate and a 1.0 percent citation rate, which is the national median, will also provide the state DOT with a positive net return on its investment. In general, once a state has invested in the equipment for a "preclear and bypass" program, its benefits will rise with increasing motor carrier participation; however, marginal benefits to the state would be expected to decrease once motor carrier participation rates exceed 30 percent. At that level, queuing at most weigh stations will be significantly reduced and the pool of unweighed non-AVI trucks will shrink rapidly.

Motor Carrier Record Database Management Strategies.— The common technological elements of the strategies are AVI/AVC/WIM, which were reviewed in Chapter Two, and the use of microcomputer databases for motor carrier records, which are briefly reviewed in this section.

Most states now maintain their motor carrier records in computerized form; however, these records may be apportioned among several mainframe computers in the different agencies that have jurisdiction over motor carrier affairs. Verification of information in these records, such as an oversize/overweight permit, even at ports-of-entry and permanent weigh stations, usually requires telephone calls and the assistance of a central office clerk. The process is labor-intensive and inefficient; as a result, complete paperwork revitalization is seldom done. If states were to automate the verification process and make records immediately accessible to police and enforcement officers, the states would net enough additional fees and fines to pay for the investment even if a state subsequently opts not to develop an automated clearance program.

The microcomputer and database management technologies to support this application are available. The key factors that will determine the shape of the microcomputer database are the following.

Participating agencies and responsibilities. A few states have organized their motor carrier regulatory functions under a single agency, but many have distributed these functions among three, four, and sometimes, five agencies, some of which may not be willing to relinquish or even share control over motor carrier records with police and enforcement officials.

Configuration of the state database. Motor carrier records may be maintained on one or more computers, depending on the number of agencies overseeing motor carrier operation. In building a database specifically for automatic clearance operations, the state will have several options: maintain a single database; periodically compile a database from the records maintained among several agencies; or link independent databases together using a data network.

Contents of the state database. It is estimated that the "average" state maintains records on 465,000 trucks—39,000 of which are based, for registration purposes, in that state and 426,000 of which are based in other states. In building a database specifically for automatic clearance operations, the state could duplicate a full set of the state's motor carrier records; compile a set of abbreviated records with sufficient information for clearance operations; or work directly with the original records through a data network.

Contents of the station database. The state would have similar options concerning the station databases: duplicate a full set of the state's motor carrier records on each port-of-entry or weigh

Table 30. Summary of costs and benefits of a preclear and bypass strategy for an "average" weigh station state break-even case for state agencies.

INPUT VALUES:

V/C Ratio	0.75	Truck Fleet	50,000
Citation Rate A	1.00%	AVI	15%
Citation Rate B	1.05%	Operating Cost	$0.58
Fine	$50		

DESCRIPTION OF STATIONS	Ports-Of-Entry High Volume	Ports-Of-Entry Medium Volume	Permanent Weigh Stations High Volume	Permanent Weigh Stations Medium Volume	Permanent Weigh Stations Low Volume	Temporary Weigh Site Low Volume
Number of Stations	0	0	6	12	2	5
Shifts/Day	3	3	1	1	1	1
Screening Hours/Shift	8	8	6	6	6	6
Screening Hours/Day	24	24	6	6	6	6
Operating Days/Year	363	300	260	130	52	52
Service Lanes/Station	2	1	1	1	1	1
Service Rate/Static Scale	100	100	100	75	75	50
Station AVI Mulitiplier	1.50	1.25	1.50	1.00	0.75	0.50
Station Citation Multiplier	2.00	2.00	2.00	2.00	2.00	20.00
Station Citation Revenue Multiplier	1.00	1.00	1.00	1.00	1.00	1.00
Trucks Approaching Station (ADTT)	3000	2000	2500	1500	700	400

NET PRESENT (DISCOUNTED) COSTS AND BENEFITS: SUMMATION

	15% AVI PARTICIPATION and 1% CITATION RATE
STATE	
Benefits	$3,476,000
Costs	$3,312,000
Net	$164,000
AVI MOTOR CARRIERS	
Benefits	$10,937,000
Costs	$1,840,000
Net	$9,097,000
NON-AVI MOTOR CARRIERS	
Benefits	$37,000
Costs	$14,285,000
Net	($14,248,000)
NET PRESENT VALUE	($4,987,000)

station computer; duplicate a set of abbreviated records with sufficient information for clearance operations at each station; create a "minimum" or "working" database consisting of truck identification numbers, a general status of "accounts" indicator (e.g., "clear"/"hold"), and special permit information; or equip the stations with dumb terminals and link them to the state's central clearance database by network.

Communications between the state database and the stations. The state would have several options including public or private dial-up telephone lines, dedicated data communication lines, and value-added packet-switching networks.

Transaction processing capability. Transactions, such as issuing permits, could be executed on station computers and uploaded in batches to the state's central computer(s); executed on-line directly to the central computer; or processed manually and keypunched into the central computer.

Three possible strategies for organizing and managing a database for clearance operations are: centralize, distribute, and network.

Strategy 1, centralize. In this situation, the responsibility for motor carrier records is centralized within a single agency, which maintains them as an integrated database on a dedicated minicomputer. From this main database the motor carrier agency would compile a "working" database that would consist of truck identification numbers, a general status of "accounts" indicator (e.g., "clear"/"hold"), and special permit information. The central office would download this working database to each weigh station computer, updating the stations' databases at intervals when a significant number of transactions accumulate. The weigh stations would be equipped with standard microcomputers capable of carrying out paperwork clearance functions. These station microcomputers or auxiliary (dumb) terminals would be tied to the state's central computer by dedicated data communication links and would provide weigh station officers with the capability to conduct direct, on-line inquiries and process transactions.

Strategy 2, distribute (Oregon Model). In this situation, the responsibility for motor carrier records is dispersed among several agencies (e.g., state police, motor vehicle registration, public utilities commission, and department of transportation), each of which maintains a separate database of motor carrier records with information pertinent to its area of functional responsibility. From these separate databases, the state DOT, as the designated lead agency, would compile a set of abbreviated motor carrier records containing all the information necessary for clearance, enforcement, and port-of-entry, and weigh station transactions. The DOT would download this abbreviated database, duplicating it on each of the port-of-entry and weigh station computers. Each major port-of-entry or weigh station would be equipped with a large microcomputer or a small minicomputer capable of handling all clearance and enforcement functions. All transactions would be processed on the station computer and uploaded to the DOT database at regular intervals (e.g., each shift or daily). The DOT computer would report the transactions to the other agency databases, update the DOT abbreviated database, and refresh the station databases on a daily schedule.

Strategy 3, network (New England Model). In this situation, the responsibility for motor carrier records is distributed among several states, each of which, in turn, has distributed the responsibility for motor carrier regulation among differing numbers of agencies within the state. Each agency compiles a minimum "working" database consisting of truck identification numbers, a general status of "accounts" indicator (e.g., "clear"/"hold"), and special permit information. This is made accessible to all states' weigh stations through a value-added packet switching network. Weigh stations are equipped with standard microcomputers capable of handling paperwork clearance functions and standard transactions (e.g., permits and violations). Transactions are reported in batches to the participating state agencies through the network. Inquiries and special transactions (e.g., special oversize/overweight permits, hazardous materials route permits) are executed directly to the appropriate state agency as interactive transactions over the network.

Automated Clearance Cost-Benefit Model

The general structure of a spreadsheet model that was developed to analyze the costs and benefits of the clearance strategies is described in this section; more details and a printout of the spreadsheet are provided in Appendix C. The spreadsheet described in this section has been specified to analyze strategy 3, "preclear and bypass."

The spreadsheet consists of five modules:

1. *Description of stations and average daily truck traffic.* This module describes the state's ports-of-entry and weigh stations—number of stations, hours and days of operation, number of service lanes (weigh scales), service capacity (trucks per hour), and average daily truck traffic approaching the facility.

2. *Queuing analysis.* This module applies simplified, steady-state queuing analyses (M/M/1, M/M/n) to the data provided in module 1. The module calculates average queue length, average time in the system, and average time in the queue as measures of congestion and delay at the weigh station. Two queuing analyses are performed: queuing before (without) AVI and queuing after (with) AVI.

The submodule queuing before (without) AVI calculates queue length and delay assuming that all trucks are directed to weigh through the station. When the volume of trucks exceeds the capacity of the station, trucks are removed (i.e., waved off) from the queue until the station is servicing trucks at a saturated, but stable level that has been defined as a volume to capacity ratio between 70 and 75 percent.

The submodule queuing after (with) AVI calculates queue length and delay assuming that AVI-equipped trucks bypass the station and, thereby, reduce the total number of trucks queuing for the weigh scales. All non-AVI trucks are assumed to weigh through the station. When the remaining queue exceeds the station's servicing capacity, trucks are removed (i.e., waved off) from the queue until the station is servicing trucks at a volume to capacity ratio between 70 and 75 percent.

The number of trucks waved off and the average time in the system before (without) AVI is compared to the number of trucks waved off and the average time in the system after (with) AVI to calculate the impact of preclearing and bypassing AVI-equipped motor carriers.

3. *Estimates of costs and benefits.* The third module estimates the costs and benefits for the state and motor carriers.

State costs include initial capital costs for station computers, AVI, AVC, and WIM equipment; recurring capital costs for replacement; annual maintenance costs; and annual operating costs. For this analysis, labor costs (i.e., number of staff and labor budget) were assumed to be constant; this is consistent with current policy in many states.

State benefits include increased fees and fines collected when non-AVI motor carriers replace the AVI-equipped carriers removed from the station queues and fees and fines collected because of more accurate and comprehensive paperwork screening.

Motor carrier costs include the capital, recurring, and annual maintenance costs of the AVI transponders and the delay costs and fines incurred by the additional non-AVI trucks weighed through the station.

Motor carrier benefits include the time savings to AVI-equipped trucks that bypass the station and time savings that accrue to non-AVI trucks when the total number of trucks remaining in the station queue drops sufficiently to reduce queue lengths and waiting time.

4. *Time stream of costs and benefits.* This module distributes the costs and benefits calculated in module 3 over a 20-year period and calculates the net present (discounted) costs and benefits.

5. *Net present (discounted) costs and benefits summation.* The final module summarizes the net present costs and benefits for the state, the motor carrier industry, AVI-equipped trucks, and non-AVI equipped trucks.

CHAPTER FOUR

RECOMMENDATIONS

This chapter presents recommendations on the implementation of national and state heavy-vehicle monitoring systems. Research essential to the implementation of these recommendations is described in the next chapter.

1. *Develop an open, coordinated national HVM system comprised of private-sector satellite-based HVM systems, private-sector roadside-based HVM systems, and state major routes HVM systems.* A single, integrated national HVM system is technologically feasible; however, the requirements of the various markets (states, motor carriers, toll facility operators, terminal managers) are sufficiently different, and the political barriers to the organization and management of a single, integrated system are sufficiently high, that the development of a single, integrated national system is not feasible at this time.

State, federal, and motor carrier industry goals for improved uniformity and productivity in the national highway and motor carrier system can be met by encouraging the development of complementary HVM systems that serve each of the major markets in a responsive and cost-effective manner.

The efforts of the public and private sectors should be directed toward identifying overlaps between HVM markets and systems where actions on common needs will unify and enlarge markets with payoffs in innovative applications, lower costs, wider acceptance, and greater productivity.

2. *Establish a national forum to coordinate the development and resolution of policy and technical issues.* A national forum should be established at which the motor carrier industry, the states, the Federal Government, and HVM system managers can develop and resolve policy and technical issues. This forum should be national in scope and actively encourage the participation of motor carriers, shippers, receivers, and HVM system operators and suppliers. The forum should focus on policy issues, equipment standards, and information exchange.

As an initial step toward this forum, a major national conference on heavy-vehicle monitoring systems should be convened. The purpose of this conference should be to seek a national consensus, insofar as practical, on the organization and management of the national HVM systems. The conference should draw upon:

- Experience of the HELP/Crescent program as it relates to industry-state relationships and multi-state coordination of HVM programs.
- Commissioned papers from selected representatives of states from other regions, including both states that have been following the HELP/Crescent program as Executive Committee members and ones that have not been involved.
- Commissioned papers from representatives of various motor carrier industry segments, including persons who have had experience with various new technologies being developed and used by industry.
- Participation by representatives of the various supplier industries such as satellite communications systems, onboard computer systems, and other communications and service systems.
- Participation by persons who have been involved in closely related programs (e.g., SHRP, the NGA Working Group on Motor Carrier Procedures, and the Radio-Frequency Identification of Transportation Equipment standard development committee).
- Commissioned papers by persons who have been involved in the evolution of organizations involving diverse interests and markets for new technologies in different fields that have analogous characteristics to the environment of HVM systems.

To achieve consensus, the conference should be organized to assure interaction among the participants and involve workshops charged with drafting recommendations through a staged, iterative process between small groups and plenary sessions. Also, to assure balance, the conference should be by invitation only and considerable care should be taken in developing the invitation list and soliciting participation.

3. *Establish state-level HVM forums to coordinate the development and resolution of policy and technical issues among state agencies.* One of the greatest challenges in the implementation of any multipurpose HVM system is coordination within individual states. In many, if not most states, several agencies are involved in regulation and taxation of motor carriers; yet, no working relationships exist on matters relating to HVM systems. All states must develop a continuing state-level forum if HVM systems are to be effective. Some states involved in the Crescent Demonstration project are currently seeking to set up such arrangements, and other states have had discussions about the need to do so. However, in relation to the problems and challenges involved, too little initiative is being taken nationally. The closest parallel to a desirable relationship is that of the NGA program, which has resulted in the formation of interagency working groups on taxation and regulatory procedures in several states. These have generally involved motor carrier industry representatives. These working groups could form the nucleus of state-level HVM forums.

It is recommended that the major interested parties join in a concerted effort to develop models for state-level forums. Once these models are developed, existing state and NGA groups should be used to publicize these efforts in order to obtain nationwide implementation of coordinating mechanisms in all states in the near term. The state agencies that should be involved include the highway department or DOT, the state police or highway patrol, the department of motor vehicles, the finance department or revenue agencies responsible for administration of highway user taxation, the public utilities commission or agency responsible for economic regulation and permits for operating authority, and other agencies responsible for inspection or regulation of trucking operations. The private sector groups that should be involved include the state trucking association, shipper and receiver organizations, and other interested industry groups.

The national associations that represent these organizations should join in an effort to define the types of organizational structures that are desired and promote their adoption in the states. A logical way to initiate such an effort is to follow the example of the NGA Working Group on Motor Carrier Procedures. NGA provided leadership and political support, and the U.S. DOT, through FHWA, provided both the "carrot and the stick"—financial support for the Working Group activities and the latent threat of Federal intervention in the event that the NGA effort was unsuccessful in achieving the objective of substantially reducing the burden of nonuniformity of state procedures.

The models for state-level forums could range from purely coordinating mechanisms to the establishment of a permanent agency responsible for planning, program development, and operations. Different models will be appropriate in different states, but whatever the mechanism selected, it should have the capabilities to address issues of program planning, acquisition, testing, installation, calibration, operation, and maintenance of equipment and systems.

4. *Establish a national training program(s) on HVM technology and management.* At present, there are very few experts within state and federal agencies who have the capability to organize and manage HVM systems. This capability must be developed within a very few years in all the states if the potential of HVM systems is to be realized in a timely and cost-effective manner. This cannot be achieved unless a comprehensive training program is established very soon.

It is recommended that a national HVM system training program be established as soon as possible. A centralized program within a unit of the U.S. Department of Transportation would be a logical locus for such training because much of the funding and program direction will be coming from them. Alternatively, federal funding could be used to support a training program within a university or state, or a combination thereof, building upon one of the organizations that has a good existing capability. Topics that should be covered by the training program include: organization and administration of HVM systems, guidelines for program planning, use of cost-benefit analysis tools in each area of application, assessment of technology and prospects for improvements, system design, preparation of specifications and procurement process, state of the art in each area of HVM application, and operation and maintenance of equipment and systems.

5. *Promote uniform equipment and information (EDI) standards.* The states and the motor carrier industry should work through the national and state HVM forums to promulgate equipment and information standards for HVM applications. These standards should encompass both equipment and information (e.g., electronic data interchange).

Standards for AVI equipment are vitally important to the success of state and private-sector roadside-based HVM systems. The motor carrier industry, states, and the Federal Government should continue active participation in Maritime Administration Cargo Handling Cooperative Program's RITE Working Group, which is working to establish AVI standards for the marine container industry; the western states' Crescent Demonstration Program; and the rail industry's Automatic Train Control System Program.

6. *Develop model statutes and guidelines for the management and regulation of HVM systems.* Although the emphasis in this project has been on applications of HVM systems under direct control of the states, other applications investigated are being, or likely will be, developed by the private sector. Some of these applications, such as the tracking of trucks for fleet management, have also raised issues about the protection of proprietary business data and the rights of drivers and owner-operators.

The investigations conducted in this project have led to the conclusion that mandatory HVM systems are not likely within the near future, except for carriers of very hazardous cargo. Under voluntary HVM systems, management will have the desired incentive of keeping all existing users satisfied and providing assurances to potential customers that all information will be treated confidentially.

Despite this assumption about the voluntary nature of the HELP system, attention to safeguards is still very important for several reasons. First, many in industry are concerned that HVM systems will eventually become mandatory systems. Second, even if HVM systems remain voluntary, the market for them could grow to the point where they are in near universal use, at least for major sectors of the industry. HVM systems would then be seen as a necessary part of doing business, and careful protection of confidential data would become an important concern. Finally, public sector users of the data may well become dependent on access to data for planning, design, and research needs, and other purposes (e.g., toll collection and auditing of mileage and other reports). Safeguards need to be worked out now, in precise terms, so that government agencies' needs will not conflict with the confidentiality needs of firms and individuals.

It is recommended that model legislation dealing with monitoring requirements be drafted so that states can enact legislation applicable to public and private sector HVM organizations.

7. *States should apply WIM and AVC technologies to improve state data collection programs.* Based on the findings reported in earlier chapters, the states should substantially increase the use of WIM systems to improve the quality of their data collection programs. Analyses conducted in this project and by several states in recent years show that WIM systems have greatly improved and that all states should begin to plan and implement major WIM data collection programs as soon as practical (as some states have already begun to do). Specific recommendations for achieving this objective are covered in the following discussion.

The overall level of deployment should be increased. The principal argument for a greater level of deployment of WIM systems is that the costs are going down, while the benefits are likely to be going up.

The low-cost WIM project in Minnesota and Iowa is likely to conclude that piezoelectric systems can provide acceptable accuracy and meet other criteria for installed costs of well under $10,000. More than one firm has already shown interest in producing and marketing piezoelectric systems when this project is successfully completed, thus assuring a competitive market.

The NCHRP project that is studying the feasibility of low-cost bridge WIM is concluding that a system can be produced for less than $10,000 (exclusive of sales cost and warranty) and meet acceptable accuracy standards and other criteria. The system design will provide axle weights within generally accepted tolerances as well as gross weights (which are usually thought of as being easier to determine with BWIM systems).

Work in Arizona, Maine, and other states is showing that portable capacitance pad systems are reliable and that the problems that have been encountered in several states with calibration and with the electronics can be satisfactorily overcome. Acceptable accuracy (although probably not as good as advertised) can be achieved. Costs are in the $25,000 to $50,000 range.

A recently accepted bid price in California shows that permanent scale bending plate systems can be brought down to about $30,000 when purchased in quantity—for a proven system that has been in successful use in many states.

Meanwhile, the recent use of WIM systems in several widely scattered states is showing a much higher proportion of overweight trucks than previously documented. This means that there is much more to be gained from better knowledge of truck weights from the standpoint of all types of planning, design, research, and enforcement purposes. The much higher actual weights mean that the true variance in axle weights or gross weights for any particular class of heavy truck or for any particular highway section or class of highway have been substantially underestimated. This means that larger samples and more sessions are needed to obtain the same precision. It also means that there is probably much greater variation in weights by season, day of the week, and perhaps other factors, than previously expected. All of this greatly increases the value of additional WIM data collection.

Finally, WIM systems will be coming into use for a larger variety of purposes—improved enforcement planning, screening of vehicles for enforcement, long-term pavement monitoring research, improved cost allocation studies, improved design procedures, and a wider variety of planning applications. In many instances the same equipment and some of the staff efforts can be used for multiple purposes, thus compounding the benefits to be derived from each dollar spent on WIM.

The benefit-cost evaluation work completed in this project suggests that the level of deployment that is warranted is on the order of magnitude of twice the level of effort currently recommended in the TMG. The level of precision recommended in the TMG for the Interstate System (plus or minus 10 percent with 95 percent confidence) is reasonable, but it should apply to the estimation of ESALs for all traffic rather than just for 3S2s. Furthermore, equipment precision should be taken into account in developing deployment programs. These two changes will approximately double the recommended number of sessions, based on relationships developed in the process of preparing the TMG. For most planning, design, and research purposes, one is primarily interested in knowing the overall impact of axle loads rather than the impact of loads from particular classes of vehicles. (For cost allocation studies and perhaps certain other specialized types of studies, the interest is in axle loads by vehicle class, although such estimates have not been made by functional class in previous studies. Estimating ESALs per vehicle for critical vehicle classes on a statewide basis is probably less demanding statistically than estimating ESALs per vehicle for all traffic for the Interstate System and for all other roads.)

Monitoring should be increased on non-Interstate highways. Several arguments have been made for placing greater emphasis on non-Interstate highways. The TMG recommends that one-third of annual weighing sessions be on Interstate routes (10 of 30 for an average state), achieving an estimated precision level that is stated as being up to twice as good as for other roads as a whole (plus or minus 10 percent with 95 percent confidence vs. plus or minus 20 percent with 95 percent confidence for ESALs for 3S2s). This degree of concentration on the Interstate System might be warranted if one were considering only the Federal interest, which is highly concentrated on the Interstate System, but when considering the public interest in highways as a whole, a much greater level of effort should be devoted to weighing on lower function class highways than recommended in the TMG.

In addition to the arguments made for increasing data collection on non-Interstate roads, a state should consider the needs for WIM systems for weight enforcement purposes. If a state employs low-cost WIM systems and optimizes its weight enforcement program in a manner similar to recommendations of this report, a large proportion of the states' WIM sites are likely to use permanent sensors imbedded in pavements on lower functional classes. This will make it less costly to collect data for planning, design, and research purposes on lower functional class systems using the same equipment at times when it is not in use for enforcement.

The cost-effectiveness analysis performed in this project suggests that the level of effort on non-Interstate highways should be about double the level recommended in the TMG, even if equipment precision is ignored and all non-Interstate roads are combined as a single system. The same level of precision recommended for the Interstate System should, as a minimum, apply to all other roads as a whole, and this criterion should apply to all vehicles as a whole rather than just to 3S2s. However, because so much uncertainty exists regarding truck weights on other roads, a state may be well advised to begin with a level of effort similar to what is recommended in the TMG, and allow the results of the data collected each year to be a guide in determining the level of effort for succeeding years.

Sampling should be based on longer route segments. The arguments for sampling longer route segments rather than HPMS sections are fewer than for the preceding two recommendations for changes in the guidelines for truck weighing. Nonetheless, they are equally convincing.

The principal argument for sampling longer route segments is that this will result in a more efficient use of data collection resources. In contrast to a basic assumption implicit in the HPMS and TMG methodology, HPMS sections are not independent of each other, particularly as relates to traffic characteristics. Studies of the network characteristics and traffic flow composition have shown that there is a strong continuity of flow along most routes over long distances. Monthly, weekly, and daily peaking characteristics, and vehicle classification mix tend to remain relatively constant over long distances outside of urban areas, often entirely across states.

This is especially true of truck traffic because of the much longer average truck trip length. And it is especially true of truck traffic on the Interstate System and other higher functional classes. To take advantage of this fact, route segments should be defined by examining available data on the makeup of traffic over long route segments (e.g., AVC and ATR data) to determine where significant changes occur. As a result of this, very long route segments may emerge as relatively homogenous route segments. These should logically have a higher probability of being selected because of their importance in the statewide network. This can be achieved by weighting samples by truck VMT or rough estimates of ESALs. (Note that this differs from the FHWA recommendation that all VMT be used as the method of allocating samples, based on the rationale that all vehicle classes are of interest. However, the authors of this report are not in agreement with this recommendation because of the much greater contribution of trucks to total ESALs, which is the primary measure of interest for pavement design, cost allocation studies, and most other weight-related analyses.)

An alternative approach for the Interstate System which should be investigated and compared with the foregoing approach is to decide that the state's entire Interstate System is going to be represented in the sample (as it is in the overall HPMS system by Federal policy). The task then becomes one of grouping HPMS sections of the Interstate System into relatively homogeneous route segments using consistent criteria to yield a given number of sites or to meet statistical criteria. (A related approach involving a more direct analytical solution is being developed and applied for the Oregon DOT by the Portland State University. They argue that the TMG approach to sampling fails to recognize that traffic volumes, traffic mix, and vehicle weights are highly correlated from section to section along continuous routes. Thus, sampled sections should be selected so as to be distant from each other. An algorithm is used to locate truck weight sites so as to minimize aggregate systemwide travel time from all sections to the weighing sites. This will tend to result in a relatively even geographic pattern of coverage. The process also allows for weighting of site characteristics using engineering or other criteria in the selection process.)

If an approach is adopted which does not involve weighing on segments that cover the state's entire Interstate System, the small sample drawn should be subjected to careful review to assure that it does not result in any major biases, such as major routes totally missing on large regional gaps.

Longer duration weigh sessions should be considered. The recommendation of the TMG for 48-hour sessions at all sites needs to be reexamined, considering several factors.

The marginal costs of extending the time period of weighing sessions decreases down the following list of types of sites, with initial costs generally increasing:

- Portable pads and electronics.
- Permanent scales or sensors with portable electronics.
- Permanent scales or sensors with permanently installed electronics, without telemetry.
- Permanent scales or sensors with permanently installed electronics, with telemetry.

An optimal WIM program for any state may involve two or more of these types of sites, with several factors being involved in determining the optimal mix. Aside from the cost tradeoffs involved, portable pads have the advantage of being able to be placed almost anywhere at any time, thus reducing the amount of avoidance of the sites by overweight trucks.

If a state determines that permanent or semipermanent WIM sites are warranted at SHRP sites and/or weight enforcement sites, this should significantly influence the optimal mix of types of sites to be used for data collection for planning, design, and research purposes. The marginal cost of using these sites for such purposes should be very low.

The desirability of having some long-term sessions, seasonal, or continuous data collection at a few sites should enter into this evaluation. Data from permanent sites may be used to develop seasonal and weekly factors at less cost than using portable pads. The values of such data are quite high now because almost nothing is known about these relationships, but they will continue to be needed even after considerable research is completed to provide data unique to each state and to monitor changes over time.

Each state should develop a procedure for predicting ESALs for any given site for project planning purposes, taking into account relationships that can be developed from long term, seasonal, and continuous weighing sites. The Minnesota DOT recently completed a research project that developed a recommended procedure that involves the use of cluster analysis to define groups of sites with similar monthly peaking characteristics and to link data from project sites to data for the clusters (*4*). Two projects soon to be completed by the Florida DOT and FHWA will provide additional recommended methodologies that can make use of such data. The most accurate approach might use a short-term weigh session at the site as a base for applying seasonal and weekly factors. Another approach, which should be somewhat less costly and somewhat less accurate, would be to use short-term AVC counts as a base for applying appropriate factors for ESALs per vehicle and for seasonal and weekly factors that are most appropriate to the site.

Longer term weighing sessions are needed in order to determine the optimal time periods for weighing sessions. Limited amounts of data from Minnesota were used to develop recommendations for substantially longer sessions (i.e., 4 to 7 days) than the 48 hours recommended in the TMG (pp. 31–37 and 48–50). One would expect that the optimal session length might be higher on lower functional classes because of greater seasonal and weekly variability of weights. The low marginal cost of increasing session lengths for permanent WIM sites should also be taken into account in determining the optimal time period to use in each state's weighing program. Finally, longer term or continuous weighing sessions can also be used to accurately detect trends in weights of detailed vehicle classes.

FHWA should revise the traffic monitoring guide. In order to facilitate accomplishment of the above recommendations for planning data collection, the TMG should be revised and updated, incorporating additional data on WIM equipment performance characteristics and costs and more recent data that can be used for default values in planning of WIM deployment strategies.

8. *States should apply WIM, AVC and AVI technologies to improve state weight enforcement programs.* Enforcement programs should be reorganized. Based on the findings in this report, it is recommended that state weight enforcement programs be reorganized to rely primarily on random deployments of weight enforcement teams, using WIM to identify potential overweight vehicles and portable scales for weighing of trucks indicated by WIM to be overweight.

The deployments of weight enforcement teams on road systems should take account of: the overweight truck travel on each road segment at each time period, if such data have been gathered by use of WIM deployed as part of the truck weight data collection program; the amount of heavy truck travel on each major road segment at each major period of the day or night; the use of "wing" teams to apprehend overweight trucks that are detouring or stopping to avoid an enforcement team; and the potential for reducing pavement damage by deterring overweight travel, in comparison to the costs of enforcement efforts.

Coordinated demonstration projects should be undertaken by two or more states to develop and evaluate detailed programs as recommended above. The demonstrations should be designed to provide evaluation of specific policies towards overweight vehicle permits, penalties, and fines, and offloading requirements. The demonstration projects should involve gathering and analyzing data on overweight travel and heavy truck travel, and modeling of strategies for deployment, their costs, and their impacts on the highway systems on which weight enforcement would occur. Detailed estimates should be developed for the costs of WIM units, enforcement teams, and backup systems.

Fines and penalties should be reevaluated. Based on the findings documented in this report, each state and other unit of government concerned with overweight travel should reexamine its fines and penalties for overweight travel, with the goal of setting the fines and penalties at the highest levels that can be expected to be enforced by the courts. Because higher fine levels are associated with lower costs for deployments necessary to deter overweight travel, it is desirable from the states' point of view to have fine levels set as high as is feasible.

The states are urged to evaluate the approximate benefits in reduced pavement damage, and potentially in reduced weight enforcement costs, that can be achieved by increasing fines and penalties to the higher levels analyzed in this report.

Federal research, demonstrations, and guidelines should support the use of WIM for weight enforcement. The Federal Highway Administration has provided critically important support to advance WIM and weight enforcement. Because many of the benefits of weight enforcement in one state accrue to other states, FHWA is the logical agency to coordinate research and demonstrations and disseminate information on good weight enforcement practices. As described in Chapter Five, research should be supported to examine the impacts of weight enforcement activities in particular states on pavement damage, including pavement damage in other states, and the relative impacts of varying enforcement policies among the states should be assessed.

Following up on this research, it is recommended that FHWA support the development of guidelines that show how to implement the most cost-effective weight enforcement strategies. These guidelines should include use of the improved analytic methodology, better default values to use in modeling the weight enforcement process, suggested procedures for field operations using WIM, use of weight data from all sources to aid in planning weight enforcement strategies, and procedures to use in evaluating enforcement efforts as part of ongoing programs.

Weight data should be used in enforcement programs. Data collection using unobtrusive WIM can provide the best information on which to evaluate current and future levels of weight enforcement. This information should be used on a continuing basis in evaluating the relative benefits and costs of different strategies and increased enforcement efforts.

Unfortunately, very little is currently being done by the states to use weight data collected for planning, design, and policy studies in weight enforcement programs. Part of the problem has been a concern that such use of these data would cause further biases in the data because overweight operators would make even greater efforts to avoid the scales. The use of WIM for data collection in place of static scales at weight enforcement sites will minimize this problem, particularly if vans and data collection personnel are not visible at the sites.

The analyses conducted in this project suggest that WIM data collection programs should be increased to a level substantially above what is recommended in the TMG, which is also a level substantially above current levels. These conclusions were reached without explicit consideration of the potential benefits for improvement of weight enforcement programs. The greatly expanded level of effort, the increased number of sites (particularly if random locations are used), and the unobtrusiveness of WIM operations will make the data far more useful for planning and evaluation of weight enforcement efforts.

Weight enforcement considerations and information needs should be incorporated in planning WIM data collection programs and in periodically adjusting locations and timing of sessions. Such considerations might include the desire to monitor heavy traffic hauling natural resources during seasonal operations or traffic serving concentrations of plants shipping and receiving dense commodities. Another consideration might be the evaluation of the effectiveness of changes in weight enforcement strategies in selected corridors.

9. *States should apply WIM, AVC, and AVI technologies to implement automatic clearance systems at weigh stations and ports-of-entry.* Automatic clearance programs should be developed to improve and speed up inspection procedures at weigh stations, ports-of-entry, and roadside inspection sites.

The development of "sorting" systems should be encouraged for port-of-entry states. These systems would seek to increase the throughput of trucks at ports-of-entry where all trucks must be weighed and their paperwork cleared.

The development "preclear and bypass" systems for weigh station states is also recommended. These systems would seek to reduce the volume of trucks weighing through the stations by allowing preregistered carriers to completely bypass the weigh station. The cost-benefit analysis of this strategy suggests that it is a very cost-effective investment for state DOTs and participating motor carriers.

Participation in automatic clearance programs should be voluntary for both the states and motor carriers. The economic benefits to states and motor carriers will be sufficient to ensure substantial participation and growth in the programs. If participation in automated clearance programs is mandated, the possibility cannot be ignored that legal challenges may significantly delay the development of clearance programs, denying significant benefits to states and participating motor carriers.

Automated clearance programs should be undertaken in concert with state-wide, mobile-enforcement programs along the lines recommended above. Automation of port-of-entry and weigh station clearance will have little effect on illegal truck operations, such as tax evasion and intentional overloading. Chronic violators avoid ports and weigh stations. The primary benefits of automatic clearance will accrue to legal operators.

Finally, the cost-benefit spreadsheet models developed for this research project should be made available to the states as tools for the states to use in planning and developing of state HVM systems.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDED RESEARCH

CONCLUSIONS

A national heavy-vehicle monitoring system is feasible if it is organized and managed as a set of coordinated and voluntary systems, rather than as a single, integrated or mandatory system. This conclusion is based on the following key findings.

There is a market for heavy-vehicle monitoring, but it is highly fragmented with several distinct markets rather than a single, unified national market. The key markets are:

- State agencies, which need heavy-vehicle monitoring data for planning, design, and research, weight enforcement, and weigh station clearance. The states are actively pursuing weigh-in-motion and automatic vehicle identification for these applications.
- Long-haul, variable route, motor carriers, which need on-demand communication and truck location information for fleet and driver management. A growing number are investigating and experimenting with automatic vehicle location and communication systems.
- In addition, there are emerging markets for heavy-vehicle monitoring information for toll collection, marine, rail, and truck terminal management, and the monitoring of shipments of very hazardous materials.

All of these markets differ significantly from one another in terms of the costs they are willing to bear, perceived benefits, the quality and quantity of data needed, and requirements for access, security, and confidentiality. The existence of these distinct markets has already encouraged the development of specialized HVM systems to serve them. Competition within each of these markets will produce more cost-effective services than will a single HVM system.

Deployment of a national HVM system, as a single system or as a set of complementary systems, is technologically feasible. The components—WIM, AVC, AVI, AVL, VMS, telecommunication systems, and computers—are available or under development. Current research, testing, and demonstrations will address the outstanding issues of improving reliability and cost-effectiveness. There is an imminent need for standardization within many of these technologies, especially AVI.

No objections were found to exist within existing statutes and case law to the use of WIM for the collection of truck weight data for weight enforcement and planning purposes. Current WIM technology is not accurate enough for enforcement under existing statutes, but could be coupled with AVI to identify and screen overweight trucks for subsequent weighing on static scales. With further refinements of WIM technology, it is expected that dynamic weight enforcement statutes will be enacted and many courts will take judicial notice of WIM, as they have radar, and accept its use as a weight enforcement tool.

No valid legal objections were found to exist relating to the use of AVI technology as an "electronic license plate" for the identification of vehicles at given points where the government currently monitors traffic, such as weigh stations and ports of entry. Vehicles are not equated with individuals, and the courts have generally held that persons traveling in a vehicle on a public road have no reasonable expectation of privacy. Nor did the findings reveal any legal objections to the development of public or private heavy-vehicle monitoring databases. As long as the purpose for which an HVM database (built from AVI data) is clearly stated, and it is managed according to existing privacy and data confidentiality statutes, an HVM database could be constructed.

Notwithstanding this, constitutional challenges to mandatory

AVI are likely. Drivers who operate trucks on an employment basis for large companies will have little basis to object, but owner-operators are in a position to argue that the location of their truck is the same as their personal location for a large proportion of the time, including extended periods when they are strictly off-duty. It is expected that the privacy issue will be decided on the degree of perceived intrusion created by an HVM system. A thin system of AVI stations capable of collecting information on vehicle movements adequate for audit purposes—in effect, the automation of existing weigh stations and ports of entry—but incapable of tracking a vehicle, is not likely to be equated by the courts with a continuous surveillance system that threatens an invasion of privacy. A dense or thick system capable of effectively tracking a vehicle for weight-distance tax administration—or for that matter, fleet management—comes closer to the type of surveillance to which truck drivers object and may be close enough to monitoring to attract judicial sympathy for a constitutional challenge.

There is no apparent political consensus among the states or the motor carriers on the need for a national HVM system and little expectation that a consensus will emerge in the near future. Within the motor carrier industry, there is support for uniform regulation of the motor carrier industry across states and actions, such as a national HVM system, that might facilitate trucking and the competitive position of the trucking industry, but there are countervailing concerns about the confidentiality of business information, the cost-effectiveness of a national HVM system, and the equity of state tax administration. Motor carriers would strongly prefer to have a private sector corporation manage a national HVM system. A national HVM system organized and managed by the public sector would have difficulty capturing and holding a viable share of the motor carrier market.

A few states support a national HVM system for expanding tax and weight enforcement programs, but most support only the development of an HVM system that serves highway planning and maintenance functions. While a handful of states are actively planning and developing state HVM systems, the majority lack the resources and political commitment to implement an HVM system until and unless there is a concerted national effort to develop an HVM system that is heavily supported by federal funding. Political support and funding for this purpose is unlikely at the present time.

Therefore, a single integrated or mandatory national system is not feasible; rather, three separate, but complementary voluntary systems, are expected to emerge to constitute a national HVM system: (1) a private sector satellite-based HVM system(s) providing high-quality fleet management and communication services to about 30 percent of heavy-trucks; (2) a private sector roadside-based HVM system(s) providing cost-effective communication, data transmission, and limited fleet management services to about 40 percent of heavy trucks (this roadside-based system will be an outgrowth of existing wire transmittal and credit information services; many carriers will use both the satellite- and the roadside-based HVM systems); and (3) a state major routes system(s) providing heavy-vehicle monitoring information for state data collection, weight enforcement, and weigh station operation (15 to 20 states will develop these systems; several will also develop tax reporting and audit services for participating carriers).

There are substantial benefits to be realized from the development and application of these HVM systems. Long-haul, variable route carriers anticipate significant benefits from improved fleet management. And, state highway agencies believe that better truck weight statistics will pay off in more cost-effective highway and pavement design. Already, motor carriers and state DOTs are investing heavily in new HVM technologies to obtain these benefits.

Detailed examination of the costs and benefits of data collection, weight enforcement, and weigh station clearance applications within a state major routes HVM system leads to the conclusion that the applications are feasible and cost-effective.

Additional benefits can be realized by concerted public and private efforts directed toward identifying overlaps between these HVM markets and services where action on common needs will unify and enlarge the markets with payoffs in innovative applications, lower costs, wider acceptance, and greater productivity. An example is AVI standardization: The railroad and marine container shipper industries are moving rapidly toward standards for automatic identification of intermodal containers and trailers for terminal management; toll bridge and toll road operators are experimenting with AVI for automatic toll collection; and the Crescent Demonstration Program is considering deployment of AVI for automated border and weigh station clearance. Adoption of common AVI standards would benefit the emerging state HVM systems and would permit private sector roadside-based HVM systems to expand diesel fuel credit check services, terminal security, and fleet management services to motor carriers.

These actions should address needs for standardization, capital formation, research and development, demonstration, regulation, or organization of HVM services. The needs will vary considerably by market and technology. NCHRP Project 3-34 and other research efforts have begun to identify these actions, but considerably more work will be necessary before implementation is accomplished.

RECOMMENDED RESEARCH

The research results strongly suggest that application of WIM/AVC and AVI technologies for data collection, weight enforcement, and weigh station clearance would lead to productivity improvements for state DOTs and motor carriers. The research results are sufficiently encouraging to warrant further research and development efforts. It is recommended that consideration be given to the following:

- A pilot program that would demonstrate these productivity gains through actual application of the technologies in several states, building on, and coordinating with, the work being done as part of the Crescent Demonstration Project.
- A synthesis of practice to document recent state experience with WIM/AVC and AVI in sufficient detail to be useful to other states in program planning and implementation decisions.
- Practical research to support improved weight enforcement programs.

Demonstration Program

The purpose of this program would be to demonstrate by actual application the productivity gains that research suggests can be achieved through the application of WIM/AVC and AVI technologies. The program would demonstrate three applications: the use of WIM for weight enforcement; the use of

WIM/AVC and AVI for automated weigh station clearance; and the use of AVI, computer, and telecommunication technologies to reduce motor carrier paperwork.

For weight enforcement, the program would demonstrate the use of high-speed WIM technology and mobile enforcement teams for screening of overweight trucks on highways and show how this could increase the productivity of state weight enforcement programs.

A typical state accomplishes 97 percent its truck weighings at fixed weigh stations and only 3 percent at temporary sites using portable scales. However, the 3 percent of trucks inspected by mobile enforcement teams generate a disproportionately high percentage of overweight fines, often accounting for 30 to 50 percent of weight enforcement fines, because the mobile weight enforcement teams apprehend chronic and egregious weight violators that systematically bypass fixed weigh stations.

In spite of the importance of these mobile enforcement teams, their productivity is low because the portable scales currently available to mobile patrols are, on the whole, cumbersome to transport, time consuming to set up, and slow in operation. These constraints severely limit the range and processing rates of the patrols. A mobile enforcement team is usually restricted to one site per day and processes trucks at a rate of 30 to 40 trucks per hour, well below the rates of 80 to 100+ trucks per hour achieved at fixed-platform scales.

The weight enforcement demonstration would have two elements. In the first, one or more states would undertake pilot programs to demonstrate the use of portable WIM mats, roadway piezoelectric WIM cables, and bridge WIM by mobile enforcement teams. The mobile weight enforcement teams would use the WIM equipment to screen approaching trucks while they are still in the mainline, then direct overweight trucks to portable scales for static weighing. When the techniques for WIM screening are established, the states would undertake the second element: to demonstrate how WIM and mobile enforcement teams can be used to implement the proportional deployment strategy recommended in Chapter Four. That strategy allocates enforcement effort to highways in proportion to the heavy-truck VMT on the highway. The effectiveness of the enforcement depends on the ability of mobile teams to randomize their enforcement pattern within the designated highway segments. This, in turn, depends on the team's ability to change sites frequently and use their time at each site most productively. The use of high-speed WIM for screening will make this possible. The demonstration will test the practical aspects of this strategy.

The productivity gains expected are, for state DOTs, an increase in the number of chronic overweight violators apprehended and, consequently, an increase in compliance rates and revenues per enforcement team; and, for motor carriers, greater competitive equity.

The demonstration would entail the following:

- Selection of sites for WIM screening.
- Selection and installation of WIM equipment.
- Development of a simplified, microcomputer database to field check motor carrier records.
- Development of operational procedures for WIM screening.
- Development of protocols for documentation and evaluation of the demonstration.
- Operation of the WIM screening demonstration.
- Specification of the proportional deployment model for the state.
- Development of randomized enforcement schedule.
- Operation of the proportional deployment/randomized schedule plan.
- Evaluation of state and motor carrier experience.

For weigh station clearance, the program would demonstrate the use of WIM/AVC and AVI technologies to "preclear and bypass" motor carriers at state weigh stations and ports-of-entry. (It is of interest that the Crescent Demonstration Project is planning to test a "sorting" strategy involving screening of AVI-equipped trucks as they move down the entrance ramps to weigh stations and ports-of-entry. If this is successful, it could be expanded to test a "preclear and bypass" strategy.)

Current practice, which is to weigh all trucks approaching a weigh station, imposes significant delays on legal carriers, because the large majority of trucks weighed at fixed weigh stations are operating legally (nationally, less than 1 percent of trucks weighed are cited for weight violations). Most of the citations issued at weigh stations are for paperwork violations, such as expired permits, or bridge formula violations, such as improper weight distribution among axles. Chronic and notable weight violators and tax evaders systematically avoid the weigh stations.

A "preclear and bypass" operation would permit carriers with good compliance and safety records to bypass weigh stations and ports-of-entry without slowing or stopping. Carriers would voluntarily purchase AVI transponders, register the identification numbers with the state, and mount the transponders on their trucks. The state would install low-cost WIM/AVC units and AVI readers in the mainline travel lanes near existing weigh stations and ports-of-entry. As AVI-equipped motor carriers passed these stations, the WIM/AVC and AVI equipment would log the carrier's passage. This record would be reviewed to verify the motor carrier's continuing compliance with state motor carrier regulations. All other trucks would be required to stop at the station as they do now.

The productivity gains expected are, for state DOTs, an increase in the total number of trucks weighed and inspected and, subsequently, an increase in compliance rates and revenues per weigh station; and, for participating motor carriers, a reduction in delays at weigh stations and ports-of-entry and, subsequently, savings in travel time and operating cost per truck.

The demonstration of a "preclear and bypass" operation would entail the following:

- Recruitment of motor carriers for the pilot program.
- Development of operational procedures for issuance of AVI numbers and disposition of data collected.
- Development of a simplified, microcomputer database to field check motor carrier records.
- Development of administrative follow-up and enforcement procedures.
- Development of protocols for documentation and evaluation of the demonstration.
- Selection of one to two pilot sites for initial demonstration.
- Selection and installation of equipment (assumes use of available, off-the-shelf equipment and access technical studies done by the HELP Program, Oregon, Iowa, Minnesota, and others).
- Operation of the demonstration.
- Evaluation of state and motor carrier experience.
- Expansion of the pilot program to establish a "preclear

and bypass" corridor demonstration involving one or several states.

- Operation of the corridor demonstration.
- Evaluation of state and motor carrier experience.

This recommended demonstration project should build upon, or be closely coordinated with, the Crescent Demonstration Project. Assuming that the Crescent does accomplish the program currently being planned, it will result in an evaluation of a somewhat simplified version of the demonstration recommended above and should provide a more detailed set of recommendations for a larger scale, more ambitious demonstration.

For paperwork reduction, the program would demonstrate the use of WIM/AVC, AVI, and OBC (onboard truck computer) technologies to reduce the cost of permit and audit requirements for motor carriers and states.

The burden imposed on the motor carrier industry by state regulations and paperwork requirements is considerable. Relief from the burden of regulation and especially from the paperwork to prove compliance with regulations is consistently pinpointed by carriers as one of the most important things government could do to assist the industry. The National Governors' Association has documented this regulatory and paperwork burden and developed recommendations for alleviating many of them; however, their recommendations are based on existing technologies, organizations, and communication systems. WIM/AVC and AVI technologies can be used to further relieve the paperwork burden incurred in complying with state regulations.

The pilot program would demonstrate two concepts to reduce state and motor carrier paperwork costs: paperless permitting and electronic logs.

Current practice requires motor carriers to carry permits (and all other paperwork, such as cab cards) in the truck and display other indicia (e.g., fuel tax stickers) on the outside of the cab confirming that their trucks are in compliance with state motor carrier regulations. For large fleets, the distribution of permits and stickers to the trucks can be a time consuming operation, and failure to display the requisite permits and stickers may result in additional fees or fines.

Paperless permitting would permit a carrier to apply electronically for permits, either directly from the motor carrier's computer to the state's motor carrier services computer or through a wire service. This step to electronic application would be a direct extension of the trend in current practices (e.g., one-stop shopping) and could be built around established techniques and procedures developed by private industry for electronic funds transfer and electronic data interchange.

After the permit was issued, the state would link the permit number to the motor carrier's truck AVI number and log the permit into the state's weigh station clearance database. The AVI transponder would act as a non-expiring indicia, and the motor carrier would not be required to carry confirming paperwork or stickers on the truck.

Electronic logs provide an opportunity to reduce the labor time and cost associated with state audits of motor carrier mileage-based tax records. Motor carriers must maintain log books documenting hours of operation, fuel purchases, and miles traveled by state. These records are subject to review by the state during tax audits and must be maintained by the carrier for a period of time, typically 4 years. The costs incurred by motor carriers and states for storing and auditing these records are substantial.

The use of onboard computers as electronic mileage logs replacing paper logbooks has been accepted by several states. The pilot program would demonstrate two applications to expand the value of OBCs. The pilot program would install radio beacons at the state borders. These beacons would continuously transmit identification and date/time codes that could be received by a passing truck and logged into its onboard computer. This mark would permit the motor carrier to segment the truck's OBC log by state and fully automate the production of mileage-based reports.

For motor carriers participating in the "preclear and bypass" demonstration, the pilot program would, with the consent of the carrier, maintain a database record of the truck's passage over the WIM/AVC and AVI units. A sample of these electronic truck sightings would be used to establish audit comparison points with the carrier's electronic OBC logs. The comparisons could be automated to reduce the labor and per diem costs currently consumed by manual record searching and matching.

The productivity gains expected from these paperwork reduction applications are, for state DOTs, more efficient paperwork checks and audits and, consequently, an increase in revenues and motor carrier compliance with state regulations; and for motor carriers, a simplification of bureaucratic paperwork procedures and a reduction in audit labor and, consequently, a savings in the overhead costs associated with state taxation and regulation. The demonstration would be a direct extension of current NGA efforts. It should also take advantage of any findings from the Crescent Demonstration Project. (The Crescent Project currently plans to set up a parallel system for electronic clearances without changing or replacing existing paperwork requirements. The evaluation of the demonstration, however, may lead to standardization of requirements and automation of existing systems as recommended for the demonstration of paperwork reduction here.)

The paperwork reduction demonstration would entail the following:

1. *For paperless permitting:*

- Selection and promulgation of AVI coding and equipment standards.
- Adoption of electronic data interchange standards.
- Provision of computer and telecommunication equipment within the state motor carrier administration offices for remote transaction processing.
- Development of operational procedures.
- Installation of AVI equipment at weigh stations and ports of entry.
- Development of protocols for documentation and evaluation of the demonstration.
- Operation of the demonstration.
- Evaluation of state and motor carrier experience.

2. *For audit paperwork reduction, additionally:*

- Development and deployment of radio marker beacons at state borders.
- Development of a database to store truck observations.
- Development and testing of procedures for the electronic selection and comparison of state observations and motor carrier logs.

Synthesis of Practice

Recent experience of the states with WIM and AVC systems should be researched and documented in a level of detail that will be most useful to other states in their program planning and implementation decisions over the next few years. This is necessary despite the availability of several recent articles and publications on the subject, because most of the available material is either too general to satisfy the technical requirements for planning and implementation decisions or too narrowly focused on specialized research or individual equipment capabilities to serve the broader needs of people involved in such decisions. With very few exceptions, the available literature provided inadequate reference material to aid in planning for any of the HVM system applications analyzed in this project despite the considerable amount of experience in many states over the last several years—particularly with WIM systems. The problem may be because of either (a) an inadequate level of funding for synthesis projects, (b) work statements that are either too general or too comprehensive, or (c) the fact that such projects do not focus sufficiently on the specific needs of program managers.

To overcome these shortcomings and address the needs for planning, enforcement, and other purposes over the next few years, it is recommended that the synthesis should encompass the following:

- *Definition of information needs.* This should be based on in-depth consideration by program managers rather than casual interviews of many people or a questionnaire survey. To achieve this objective, such a synthesis project should be carefully designed to attract experienced program managers to devote the required level of effort.
- *Cost data.* Experience shows that available data are almost always incomplete either because persons contacted do not have access to all cost data or choose to provide only readily available information. Good cost data can be obtained only by reviewing actual records and by covering all aspects of costs, including all items identified below. Sponsoring agencies may have to be asked to make formal requests for such data to achieve this objective, and confidentiality of the data may have to be promised.
- *Procurement experience.* The survey should document mistakes made, lessons learned, full costs of the procurement process, specifications used and improvements that are needed based on recent experience particularly as relates to precision and other performance measures, suppliers responses to the procurement process, and negotiations process.
- *Installation.* This should include the state's experience in overseeing the installation process, all costs incurred, difficulties with any environmental conditions (e.g., pavement roughness, drainage, geometrics, or other site features).
- *Calibration.* One of the problems appears to be that only the best of calibration experience is reported in the literature. Another is the lack of almost any complete accounting of the staff time and related costs involved. Very little has been documented on long-term experience regarding the deterioration of precision over time or the frequency of recalibration needed.
- *Operating and maintenance requirements.* All aspects of operating and maintenance costs should be documented, including set-up time for data collection or enforcement sessions, down-time frequency and duration, office staff time required, and maintenance of electronics, sensors, and other equipment.
- *Safety experience.* This should include time required for protection of operations during installation and calibration, set-up of equipment, any accident of incident experience, and any lessons learned.
- *Enforcement experience.* Only a very few states have had actual experience using WIM for enforcement purposes on the mainline of highways; yet, because this appears to be so promising, considerable attention should be devoted to documenting this experience as well as the assessments of other enforcement officials who have seriously considered such applications.
- *Statistical data.* Relatively little data have developed on several statistical measures needed for planning and research purposes, such as means and variances of classification counts, equivalent single axle loads, and other weight measures. These should be systematically compiled and reported by functional class and for various strata such as by seasons and day of the week.
- *Overhead costs.* Most overhead estimates are difficult to find, and when available are difficult to define. Often overhead measures fail to account for full support services, administrative or management time, and capital/depreciation costs.
- *Organization, training, and other administrative experience.* This should include training time and costs at start-up as well as periodic retraining needs, experience in sharing use of WIM systems and data among different organizations within the state, and any lessons learned about the way in which WIM systems should be organized.

To assure that this synthesis provides the most useful data and reference material for the states, the research team should work closely with a few selected, interested states throughout the process.

Research to Support Improved Weight Enforcement Programs

Efforts made to support improved weight enforcement programs should be continued and targeted to specific needs that have been identified in this project. Specific items include:

- Analysis of the travel patterns of truck operations, particularly heavy trucks, including distributions of travel across functional classes in relation to trip length—a necessary element of the weight enforcement model for which data are currently unavailable.
- The benefits of improved weight enforcement on pavement damage reduction, including benefits in neighboring states. More accurate estimates of costs of pavement damage per ESAL-mile are particularly needed.
- Evaluation of the effectiveness of different enforcement strategies in terms of deterring overweight operations and increases or changes in the pattern of citations of violators.
- Evaluation of the impacts of increases in fines and penalties and more stringent off-loading requirements.
- Improvements to the weight enforcement model developed in this project, including improvement of the default values developed in Appendix A, and demonstration of the application of the model for state weight enforcement planning.
- Documentation of the effectiveness of specific types of field practices for enforcement programs, particularly the use of WIM for screening of overweight vehicles for weight enforcement.

• Testing of alternative strategies for deployment of WIM specifically for data collection to aid in enforcement planning.

All of these items should be used to develop guidelines for improved weight enforcement, as recommended in Chapter Four.

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3. OREGON DEPARTMENT OF TRANSPORTATION, Highway Division, *Final Report: Weigh-in-Motion and AVI Demonstration Project* (September 1986).
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APPENDIXES A, B, C, AND D

APPENDIX ITEMS NOT PUBLISHED

Appendix materials contained in the report as submitted by the research agency are not published herein, but are listed here, by title, for the convenience of qualified researchers in the subject area, who may obtain copies on loan, or for purchase at the cost of reproduction, of any or all of the appendixes, by written request to the NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, D.C. 20418.

• Appendix A—Weight Enforcement Model
• Appendix B—Cost-Effectiveness Model for WIM Data Collection
• Appendix C—Automated Clearance for Ports-of-Entry and Weigh Stations: Cost-Benefit Analysis Model
• Appendix D—National Heavy-Vehicle Monitoring System Organization and Management Scenarios

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