# Truck Accident Countermeasures on Urban Freeways 

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16. Abstract

In addition to fatalities and injuries resulting from truck involved accidents, excessive costs and delays caused by these accidents and incidents have prompted several operating agencies to consider various strategies to reduce the truck accident/incident problem. This study was undertaken to identify truck accident countermeasures implemented in different areas of the U.S. Issues considered when selecting countermeasures for review in this study included urban freeway volumes of 95,000 vehicles per day or higher, a significant number of trucks in the traffic stream (typically 5 percent or more), and countermeasures involving road design. The study omitted countermeasures directly related to the vehicle and the driver. This project included the following steps: literature search, telephone survey, and field visits to selected sites.

The information collected by this project is intended to assist agencies in identifying, selecting, and implementing truck accident countermeasures. Experiences with the following truck accident countermeasures are included in the report: lane restrictions, separate truck facilities, ramp treatments, truck diversions and bans, reduction of shoulder parking, urban truck inspection stations, incident response management, differential speed limit, increased enforcement, tall barriers, and mainlane treatments. Additional information on this study is contained in Report No. FHWA-RD-92040.
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#### Abstract

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### 1.0 INTRODUCTION

## INTRODUCTION

The issue of truck accidents on urban freeways is a vital concern for both traffic managers and the general public. With the passage of the Surface Transportation Assistance Act of 1982, the use of larger combination vehicles on the highway system has increased. The rise in truck volume, the interaction of these large vehicles with other traffic, and the publicity given to major truck accidents has focused public awareness on the consequences of truck accidents and incidents. In addition to fatalities and injuries resulting from truck involved accidents, excessive costs and delays caused by these accidents and incidents have prompted several operating agencies to consider various strategies to reduce the truck accident/incident problem.

A literature review, telephone interviews with representatives from selected operating agencies, and visits to selected sites identified countermeasures used to reduce truck accidents on urban freeways. These countermeasures included lane restrictions, separate truck facilities, ramp treatments, truck diversions and bans, reduction of shoulder parking, urban truck inspection stations, incident response management, differential speed limits, increased enforcement, tall barriers, and mainlane treatments. This report contains a description of each selected countermeasure, where the countermeasure has been installed, and a summary of the experiences and issues associated with the countermeasure. The more detailed case studies and the annotated bibliography are included in a separate report. ${ }^{(1)}$

## RESEARCH OBJECTIVES

The objectives for this project included the following:

- Identification of countermeasures that have been implemented to reduce the frequency and input of truck accidents and incidents on high volume urban freeways.
- Collection of information, such as safety and delay benefits, institutional constraints, spillover impacts, implementation efforts, and others, on selected countermeasures.


## ORGANIZATION OF REPORT

This final report presents a summary and synthesis of implemented truck accident countermeasures, provides an executive summary of the case studies, and summarizes information found in the literature. An outline of the study procedure precedes the individual countermeasure summaries. In each summary, there is a description of the background, implementation issues, and the effectiveness of the countermeasure at each location. Following the descriptions is a synthesis of the various applications.

### 2.0 STUDY PROCEDURE

## IDENTIFICATION OF POTENTIAL COUNTERMEASURES

Truck accident countermeasures investigated in this study included those related to roadway design and operations. Countermeasures directly related to the vehicle and driver were excluded. The study procedure began with a literature search to identify truck accident countermeasures. The literature search identified reports and articles that discuss countermeasures either considered or actually implemented to reduce truck accidents. The search revealed that although numerous articles have been published pertaining to truck accidents, articles pertaining to countermeasures on urban freeways to reduce truck accidents are limited. In many instances, the introduction of a countermeasure was the result of a highvisibility accident involving a truck. In most cases, implemented truck accident countermeasures were not thoroughly evaluated to determine their effectiveness.

An initial telephone survey supplemented the literature in determining countermeasures. The survey also identified agencies and individuals who would provide information for the study. The survey of selected States was directed to the traffic engineering or safety division of the State transportation agency. The initial question concerned whether the State had, either at a point or along a freeway segment, implemented a countermeasure to reduce the frequency and/or severity of truck accidents on high volume urban freeways. A positive response to this question was followed with general questions on the site location, the effectiveness of the countermeasure, and the availability of data on the effectiveness and/or problems in implementing the countermeasure. It should be noted that the telephone survey was not intended to be inclusive of all States, but attempts were made to provide regional representation.

The 14 road and road environment countermeasures initially identified from the literature, phone conversations with representatives from governmental agencies, and the research team's experiences were: active signs, differential speed limits, fixed radar, height warning systems, increased enforcement, urban truck inspection stations, lane restrictions, incident response management (major and minor), passive signs, reduction in shoulder parking, separate truck roadways (facilities) and truck bans.

## SELECTION OF COUNTERMEASURES FOR INVESTIGATION

Of the 14 countermeasures initially identified, 7 were targeted for extensive case studies. The criteria used to select the targeted countermeasures were: perceived potential accident reduction capability, general data or information availability of current interest, and regional representation. The emphasis of the data collection efforts for each targeted countermeasure follows:

- Lane Restrictions: Implementation issues include traffic volumes, number of trucks, number of lanes available or restricted to trucks, provision of passing
opportunities for faster vehicles, presence of an engineering study, and political pressures associated with the restriction.
- Restrictive Truck Facilities: The New Jersey Turnpike and truck bypass lanes in California and Oregon were built to accommodate trucks on separate facilities. In all known cases, other vehicle types are allowed on the truck facilities.
- Ramp Treatments: Active and passive signs and minor reconstruction of ramps were included. Any special design or maintenance procedures aimed at reducing truck accidents at ramps were noted.
- Truck Bans/Diversions and Time Restrictions: The legal and institutional issues were investigated for both statutory and voluntary diversions. Information was requested regarding the percentage of vehicles diverted.
- Reduced Shoulder Parking: When the parking area capacity of rest areas is exceeded, truck drivers park on ramps and freeway shoulders, creating a hazard for other motorists. Information was sought on solutions that reduced shoulder parking.
- Urban Inspection Stations: Emphasis was placed on implementation, rather than on the relationship between number of inspections and accident rates. Issues related to the implementation of inspection stations on high volume urban freeways were identified.
- Major Incident Response and Clearance: There are many elements of incident response, but the emphasis of this effort included only those elements that reduced delay time, and thus secondary accidents, when the primary incident involved a truck. Of primary interest were contractual arrangements between public agencies and towing contractors or the purchase of heavy-duty tow trucks by public agencies.

In addition to collecting information on the seven targeted countermeasures, the contractor also collected information on other countermeasures that were installed nearby or in the surrounding urban areas. This resulted in more than seven countermeasures being included in the study. These additional countermeasures did not have the heavy emphasis of information gathering as the targeted countermeasures, but they provide additional information on the variety of countermeasures implemented in the United States.

## COLLECTION OF INFORMATION ON IMPLEMENTED COUNTERMEASURES

The methodology used during the field site visits and phone calls to an agency's representative was very important in the uniform and consistent collection of data for each case study. Having similar information on each case study site was essential when the case studies were synthesized. Thus, a series of questions were developed to provide consistency.

The first questions were the same for all countermeasures, however the remainder were designed for each targeted countermeasure.

Sites selected for visits were chosen based upon maximizing the number of countermeasures investigated and achieving regional representation. Upon approval of the list of sites to be visited, the contractor sent a formal request for assistance 2 weeks prior to the date scheduled for the visit. The letter was addressed to the person responsible for providing assistance to the contractor. Included in the request for assistance was a list of questions on the specified countermeasure(s). It also included questions regarding any other truck accident countermeasures not specifically discussed previously. The site visit trip consisted of the following:

- Interviews with State agency contacts and individuals who had experiences with the countermeasure(s).
- Visits to the implemented countermeasure site.
- Photographs and videotape of the countermeasure and/or site.
- Obtaining sketches or schematics of the site (if appropriate).
- Obtaining copies of relevant documents (for example, copies of important local government/citizen correspondence regarding the implementation of the countermeasure, in-house reports on the countermeasure, and data on level of service, travel speeds, volumes, etc. for before and after the implementation).

Interviews with truck drivers and industry representatives regarding specific implemented countermeasures supplemented other information gathered during field trips. This information was obtained by contacting truck drivers and industry representatives who were familiar with the specific countermeasures. Specific questions included the following:

- How does (the countermeasure) affect truck operations?
- How often do you use the affected facility?
- What additional operating costs, if any (e.g. time delays), are associated with the countermeasure?
- Are there any groups or categories of trucks not affected, and how significant are they?
- Do you think the facility is safer now than before?
- Are any other facilities less safe now because of changes?
- What other truck accident countermeasures related to the roadway do you think should be used?


## SYNTHESIS OF CASE STUDY INFORMATION

The information collected during the individual case study trips included comments from discussions with agency personnel, truck drivers, and other materials provided by agencies. The information collected for each site was assembled into a case study format to provide detailed information on the investigated countermeasures. Issues discussed in each case study included:

- Background information.
- Safety benefits.
- Delay benefits.
- Institutional constraints.
- Spillover impacts.

The case studies for each site visited and the annotated bibliography are included in a separate report. ${ }^{(1)}$ The information was synthesized by countermeasure rather than by site. The emphasis during the synthesizing efforts was to compare the effectiveness of countermeasure applications from differing locations when possible and to compare design elements when appropriate. The following sections of this report contain the findings from the synthesis.

### 3.0 LANE RESTRICTIONS

## INTRODUCTION

Several States restrict the lanes in which trucks may operate. The objective in restricting trucks to the right lane or lanes is typically to improve highway operations and reduce accidents. To provide for uniform pavement wear, trucks are sometimes restricted from the right lanes. Lane restrictions through construction zones are used to move the trucks away from workers and from narrower lanes.

## LITERATURE SOURCES

In order to assess the effect of lane restrictions for trucks, the Federal Highway Administration (FHWA) in 1986 asked their division offices to report on experiences of States with lane restrictions. ${ }^{(2)}$ The Maryland State Highway Administration sponsored another study in 1988 to evaluate lane restrictions; this study also included a survey of States. ${ }^{(3)}$ The FHWA survey indicated that 14 States have implemented restrictions to improve highway operations. While a benefit of improved highway operations is reduced accidents, only eight States indicated their truck restrictions were primarily for the purpose of reducing accidents. The field survey also indicated that, in most cases, restrictions have been applied without detailed evaluation plans, including "before and after" studies. Little change in accident experience was noted under any of the restrictions.

In the Maryland study, State highway agency officials showed mixed reactions on the effectiveness of lane restrictions on urban freeways. ${ }^{(3)}$ In those States where restrictions were used, reactions were positive. Yet, these reactions were based purely on judgements; no objective studies had been conducted to evaluate the impact of the restrictions in those States.

Information on accident experience with lane restrictions from two States was included in the FHWA survey. ${ }^{(2)}$ Florida, in 1988, conducted a 6 -month experiment to determine the effect of prohibiting large trucks from using the left lane from 7:00 am to 7:00 pm on I-95 in Broward County. With signs about every mile, good media coverage, and strict police enforcement, 98 percent truck driver compliance was achieved. The overall accident rate for all vehicles decreased 2.5 percent for an all-day (24-hour) period, but increased 6.3 percent during the prohibition period (7:00 am to 7:00 pm). The proportion of accidents involving three or more axle trucks decreased 3.3 percent during the hours of the restriction. Also in 1982, Louisiana installed six signs on the $305 \mathrm{~km}(190 \mathrm{mi})$ of I-20 through the State. These nonregulatory signs, which were installed at truck weigh stations, requested truck drivers to use the left lane due to pavement deterioration in the right lane. Sixteen to 21 percent of the trucks shifted to the left lane. While there was an increase in traffic accidents after the signs were installed, there was also an increase in traffic volume.

Several studies were conducted on the lane restrictions implemented on the Capital Beltway. ${ }^{(4 \pi)}$ These studies are discussed beginning on page 10.

Hanscom has addressed the operational effectiveness of restricting trucks from designated lanes on multilane highways. ${ }^{(8)}$ His study involved two States where truck lane restrictions were implemented at two sites with three lanes per direction and one site with two-lanes per direction. The three-lane sites were located near Chicago in an urban fringe area while the two-lane site was located in rural Wisconsin. The author concluded that favorable truck compliance effects were evident at all three locations, however, violation rates were higher at the two-lane site as a result of increased truck concentrations caused by the truck restriction. Reduced speeds of impeded vehicles following trucks were also noted at the two-lane site. At the three-lane sites, the results of the lane restriction were beneficial traffic flow effects and reduced congestion. No speed changes (between the restricted and adjacent lanes) were observed to indicate any adverse effect on implementing the truck lane restrictions. The effect of lane restrictions on accidents was not provided.

Garber and Gadiraju used simulation to study the effects of lane restrictions and found that restricting trucks to the right hand lane resulted in a decrease of vehicular headway in this lane. ${ }^{(9)}$ The effect was more significant on highways having three or four lanes in each direction, or with an AADT greater than 75,000 , with at least 4 percent trucks. There was a slight increase in right lane accidents due to the lane restrictions, according to the simulation program.

## FIELD SOURCES

## Michigan

Statewide lane restrictions in Michigan require trucks to use the right two lanes on roadways that have three or more lanes. This law was passed in 1985 because trucks often occupied all lanes for passing purposes, restricting passing opportunities for faster moving vehicles. The sign used in Michigan provides the message: "ALL TRUCKS USE 2 RIGHT LANES." The cost of each ground-mounted sign is estimated to be $\$ 250$ to $\$ 300$, but the total number of the signs installed is not known. Establishing lane restrictions was thought to be politically motivated; apparently no studies were conducted to evaluate this countermeasure before implementation.

## California

The California Motor Vehicle Code allows the California Department of Transportation (CALTRANS) or local authorities to limit the lanes in which specified vehicles can operate based on an engineering and traffic investigation. This provision has apparently been in existence since 1963, with the latest revision in 1989. CALTRANS restricts trucks to the right two lanes on freeways with three or more lanes.

## New Jersey

The New Jersey Turnpike Authority (NJTA) was one of the first to impose lane restrictions for trucks in the 1960's. The restrictions do not allow trucks in the left lane of
turnpike roadways that have three or more lanes by direction. The turnpike has dual-dual roadways (two "barrels" of lanes in each direction, typically three lanes per barrel) from Interchange 8 A to Interchange 14, a distance of $53 \mathrm{~km}(33 \mathrm{mi})$. On the dual-dual portion of the turnpike, buses are allowed in the left lane of the outer barrel or roadway. The effect is that most buses use the left lane with the right lane(s) being occupied by trucks. When an incident or maintenance work forces closure of the outer roadway, lane restrictions are still imposed on the inner roadway. Regulatory signs are used with the following message: "NO TRUCKS OR BUSES IN LEFT LANE." Automobiles are also restricted by the following regulatory sign message: "CARS USE LEFT LANE FOR PASSING ONLY." Automobiles also use the outer roadway; the proportions are approximately 60 percent on the inner roadway and 40 percent on the outer roadway. Sources at the NJTA stated the compliance rate for truck lane restrictions is very high.

Atlanta, Georgia

Lane restrictions are currently in effect on all State and Federally funded highways in Georgia. Beginning September 1986, trucks (defined as vehicles with more than six wheels) were restricted to the right lane(s) except to pass or to make a left-hand exit. On roadways with three or more lanes in each direction, trucks are restricted to the right two lanes. This legislation was passed with the intent to prevent trucks from impeding other traffic desiring to pass. On urban freeways, trucks were often observed travelling abreast across several lanes, thus denying passing opportunities for other vehicles.

Another reason cited by Georgia officials for initiating lane restrictions for trucks was their over-involvement in weaving and lane-changing accidents. In a review of truck accidents by the Georgia Department of Transportation (GA DOT) officials, 53 percent of accidents on I-285 were found to be "sideswipes same direction." By comparison, this category is only 24 percent for all vehicles on I-285. A closer analysis of the "sideswipe same direction" truck accidents revealed that "changing lanes improperly" was cited as a contributing factor in 50 percent of these accidents.

The lane restrictions were implemented in stages. The Atlanta metropolitan area was the first stage of implementation (within Atlanta, I-285 was the first roadway). According to GA DOT officials, the lane restrictions signs cost $\$ 88$ per sign, which includes the cost of two $4-\mathrm{m}$ ( $14-\mathrm{ft}$ ) sign posts. As of the summer of 1991, 280 ground-mounted signs were installed on the right side, and another 101 were scheduled to be installed on the left side of the freeway. This is a total of 381 signs at a total cost of $\$ 33,528$. Georgia DOT uses one sign truck and one two-person crew, however, the cost above does not include labor and equipment costs.

Georgia DOT officials commented they do not have the necessary support of local law enforcement officials to heavily enforce lane restrictions (and other truck restrictions). Efforts to allow Georgia DOT Weight Enforcement personnel to enforce lane restrictions have been unsuccessful.

## Capital Beltway

The Capital Beltway lies within both Maryland and Virginia. Two lane restrictions that exist on the Beltway, (typically four lanes in each direction) are:

- All trucks are restricted from the left lane.
- Hazardous materials are restricted to the right two lanes.

Maryland. In Maryland, following a major truck accident, the Washington, D.C. news media compared the Capital Beltway to the Baltimore Beltway. The comparison implied that the Baltimore Beltway was safer. Thus, Maryland State Highway Administration (MSHA) implemented truck lane restrictions on Maryland's portion of the Capital Beltway, however this was more because of political pressure than accidents. Overall, the lane restrictions did not seem to reduce accidents, but auto drivers felt safer. A MSHA representative commented that there was no significant change in the number of accidents or accident severity; accidents were simply moved from the fast lanes to the slower ones.

In a 1988 study, Sirisoponsilp and Schonfeld reported on the strategies used by State highway agencies to restrict trucks from certain lanes and the impact the restrictions had on traffic operations and safety. ${ }^{(3)}$ State highway agency officials showed mixed reactions on the effectiveness of lane restrictions on urban freeways. In States where restrictions were used, reactions were positive. Yet, the reactions were based purely on judgements; no objective studies had been conducted to evaluate the impact of restrictions in those States. The authors concluded that although truck lane restrictions have been imposed by a number of States for many years, the effects of the restrictions on traffic operations and safety are still not wellknown and their cost effectiveness is still doubtful.

Virginia. The Virginia Department of Transportation (VA DOT) instituted a lane restriction for trucks on the I-95 section of the Capital Beltway between I-395 and west of the Woodrow Wilson Bridge (near the Virginia State line) on December 1, 1984. An analysis of the Virginia I-95 data for 1985 showed that the accident rate declined slightly during the restriction, and there was a reduction in accident severity. ${ }^{(4)}$ As a result of this decrease of accident severity level, along with favorable public perception, the authors recommended that the restriction be retained.

A subsequent study evaluated accidents, speeds, and volumes along the Virginia I-95 section to determine the effects of the countermeasure. ${ }^{(5)}$ The study included data collected during the 24 -month period prior to implementation of the restriction and data collected (periodically) during the 24 -month period following implementation. An analysis of the data showed that the accident rate increased 13.8 percent during the restriction; however, there was no change in the fatal and injury accident severity. Given the lack of an increase in severity level, along with favorable public perception and Maryland retaining its lane restriction on the beltway, the authors recommended that the restriction be retained in Virginia.

In 1988, a further analysis of the Virginia I-95 data demonstrated that the accident rate increased for trucks on southbound I-95 during the truck lane restriction periods. ${ }^{\left({ }^{( }\right)}$ Given this result, along with the increase discovered in the previous study, the authors recommended the truck lane restriction be removed. ${ }^{(5)}$ A subsequent evaluation indicated that the total number of accidents increased where restrictions had been enacted, and that accident rates tended to be lower where less restrictions were present. ${ }^{(6)}$ The authors found that political and public perception of trucks restricted to the right lanes seems to make the highways safer. They concluded that, based on their study and on other studies, existing restrictions should be removed and additional restrictions should not be considered.

## Chicago, Illinois

In Illinois, lane restrictions are in effect on all freeways that have three lanes or more in each direction. Trucks are restricted to the two right lanes. The sign used is a regulatory sign with the message "TRUCKS USE 2 RIGHT LANES." The signs, which have black letters on a white background, are posted both on overhead structures and along the roadside. On the Dan Ryan Expressway, ( -90 near downtown), trucks are only allowed in the outside lanes of the outer roadway. The inner roadway is meant to be used for long-distance express traffic, while the outer roadway is intended for local traffic and trucks. Trucks are not allowed on the Kennedy reversible express lanes ( $1-90 / 94$ northwest from downtown).

Lane restrictions have been in place in Chicago since 1964. They were implemented because, in some situations, trucks were occupying all available lanes. (for example, passing slower trucks in remaining lanes), forming a roadblock to other traffic. According to Illinois Department of Transportation (IDOT) personnel, the restriction was initiated by the Chicago mayor. Through his contacts with several trucking concerns, he solicited their cooperation in accepting the lane restriction. An IDOT administrative engineer believes there would be significant objections from other drivers if lane restrictions for trucks were now relaxed. Observations of truck traffic indicates that the majority of trucks stay in the second lane at interchanges, thus allowing entering and exiting motorists easier access to the outside lane at interchanges. The lane restrictions are typically relaxed in advance of major interchanges, so trucks can use other lanes or merge left if desired.

## SYNTHESIS OF RESULTS

Two surveys of State practice, one in 1986 by FHWA and the other in 1988 by Maryland, yielded differing results on the number of States which have lane restrictions for trucks. One reason was the differing response rates to the surveys. Only the FHWA survey requested the reason for implementing lane restrictions. The most common reasons given were: 1) to improve operations ( 14 States), 2) to reduce accidents (8 States), 3) for pavement structural considerations (7 States), and 4) restrictions in construction zones ( 5 States). It should be noted that some States provided more than one of the four reasons. A total of 26 States used lane restrictions, according to survey information. They were intended as a truck accident countermeasure in the following States included in this study: Florida, Georgia, Maryland, Oregon, and Virginia.. Finally, the field survey also indicated
that, in most cases, restrictions have been applied without detailed evaluation plans, including "before and after" studies. Where accident analyses were undertaken, little change in accident experience was noted under any of the restrictions. ${ }^{(2)}$

Georgia adopted lane restrictions because, on urban freeways, trucks were often observed travelling abreast across several lanes, thus denying passing opportunities for other vehicles. There was also an overinvolvement of trucks in weaving and lane changing accidents. The truck driver was determined to be at fault in 72 percent of the "changing lanes improperly" violations. Georgia DOT concluded that restrictions to the right lane(s) would reduce the occurrence of lane changing problems with large trucks.

Field sources report that lane restrictions have been imposed in California, Illinois, Michigan, and New Jersey, yet no detailed studies were found in those States which evaluated the effects these restrictions had on traffic operations or accidents. The compliance rate in New Jersey was reported to be high, probably because of increased enforcement. In California, imposition of lane restrictions requires an "engineering and traffic investigation." In Chicago, lane restrictions were implemented because, in some situations, trucks were occupying all available lanes (for example, passing slower trucks in remaining lanes), forming a roadblock to other traffic. Local transportation officials believe that other drivers would object to relaxed lane restrictions for trucks.

Table 1 is a summary of experience regarding lane restrictions in various other States, plus two research studies. There are no long-term data or findings that justify truck lane restrictions for truck-involved accidents.

Table 1. Results of lane restrictions.

| STUDY | CRITERIA |  |  |
| :---: | :---: | :---: | :---: |
|  | Study Conditions | Study Outcome | Change in Acc./Acc. Rates |
| Florida ${ }^{(2)}$ | 1988 Study: I-95, Broward Co. 6 months, 7am to 7 pm | Public feels safer with lane restrictions for trucks | Overall acc. up 6.3\% 7am to 7pm; Truck acc. down 3.3\% |
| Georgia | Evaluated accident reports for accidents on I-285: trucks were at fault in $72 \%$ of lane-changing violations | Trucks occupying all lanes, prohibit passing without restriction | Unknown |
| Illinois | No study | Public feels safer, and better operations | Unknown |
| Maryland | Capital Beltway | Political motivation; Public feels safer, continued use not based on engineering study | Study stated effects on safety not well known |
| Virginia ${ }^{(4-7)}$ | Capital Beltway, four studies, one for 24months, others for 12months | Public and political perception: safer hwys, engineering study recommended removal | Acc. rate increased $13.8 \%$ during 2-yr study; Second study also showed increase |
| Garber ${ }^{(9)}$ <br> Study | Simulation based on data from nine sites | Decreased headways in right lane | Slight increase in right lane accidents |
| $\begin{gathered} \text { Hanscom }^{(8)} \\ \text { Study } \end{gathered}$ | Two 3-lane suburban sites, all <100,000 AADT | Beneficial traffic operations and reduced congestion | Unknown |

### 4.0 SEPARATE TRUCK FACILITIES

## INTRODUCTION

Removing trucks from the general freeway traffic stream was accomplished in at least three States by providing separate truck facilities. These separate truck facilities are roadways designed to relieve existing lanes of heavy truck traffic. Such facilities are located on the New Jersey Turniike, along I-5 and other locations in the Los Angeles area, and on I5 near Portland, Oregon. None of these facilities are exclusively for truck traffic; smaller vehicles are also allowed. The feasibility of separate truck facilities in Texas and between San Pedro Bay and downtown Los Angeles is documented in the literature.

## LITERATURE SOURCES

In the Houston, Texas area, Stokes and Albert evaluated the feasibility of exclusive truck facilities parallel to I-10 and I-45, while Lamkin and McCasland studied their feasibility for the Beaumont-Houston corridor. ${ }^{(10,11)}$ Truck traffic volumes and accident statistics examined by Stokes and Albert indicate that measures directed toward improving truck operations and safety should be implemented. ${ }^{(10)}$ Lamkin and McCasland, however, conclude that existing and future trends do not warrant the construction of an exclusive truck facility, and recommend constructing additional travel lanes on the existing roadway to be shared by trucks and non-trucks. ${ }^{(1)}$

Holder et al. documented truck movement data on the North Freeway (1-45) in Houston, Texas to determine the potential for truck usage of the North Freeway contraflow lane. ${ }^{(12)}$ The authors concluded that few trucks would choose to utilize the contraflow lane and that motorists would benefit little from their removal.

Two proposals for separate truck facilities in Los Angeles include using the paved Los Angeles River channel as an exclusive facility, and using the Alameda Street corridor to carry trucks and trains within a right-of-way also shared by automobiles. The Los Angeles County Transportation Commission (LACTC) sponsored a study that examined the feasibility of using the Los Angeles River as an exclusive truck facility. ${ }^{(13)}$ The paved river bed could accommodate at least a single lane in each direction. The river is dry much of the year, and the river bed is paved for $32 \mathrm{~km}(20 \mathrm{mi})$ between the ports and the downtown. During the rainy season, however, the river bed would not be usable, forcing trucks back onto local freeways. Current challenges to be faced include the cost of the facility (estimated at near $\$ 400$ million), meeting approvals of the Army Corps of Engineers regarding flood control, and opposition from some jurisdictions along the route.

The second truck facility currently under consideration would use the Alameda Street corridor, which is also a connector between San Pedro Bay and downtown Los Angeles. The San Pedro Bay is the busiest harbor area in the United States, generating 19,000 truck trips and 25 freight trains daily. In August of 1989, the Alameda Corridor Transportation Authority was established to lead the effort in implementing a truck/rail corridor between San

Pedro Bay ports and downtown Los Angeles along the current Alameda Street corridor. Many of the port trucks have destinations at the Santa Fe and UUnion Pacific rail yards near downtown Los Angeles. The current proposed cross-section provides for median freight rail lines to operate below street level and to be grade-separated at intersections. Trucks would be in their own lanes adjacent to the median and cars would be in the outside lanes.

## FIELD SOURCES

Los Angeles, California

The separate truck facilities in California were generally built in the 1970 's, so detailed information justifying their construction is scarce. Trucks are restricted to the right lane(s) in California, which means that if trucks exit the mainlanes from the right side and re-enter from the right, there is little or no weaving required for the trucks when a lane is added at an interchange. In sections of the road where the weaving capacity is exceeded, removing trucks from those sections would allow smaller vehicles to utilize the available capacity. In fact, one initial reason why CALTRANS constructed these bypass lanes was to reduce foreseeable weaving problems with all traffic passing through the mainlanes at the interchanges. One example is the I-405/Route 110 bypass, which was built strictly to eliminate weaving for trucks. In locations where truck demand is high, CALTRANS tries to design the geometrics as satisfactory for truck operations as possible. For example, I-5 at State Route 14 carries an average daily traffic of 122,$000 ; 13.5$ percent of this volume is trucks. Because land is so expensive in California, CALTRANS evaluates each situation very carefully. Even where economically justified, constructing additional truck facilities might be politically difficult. The cost of the truck bypass is dependent upon available existing facilities. For example, an existing roadway was kept intact for use as a truck bypass at the Route 91 interchange and the interchanges of I-5 with Routes 14 and 210 north of Los Angeles (see figure 1). According to a CALTRANS representative, the current emphasis is on building high-occupancy vehicle (HOV) facilities, and if given the choice between bypass lanes and HOV options, the choice might now gravitate toward HOV facilities.

Another truck bypass lane has been built on I-5 at Route 99 near Grapevine. CALTRANS engineers stated that these truck bypass lanes were not necessarily built at all locations where truck volumes were high. For example, I-710 in Los Angeles has a high incidence of truck traffic without having bypass lanes for trucks. One engineer stated that the locations of truck lanes are motivated by engineering decisions and are not political.

## New Jersey Turnpike

The New Jersey Turnpike consists of interior (auto) lanes and exterior (truck/bus/car) lanes within the same right-of-way. For $37 \mathrm{~km}(23 \mathrm{mi})$ of the Turnpike, the interior and exterior roadways in each direction have three lanes. On the $14 \mathrm{~km}(9 \mathrm{mi})$ section that opened in November 1990, the exterior roadway has two lanes while the interior roadway has three lanes per direction (see figure 2). Each roadway has $3.67-\mathrm{m}$ ( $12-\mathrm{ft}$ ) lanes and


Figure 1. Schematic of truck bypass near Route 14 and Route 210.
$3.67-\mathrm{m}$ ( $12-\mathrm{ft}$ ) shoulders. Directional flows are separated by a concrete median barrier, and the inner and outer flows are separated by a metal beam guardrail. Trucks and buses are restricted to the outer roadway, but smaller vehicles can use either the inner lanes or outer lanes. The current mix of automobile traffic is approximately 60 percent on the inner roadways and 40 percent on the outer roadways. The turnpike authority believes segregation of vehicles by size represents an improvement in safety for all motorists using the facility.


Figure 2. New Jersey Turnpike cross-section.
In 1971, the New Jersey Turnpike Authority (NJTA) opened the first segment of the dual-dual roadway. Instead of adding a fourth, fifth, and sixth lane in each direction contiguous with the existing roadway, they elected to separate the lanes as two parallel roadways in each direction with physical barriers (metal beam guardrail). The roadway's typical cross-section had 12 total lanes with 2 three-lane "barrels" in each direction. The dual-dual cross-section was used for two reasons: 1) traffic management had a goal of automating traffic control, and 2) for allowing flexibility in closing parts of the roadway for maintenance activities or accidents. Initially, the dual-dual cross-section extended from Exit 10 to Exit 14 , but currently the dual-dual roadway begins at Exit 8A.

The additional construction cost of the dual-dual roadway comes from the costs of the additional right-of-way, the metal beam guardrail, additional pavement (shoulders), additional length of overhead structures, and increased interchange costs due to additional ramps. The approximate construction cost of a dual-dual freeway with 12 lanes is $\$ 15$ to $\$ 18$ million per $\mathrm{km}(0.6 \mathrm{mi})$, excluding interchanges. Some new interchanges in urban and suburban areas are costing the turnpike authority over $\$ 100$ million, including toll plazas and related appurtenances. One new interchange in a rural area cost $\$ 45$ million. It consisted of 11 toll lanes, using existing outside ramps, but new inside ramps were built. The NJTA just recently completed an improvement that widened a $17.7-\mathrm{km}(11-\mathrm{mi})$ six-lane segment of nondualized freeway to a dualized freeway with 10 lanes ( $2-3-3-2$ configuration). The cost of this improvement, including some interchange improvements, was $\$ 300$ million. Another improvement currently underway to add one additional lane in each direction to an existing 19.3 km ( $12-\mathrm{mi}$ ) segment of dual-dual roadway, plus some interchange improvements, will cost approximately $\$ 368$ million.

Rough estimates of non-dualized freeway indicate a cost of approximately $\$ 6$ million per km ( $\$ 10$ million per mi), excluding environmental issues which must be addressed. This might include relocation of houses and construction of a noise barrier, which in one example, cost $\$ 28$ million for a $24-\mathrm{km}(15-\mathrm{mi})$ segment of freeway.

A significant difference in truck accident rates exists between the dualized and nondualized roadways of the New Jersey Turnpike. According to NTTA records, the truck accident rate for 1990 on the dual-dual portion was 114.0 accidents per 100 million vehicle miles ( 100 MVM ), compared to 176.7 for the non-dualized portion. There are important differences between the dual-dual and the non-dualized roadways related to design, operations, and safety.

## Portland, Oregon

A countermeasure implemented in the Portland area was a truck by-pass at the Tigard Street interchange similar to those described for California. The bypass lane allows trucks to stay in the right-hand lane, exit onto a truck roadway (cars permitted also), and re-enter the traffic downstream of that interchange on the right-hand side. The mainlanes are built on a significant grade such that, without the truck roadway, larger vehicles are forced to climb a grade then weave across faster moving traffic entering the mainlanes to the right of trucks in the merge area. These speed differentials create operational as well as safety problems. This segment of Interstate 5 has three lanes in each direction.

Several advance signs provide information to truck drivers. The first sign indicating the truck bypass is a large sign support in the median with the third entry on the sign providing the message "I-5 TRUCK LANE $1 / 4$ MILE." The sign has white letters on a green background. The second sign approaching the truck bypass, also white on green, is a sign with the Interstate shield on the top line and the words "TRUCK LANE" on the second line supplemented by an arrow pointing upward to the right. The third sign is a regulatory sign using black letters on a white background mounted overhead with the message "ALL

TRUCKS MUST USE TRUCK LANE." The fourth sign, also mounted overhead, has the Interstate shield on the first line, "TRUCK LANE" on the second line, and " $3 / 4$ MILE" on the third line with a downward arrow indicating the outside lane. The fifth sign is also overhead with the first line the Interstate shield and the second line "TRUCK LANE" with an arrow pointing upward and to the right. This white on green sign is placed just upstream of the location where the truck bypass exits the mainlanes.

Design drawings for this truck lane were not available, so the following dimensions are approximate. The bypass is a single lane until the ramp merge, with a $1.2-\mathrm{m}(4-\mathrm{ft})$ inside shoulder and a $3-\mathrm{m}(10-\mathrm{ft})$ outside shoulder. This segment is 0.5 to 0.6 km ( 0.3 to 0.4 mi ) in length. The single lane truck bypass joins a two-lane entrance ramp which then merges with I-5.

Observations of trucks travelling northbound indicate nearly every truck uses the truck bypass. Regulatory signs require all trucks to use it, which means a citation could be issued if trucks do not use the truck lane. Only one large truck out of several hundred observed did not use the bypass. This truck reduced its speed approximately $32 \mathrm{~km} / \mathrm{h}(20 \mathrm{mi} / \mathrm{h})$ negotiating the grade, then moved over from the third lane to the outside lane just downstream of the interchange.

No before and after accident data were available for the truck bypass lane. Removal of the slow-moving trucks from the complex weaving section has substantially eliminated the operational problem at this site, according to Oregon DOT officials. Truck speeds in the merge area now are typically $80 \mathrm{~km} / \mathrm{h}(50 \mathrm{mi} / \mathrm{h})$ with the truck lane, where they had been 32 to $40 \mathrm{~km} / \mathrm{h}$ ( 20 to $25 \mathrm{mi} / \mathrm{h}$ ) without it. The cost of the truck bypass was included in the cost of a major rehabilitation of I-5 south of Portland. No specific cost data for this portion of the project were available.

## SYNTHESIS OF RESULTS

Separate truck facilities have been considered for at least four locations. Two Texas studies evaluated exclusive truck facilities, and found that trends did not warrant the construction of this type of facility. ${ }^{(10,11)}$ Their recommendations, however, were to construct additional travel lanes on an existing freeway. A third Texas study recommended against allowing trucks to use the North Freeway (I-45) contraflow lane, suggesting that little benefit would accrue to general traffic from their removal. ${ }^{(12)}$

The separate truck facilities in California were constructed primarily to reduce weaving problems at interchanges, so their applications are shorter than those evaluated in Texas. Proposals for future separate truck facilities include: 1) using the Los Angeles River channel as an exclusive two-lane truck facility and 2) using the Alameda Street corridor to carry trucks and trains within a right-of-way also shared by automobiles. The current proposed cross-section includes separate truck lanes adjacent to the median.

In Portland, Oregon, a truck by-pass was built due to significant grades and an undesirable weaving situation on the mainlanes. Removal of slow-moving trucks from the complex weaving section has substantially eliminated the operational problem at this site. The concept used for this bypass facility is similar to that used in California; the difference in this case is the severe grades which impact weaving speeds more than in most of the California examples.

The New Jersey Turnpike provides an outer roadway for trucks and buses (optional for cars) for an extended portion of its length. This makes it somewhat different from the other shorter facilities above. The longest California bypass facility is approximately 6 to 8 km ( 4 to 5 mi ) in length, utilizing an old existing roadway for trucks to operate parallel to the mainlanes. Their effectiveness in reducing accidents has not been evaluated.

### 5.0 RAMP TREATMENTS

## INTRODUCTION

Restrictive geometry on ramps and interchanges, resulting in reduced safety for largetruck operations, has become a concern. Interchanges and ramps can be especially difficult for large trucks when inadequate design elements such as tight radius ramps, abrupt changes in compound curves, and short acceleration and deceleration lanes are combined with inappropriate posted advisory speeds.

## LITERATURE SOURCES

Ramp Geometry. Ervin et al. studied specific ramps that were involved in truck accidents. ${ }^{(14)}$ Six specific ramp design features contributing to truck accidents were: poor transitions to superelevation, abrupt changes in compound curves, short deceleration lane preceding tight-radius exits, curbs placed on the outside of ramp curves, lowered friction levels on high speed ramps, and substantial downgrades leading to tight ramp curves. Results showed that various aspects of the American Association of State Highway and Transportation Officials (AASHTO) policy on geometric design result in a very slim margin of safety for the operation of heavy trucks on ramps.

Firestine et al. used the Ervin et al. research results and developed examples that can guide engineers in designing interchanges. ${ }^{(1)}$ The goal is to reduce the likelihood of truck accidents on highway interchanges. The authors proposed the following countermeasures: incorporating a greater safety margin into formulations for side friction factors; reviewing and modifying posted speed limits and advisory speeds; improving curve condition and downgrade signs at interchanges; increasing deceleration lane length; eliminating outside ramp curbs or overlaying with wedges of pavement; resurfacing ramps with high friction overlays; and redesigning sites where accidents are common.

In 1988, VA DOT conducted a field study of the ramps and interchanges of the Capital Beltway. ${ }^{\text {() }}$ The study found several conditions of concern relative to traffic operations and environmental safety. These conditions included posted speeds that exceeded safe speeds on loops and ramps, interchange configurations which violate driver expectancy at their approach, inadequate or poor visibility of advanced signing, and landscaping and vegetation which obscure a driver's line of sight.

Ramp Signing. Maryland and Virginia reevaluated ramp speeds on the Capital Beltway to determine whether the posted speeds were appropriate for trucks. Virginia reduced speeds on 44 ramps; Maryland also reduced speeds on several ramps. ${ }^{\text {(n) }}$ California is currently evaluating the adequacy of speed signing for trucks on turning roadways.

In 1991, the Federal Highway Administration sponsored research on a passive and an active device for trucks. ${ }^{(16)}$ Initial testing used a static "truck tipping" sign to determine its effectiveness in reducing truck speeds on the approach to ramp curves. The active device
added lights to the static sign which flashed in a "wig-wag" fashion to warn truck drivers when they were approaching the curve at an unsafe speed. The lights were activated only by trucks, in contrast to a system used in Atlanta that responds to both cars and trucks travelling faster than the preset speed.

## FIELD SOURCES

## New Jersey

Ramp shoulder improvements have recently been implemented along the New Jersey Turnpike. On superelevated ramp curves, the shoulder was sloped toward the outside of the curve to accommodate snow melt away from the ramp, however, this was only a problem when snow was plowed to the outside of the curve. The New Jersey Turnpike Authority found that it was feasible in many locations to plow snow to the inside, and design the entire ramp surface (shoulder plus mainline) at the same cross-slope.

## Atlanta, Georgia

Two ramp locations were identified by the District Traffic Engineer of the Georgia Department of Transportation (GA DOT) as having improvements specifically relevant to trucks. These were located at interchanges of radial freeways with I-285. Each of these interchanges uses collector-distributor (C-D) roads. Their descriptions are as follows:

- I-285 eastbound to I-75 northbound in Cobb County (south of downtown): GA DOT made several improvements to this ramp at different times. These included: static warning signs, an active warning device, improving the inside (left) shoulder, and improved superelevation.
- I-285 eastbound to I-75 southbound in Clayton County (north of downtown, see figure 3): GA DOT added superelevation, an active message device, a truck tipping sign, and chevrons.

According to GA DOT officials, the ramp at I-285 and I-75 in Cobb County was at one time the ramp location with the highest number of truck accidents in the Atlanta metropolitan area. From the freeway, motorists make a right-hand exit onto a collectordistributor roadway, pass under I-75, then make a left-hand exit onto the ramp which crosses under the mainlanes of I-285. Two separate construction projects made improvements to the ramp. One project improved the inside shoulder cross slope to match the cross slope of the main ramp lanes, and added a concrete safety barrier. These improvements were prompted by truck accidents involving rollovers to the inside of the curve. A second project increased the superelevation on the ramp. Georgia DOT officials stated that increasing the superelevation on the main lanes of the ramp to 8 percent helped more than anything else to reduce accidents.


Figure 3. Ramp treatments at I-285 eastbound to I-75 southbound in Clayton County.

Even with recent improvements, GA DOT is currently planning additional traffic control devices including a new active message sign. The current active device uses wigwags attached to a static warning sign. The device is activated by any vehicle that approaches the ramp faster than the preset speed. The threshold speed is set based on the AASHTO design speed which does not necessarily consider high center of gravity vehicles. These active devices are installed on several ramps in the Atlanta area. Casual observations indicate they flash continuously, thus losing their effectiveness as active devices.

The ramp from I-285 eastbound to I-75 southbound in Clayton County south of downtown was retrofitted with an active warning sign and chevrons, and the superelevation on the ramp was increased from 8 percent to 10 percent. The increased superelevation improvement was accomplished by contract and not by state personnel, and the construction plans were signed in January 1987. A truck tipping sign with a " 40 MPH " speed advisory plate is used near the start of the ramp.

Georgia DOT officials observed the following pattern of effectiveness for their active devices using wig-wags. When first installed, speeds of most vehicles were reduced. After an initial familiarization period, motorists became accustomed to their presence, and with their own perceived safe speed on the roadway, speeds once again increased. With commuters, the time period is less than for unfamiliar motorists, but within a month or so familiarity tends to reduce the active device's effectiveness.

The District Traffic and Safety Engineer does not believe signs (active or passive) are effective in reducing vehicular speeds, and that the presence of law enforcement officers is necessary to slow motorists. Georgia DOT, however, does not place regulatory speed signs on ramps due to a perceived liability problem. One problem with the "truck tipping" sign noted by this engineer is recognition. Georgia DOT has received numerous phone calls requesting an interpretation of the sign's meaning. To improve driver understanding, GA DOT personnel added a supplemental "TRUCKS" plate below the truck tipping sign.

Georgia DOT does not have an official sequence of improvements for ramp curves, however, one set of ramp improvements occurred as follows. First, the number of chevrons was increased, then the size of chevrons was increased, then truck tipping signs (static) were added, then finally, the over-speed warning device (wig-wag) was installed. If all of these actions remain insufficient, then the ramp will be reconstructed (for example, add superelevation).

## Capital Beltway

Maryland. The MSHA first used a ball bank indicator to check all ramps on the Beltway within their jurisdiction, using both a car and a truck in their testing. They found that some ramps had posted advisory speeds that were too high according to the traditional method. MSHA personnel feel that this method is currently inadequate. Upon checking all ramps, they installed "truck tipping" signs on ramps that appeared to be problematic (higher than the statewide average accident rate). These signs used the new diamond grade reflective
sheeting that is superior to lower grades of reflectivity. The signs employ an arrow (diagrammatic), an advisory speed, and the truck pictograph. The MSHA source indicated there is some confusion as to the meaning of the arrow (diagrammatic) on this sign. Some motorists seem to think the arrow is going the wrong way.

One of the truck overturning locations was on I-95, where southbound traffic is required to make a left-hand exit to go eastbound on the Capital Beltway. The posted speed limit is $88 \mathrm{~km} / \mathrm{h}$ ( $55 \mathrm{mi} / \mathrm{h}$ ), and the tipping sign uses an advisory speed of $72 \mathrm{~km} / \mathrm{h}$ ( 45 $\mathrm{mi} / \mathrm{h}$ ). The sign is located approximately $1.61 \mathrm{~km}(1 \mathrm{mi})$ upstream from the ramp gore on an overhead structure. The sign, which was installed in January or February of 1990, measures 1.8 m by $2.1 \mathrm{~m}(6 \mathrm{ft}$ by 7 ft ) and includes a diagrammatic (arrow) depicting the alignment of the ramp.

Virginia. VA DOT installed truck tipping signs at the following ramps on the Capital Beltway: 1) I-95 northbound to US 1 northbound ramp in Alexandria, 2) Route 236 eastbound to I-495 northbound, and 3) I-495 northbound to Route 236 westbound. All three of these ramps are loop ramps with " 20 MPH " advisory speed plates used in conjunction with the truck tipping signs. The cost of these 1.2 m by 1.2 m ( 48 -in by 48 -in) diamondshaped signs plus 0.6 m by 0.6 m ( $24-\mathrm{in}$ by $24-\mathrm{in}$ ) advisory speed plate and post was $\$ 282$ each. Virginia DOT sources did not think these signs were installed as a result of accidents, but were a proactive measure to prevent tanker truck overturning accidents. The signs used a tanker silhouette instead of the more commonly used van silhouette (see figure 4). Sign placement is also important in warning drivers of hazards on ramps. A Virginia design engineer believes that some of the warning signs are placed so close to the ramp that they do not allow truck drivers enough reaction time.

Virginia also reduced advisory speeds on several ramps on the Capital Beltway. VA DOT used a ball-bank indicator in a car tested on all ramps within its jurisdiction on the Beltway; it found that speeds needed to be adjusted on 44 ramps. VA DOT also tested the ramps using a ball-bank indicator inside a truck. The results were not significantly different from the auto readings, unless the loaded truck had a high center-of-gravity or the load was subject to shifting while the vehicle was turning.

Virginia's procedures for sign implementation usually begin with an engineering study for placement, but sometimes the process starts with recommendations from the State police. Virginia personnel stated they are using the same truck tipping sign first used by Maryland, however, at the two interchanges of I-95/US-1 and I-495/Md 236, they installed signs that depicted a tanker silhouette.

## Detroit, Michigan

A freeway ramp has been altered with ramp treatments to mitigate accidents involving trucks. The ramp is a two-lane freeway-to-freeway connector located in downtown Detroit, where I-75 (Chrysler Freeway) northbound traffic continuing on I-75 must exit the freeway mainlanes onto this ramp. The directional orientation of traffic on I-75 northbound changes


Figure 4. Truck tipping sign on the Capital Beltway.
from an easterly direction to a northerly direction. Interstate 375 traffic must also interchange at this location (see figure 5). No specific truck counts were available for this ramp, but Michigan DOT personnel stated the daily number was approximately 6,000 .

Ramp improvements included signs, an increase in superelevation and construction of a tall barrier. Additional information of the tall barrier is provided in Section 12.0. Originally, the superelevation was less on the outside lane than on the inside lane. It also included an outside barrier curb which could have contributed to combination vehicle rollovers. The improvement removed the differing cross-slope rates and formed a constant superelevation rate of 7.4 percent over the full width of the ramp to the outside barrier. The other major improvement was construction of a tall barrier on the outside of the ramp curve to contain high center-of-gravity vehicles and loads that might be dumped on other ramps and the freeway below. The improvements on this ramp were completed between 1977 and 1980 according to Michigan DOT.

According to a Michigan DOT traffic engineer, the problem at both ramps was practically identical. Both ramps were built with tight geometrics; one was built next to a large building that limited available right-of-way. Michigan DOT had installed extensive signing first in an attempt to reduce accidents, but results were insufficient.

The cost of all elements for this improvement was difficult to determine because warning devices were probably installed in phases, and more than 10 years has passed since


Figure 5. I-75/I-375 Interchange and cross-section showing ramp improvement.
the improvement was implemented. A typical sequence of improvements used by Michigan DOT is to install signs, then flashers, then symbol signs. Michigan DOT has used groundmounted and overhead static warning devices, both with and without flashers.

## Hagerstown, Maryland

In 1984, MSHA installed oversized truck tipping signs on the eastbound and westbound exit ramps of I-70 in an attempt to reduce the number of truck rollover accidents that had occurred there (see figure 6). The ramps were used for a recent research study sponsored by the FHWA to determine the effects of these signs on truck speeds. ${ }^{(16)}$ Both of the ramps are loops, each built with a radius of $70.12 \mathrm{~m}(230 \mathrm{ft})$ and on a descending grade.

Warning signs, such as the truck tipping signs, are typically installed based on an engineering study. A key input is the number of truck accidents of the type expected to be reduced by this warning sign. The number of overturned combination vehicle accidents that occurred on the two loop ramps over the 3-year time period from 1985 through 1987 was six on the westbound connector and seven on the eastbound connector.


Figure 6. Truck tipping sign in Hagerstown, Maryland.

Two additional efforts that MSHA has made or is considering will improve sign warning to truck drivers. One is the use of the new diamond grade reflective sheeting that presents a brighter image to motorists at night. Their other effort concentrates on placing signs near the approach to ramps. In some cases, signs were placed too close to the actual problem to allow sufficient reaction and deceleration. The signs might be moved upstream, or another sign might be used upstream with the word "RAMP" placed in addition to the sign near the gore area. The main goal is to warn truck drivers of impending ramp conditions.

The sign being used by MSHA is similar to that used by CALTRANS. According to MSHA personnel, there seems to be some misunderstanding of the meaning of the diagrammatic (arrow) used on these signs. Its meaning is intended to reflect the alignment of the ramp. The only other problem which MSHA officials identified with the signs was overuse; they warned that overuse would diminish its effectiveness.

An additional improvement to the westbound I-70 to southbound I-81 connector involved increasing the shoulder cross-slope to match the ramp superelevation. Originally, the ramp width was 4.8 m ( 16.0 ft ), and at the outside break in the cross-slope, a $3-\mathrm{m}$ ( $10-\mathrm{ft}$ ) shoulder sloped away from the ramp mainlane. The maximum superelevation of 6.0 percent was developed over a distance of $61 \mathrm{~m}(200 \mathrm{ft})$, beginning with a normal cross-slope of 1.6 percent. The cross-slope improvement added $1.8 \mathrm{~m}(6 \mathrm{ft})$ to the "effective width" of the ramp, so the widened total width was $6.6 \mathrm{~m}(22 \mathrm{ft})$. At the outside edge of this width is a break in the cross-slope with a maximum of a 7.0 percent break (algebraic difference).

## Harrisburg, Pennsylvania

PennDOT installed truck tipping signs on two ramps in the Harrisburg area. One of these signs was added to the westbound Pennsylvania Route 283 ramp which forms a connector to I-283 northbound. The mainlanes on this segment of Route 283 carry an average daily traffic of $40,940 \mathrm{vpd}$ with 13 percent trucks. This four-lane roadway serves traffic to and from the Harrisburg airport, the Pennsylvania Turnpike, and the city of Harrisburg.

The second sign was placed on the eastbound I-81 exit ramp which connects with US $22 / 322$ northbound. This is a fully directional interchange on the north side of downtown Harrisburg. The I-81 northbound only traffic volume in July 1991 was $31,835 \mathrm{vpd}$ with 21 percent trucks. (The average daily traffic is approximately double this number, or 63,000 vpd.)

Truck tipping signs were installed on July 26,1988 on the two ramps. The westbound PA Route 283 to northbound I-283 ramp also had rumble strips installed several years before the truck tipping sign was installed. Accident reports were not available for this analysis, however, the Pennsylvania Department of Transportation (PennDOT) provided accident summaries for the truck-involved accidents that occurred on the ramps. During the before installation time period (January 1, 1988 to July 25,1988 ) on the I-283 ramp, there
were five truck accidents that could have been affected by this countermeasure (single vehicle rollover or struck object categories), and during the after period (July 27, 1988 to February 23,1991 ), there were four truck accidents of this type. For the I-81 interchange, there was only one truck accident during the same before period and one during the after period. The time period and the details of the accidents are limited, however, there was no indication of accident reduction. There was also no information available regarding the impact of the signs on truck speeds.

The cost of signs in Pennsylvania is typically $\$ 118 / \mathrm{m}^{2}\left(\$ 11 / \mathrm{ft}^{2}\right)$ for signs installed by PennDOT. One $1.2-\mathrm{m}$ by $1.2-\mathrm{m}$ ( $48-\mathrm{in}$ by $48-\mathrm{in}$ ) sign was placed on each ramp. Based on this unit cost, each sign would cost $\$ 240$. No costs were available on labor and equipment required to install the signs.

## Los Angeles, California

The Route 91 eastbound to the I-605 northbound ramp in Los Angeles has been treated with several traffic warning devices, some specifically for trucks. It is a two-lane ramp that exits the mainlanes to the right and follows a sweeping curve to the left to join the mainlanes of I-605. This ramp has had numerous accidents involving both automobiles and trucks. CALTRANS added chevrons, a large 2.4 m by 2.4 m ( 8 - ft by 8 - ft) truck tipping sign, turn warning signs, and a large overhead sign with $305-\mathrm{mm}$ ( $12-\mathrm{in}$ ) diameter yellow wig-wags. One CALTRANS engineer stated that they typically use oversized warning signs more than the truck tipping sign.

CALTRANS installed chevrons to the eastbound Route 91 to the northbound I-605 connector in December 1986. The large overhead sign with 305 mm (12-in) diameter yellow wig-wags was installed in May 1986. The turn warning signs near the gore area were installed in December 1986 and the large truck tipping waming sign (approximately 2.4 m by 2.4 m [ 8 ft by 8 ft$]$ ) was installed in May 1977.

A comparison of only the accident types expected to be reduced by the countermeasure (overturning and single vehicle struck guardrail accidents) revealed that the number of accidents during the after period was approximately half of what it was during the before period. The before period was 1981 through 1984, and the after period was 1987 through 1990. Half of the before accidents involved personal injuries, whereas only 2 of the 10 accidents in the after period involved injuries. This represents a significant reduction, although most of the accidents in both time periods included overturned trucks -another indication of severity. Ramp classification counts were not available for making comparisons of accident rates between the before and after period. Conclusions regarding effectiveness are also weaker due to no detailed accident reports.

## Pennsylvania Turnpike

A higher than expected number of truck rollover accidents occurred at two eastbound exit ramps on the Pennsylvania Turnpike. These two ramps are at Interchange 12 (Breeze-
wood) and Interchange 16 (Carlisle). From June 1985 through December 1988, there were 16 truck rollover accidents on the Breezewood eastbound exit ramp, and nine for the Carlisle exit ramp. The accident history for the period after improvements at these two locations indicates an apparent improvement at the Breezewood exit, but little or no difference at the Carlisle exit. No ramp traffic classification counts were available to allow consideration of exposure.

The modification at the Breezewood eastbound exit involved changing the cross-slope of the shoulder to match the cross-slope (superelevation) of the mainlane and installing a slotdrain. On a mainlane curve to the left, superelevated sections slope to the inside of the curve (right to left as seen by motorists), but PennDOT standards allow the shoulders to slope downward to the outside of the curve (left to right as seen by motorists). This results in a "break-over" point at the outside pavement edge. When vehicles traversing a curve to the left veer onto this shoulder, their effective superelevation is decreased. Because the original design facilitated pavement surface drainage (e.g. rain and snow melt) away from the travel lane, a slot-drain became necessary with the new design.

The maximum superelevation used by the authority on ramps and mainlanes is 8.3 percent. They considered one and one-quarter inches, or 10 percent, but decided that was too steep for ice/snow. The cost of improvements at these ramps was unavailable. Turnpike sources believe other interchange improvements were completed at the same time and separate costs would not exist. Apparently, no warning signs were installed on the ramp prior to shoulder improvements.

The exit ramp at Interchange 16 was improved by installing a $1.2-\mathrm{m}$ by $1.2-\mathrm{m}$ ( $48-\mathrm{in}$ by 48 -in) diamond-shaped black on yellow truck tipping sign on the eastbound exit ramp. The turnpike commission also installed a taller, stronger guardrail along the outside of this ramp curve to the left. It consisted of two "W-beam" sections, one on top of the other on a metal post system, making the height greater than the standard $812.8 \mathrm{~mm}(32 \mathrm{in})$.

## Pittsburgh, Pennsylvania

Several warning devices, additional superelevation, and a tall reinforced concrete barrier for containing cars and trucks were installed at the interchange of I-70/I-79 near Washington, Pennsylvania approximately $48 \mathrm{~km}(30 \mathrm{mi})$ south of Pittsburgh. PennDOT engineers reported that prior to the improvements several fatalities had occurred at the location.

The initial countermeasure for the ramp was to modify and increase the number of signs located on the approach to the ramp. The signing contract work began on August 2, 1984 and was completed on June 12, 1986. Based on additional evaluations before and after installing the new signs, PennDOT investigated additional countermeasures, including alternative designs for barriers. A tall barrier, which would contain large combination vehicles as well as smaller vehicles, was selected. The tall barrier contract was awarded on January 21, 1985 and was completed on June 27, 1985.

The total cost of the signing project was $\$ 232,011$; the cost of the high wall barrier project was $\$ 602,333$. The signing project included removal of certain existing traffic signs, installation of structure-mounted signs, and installation of a guide rail (excludes tall barrier). Funding on each contract was 90 percent Federal and 10 percent State.

PennDOT provided before and after accident history, however, the after data were affected by a detour in place during reconstruction in 1989-1990. Evaluations of accidents included only truck-involved types expected to be reduced by the countermeasures implemented. Analysis of the after period of 1987 through 1990 revealed no accidents, whereas two to six truck accidents occurred each year of the before period from 1980 through 1983. During the signing installation and tall barrier construction, traffic was also maintained and could be a factor in the number of accidents during that period.

## SYNTHESIS OF RESULTS

Several ramp treatments used passive and active devices, others used minor reconstruction to achieve a reduction in accidents. Devices were typically installed in phases, with standard size passive devices installed first followed by larger passive devices. The next step was sometimes the addition of flashing lights attached to a passive sign, or perhaps an active element. More expensive treatments involving minor reconstruction sometimes followed if the other countermeasures were not effective. The addition of tall barriers was also sometimes included on the outside of ramp curves to contain trucks and their loads.

Passive signs are used to warn truck drivers of the ramp geometry and a rollover hazard for large trucks. The effects of these signs on truck speeds on ramps will be documented in the current FHWA study titled "Ramp Signing for Trucks." At the present time, however, the effectiveness of these signs is not well known, even with devices such as "wig-wags" to increase conspicuity. Passive warning signs are being used in several States, including California, Virginia, Maryland, and Pennsylvania.

One problem noted with the "truck tipping" sign is motorist recognition. Georgia DOT has received numerous phone calls requesting an interpretation of the sign's meaning. To improve driver understanding, DOT personnel added a supplemental "TRUCKS" plate underneath the truck tipping sign. Motorists in Maryland perceive the arrow (diagrammatic) on the typical diamond-shaped sign to be "going the wrong way."

A ramp improvement in Los Angeles and another near Pittsburgh resulted in a noticeable reduction in truck accidents. The Los Angeles ramp serves as a connector for Route 91 eastbound traffic desiring to go northbound on I-605. A comparison of only the accident types expected to be reduced by the countermeasure revealed that the number of accidents during the after period is approximately half of what it was during the before period. Most of the accidents in both time periods included overturned trucks. At the I-79/I-70 ramp in Pennsylvania, evaluations of accidents included only truck-involved types expected to be reduced by the countermeasures implemented. Eleven of the 17 large truck accidents during the before period involved an overturned truck. Two to six truck accidents

## Section 5.0 Ramp Treatments

occurred during each year of the before period from 1980 through 1983, whereas, the after period of 1987 through 1990 revealed no accidents at all involving trucks. Common features of both ramp treatments are the use of oversized signs and flashing lights. No active devices are used on either ramp. The Pennsylvania ramp uses rumble strips and a tall barrier, but the Los Angeles ramp does not.

Active devices which use passive signs with flashing lights fastened to them are used on ramps to inform truck drivers that their speeds are excessive for conditions. These devices are either used or being tested in Georgia, Michigan, and Maryland. In Atlanta, these devices do not discriminate between cars and trucks, and they tend to flash continuously. This feature is thought to reduce the effectiveness of the devices, however, no studies have been done to verify this observation. A study is currently underway to determine the effectiveness of active devices in reducing truck speeds. No results are currently available.

Georgia DOT officials observed the following pattern of effectiveness for their active devices using wig-wags. When first installed, speeds of most vehicles are reduced. After an initial familiarization period (the "novelty" effect), motorists become accustomed to their presence, and with their own perceived safe speed on the roadway, their speeds once again increase. The time period for commuters is less than for unfamiliar motorists, but within a month or so familiarity tends to reduce the active device's effectiveness.

Minor reconstruction of ramps has been used by agencies in Michigan, Georgia, Maryland, New Jersey, and Pennsylvania in an attempt to reduce truck accidents. Because other actions preceded or accompanied the reconstruction, effectiveness is subject to interpretation. Reconstruction is typically preceded by installation of warning devices, usually static signs. An example of reconstructing a ramp to reduce truck accidents occurred on I-75 in Detroit. The improvement removed the differing cross-slope rates and formed a constant superelevation rate over the full width of the ramp to the outside barrier. Ramp improvements also included signs and construction of a tall barrier. On the I-75/I-285 ramp in Atlanta, Georgia which was reconstructed, accident reports did not verify local perceptions that truck rollover accidents had been significantly reduced. Reconstruction has also been used on ramps in Maryland, New Jersey, and Pennsylvania. In these States, the outside shoulder cross-slope on the ramp was raised to create constant superelevation across the shoulder and the mainlane. No accident histories are available for evaluation.

### 6.0 TRUCK DIVERSIONS OR BANS

## INTRODUCTION

Regulatory bans have been used near Cincinnati and Atlanta, and in Los Angeles, San Francisco and San Diego. Voluntary bans have been used in Minneapolis/St. Paul, Los Angeles, and in the Washington, D.C. area. Los Angeles is currently recommending a restriction on trucks that would force deliveries to be made during nighttime hours.

## LITERATURE SOURCES

A fiery truck accident on the I-71/75 segment in Covington, Kentucky (south of Cincinnati), locally known as "cut-in-the-hill," resulted in the imposition of a truck diversion order by the Kentucky Governor on July 8, 1986. Trucks were diverted from northbound I$71 / 75$ to I-275, a freeway bypass around Cincinnati. A study conducted by the Ohio-Kentucky-Indiana (OKI) Regional Council of Governments examined two specific aspects of the diversion order: the impact of the diversion on traffic volumes and the impact on truck accidents for the regional Interstate system. ${ }^{17}$ Prior to the diversion, trucks volumes were evenly split by direction on most segments of the Interstate system. On the cut-in-the-hill however, southbound truck volumes were noticeably heavier than northbound volumes. The mandatory diversion has made this imbalance even more pronounced. Contrary to a common perception, trucks were not overly involved in accidents on the cut-in-the-hill segment nor on the regional Interstate system. Prior to the diversion, the annual accidents involving trucks followed a pattern similar to total accidents. The diversion order was expected to shift accidents from the interior Interstate highways to I-275 with no net change in accidents for the entire region. For the cut-in-the-hill accidents, however, the diversion was expected to reduce truck involved accidents by approximately 9 percent.

In 1988, the California legislature commissioned a study to investigate the impact of large trucks on peak-period freeway congestion. Cambridge Systematics, Inc. found the volume of large trucks on freeways does not have an inordinate impact on peak period congestion, but truck-involved accidents and incidents do have a significant impact on freeway congestion and delay. ${ }^{(19)}$ The authors analyzed various freeway and truck management strategies including peak-period truck bans. They concluded that while peak-period truck bans would temporarily reduce congestion on core freeways, congestion would increase on parallel arterial routes.

Route 163 south of Interstate 8 through Balboa Park in San Diego, considered one of the most beautiful sections of urban freeway in the country, is the site of a truck ban. ${ }^{(18)}$ The merging of traffic from five lanes to two lanes, a six percent grade, and a lack of acceleration and deceleration lanes for interchanges contribute to heavy congestion on the freeway. Public opinion prohibits construction of additional lanes because of the extensive landscaping and scenic location of the section. In an effort to manage congestion on the freeway, San Diego restricted trucks from Route 163 through Balboa Park.

## FIELD SOURCES

Atlanta, Georgia

In December 1978, GA DOT exercised their right to restrict trucks by enacting an order that required through trucks approaching Atlanta to use I-285 (a circumferential freeway) instead of using the freeways within the I-285 loop. Signs were placed on the freeways approaching I-285 to inform truck drivers of the ban. In a December 1986 forum made up of law enforcement, engineering, and policy-making personnel, several potential solutions were identified, including installing additional overhead signs to inform truck drivers of the ban.

At the outset of this ban (December 1978), GA DOT tried to control the use of interior freeways by issuing a decal to truck drivers who qualified. Based on the number of requests received from all over the country, officials realized that issuing decals would be an overwhelming task, so it was discontinued. Because of the intense labor needs and lack of space available for inspecting a truck's bill of lading, enforcement personnel typically do not check a truck's destination unless the truck is involved in an accident. Truck drivers in violation of the truck ban are then cited.

In the 2-week period following the forum, GA DOT increased signing for trucks around the Atlanta area. On Interstate routes just prior to their junction with I-285, six additional $2.1-\mathrm{m}$ by $2.4-\mathrm{m}$ ( 7 -ft by 8 - ft ) overhead signs with the message "ALL THRU TRUCKS OVER 6 WHEELS MUST USE I-285" were installed. Their cost was $\$ 500$ each, excluding labor and equipment.

No attempt has been made by GA DOT to quantify the benefits of the truck ban countermeasure or to assign cost savings to it, however, they did estimate that combination truck travel on interior freeways was reduced from 6 to 2 percent, or approximately 6,000 trucks per day. No detailed accident information exists for the period before December 1978 when this ban was initiated. For the after period of 1984 through 1989, too many unknown factors could have affected accidents to draw definitive conclusions.

To evaluate truck driver compliance with this ban, a study was performed by GA DOT on March 25, 1980. The study involved a 24 -hour count period, and established count stations at each interchange with I-285. In this 24 -hour period, a total of 18,996 trucks approached Atlanta on the major freeways. Of this total, 14,555 ( 76.7 percent) exited onto I-285 leaving 4,411 ( 23.3 percent) trucks remaining on the approach freeway toward downtown Atlanta. Twelve observation vehicles followed random samples of trucks that continued past I-285 and onto interior freeways to determine if they continued through Atlanta without stopping to load or unload. Study personnel followed a total of 650 trucks in the 24 -hour period. Results showed that 5.4 percent of those followed passed through Atlanta, violating the truck ban. Approximately the same number of violations occurred at night as in the daytime. Georgia DOT officials suspect that the compliance rate is lower now, due to the lack of support by local law enforcement.

## California

Los Angeles. The increasing length of the peak periods on urban freeways in Los Angeles has caused policy-makers to seek solutions from several possible sources. For example, I-405 (the San Diego freeway) is typically congested on weekdays from 5:00 am until $8: 00 \mathrm{pm}$ Two examples of freeways in the city of Los Angeles that completely ban trucks are the Ventura Freeway and the Pasadena Freeway. Opened in 1940, the Ventura Freeway is one of the first freeways to be constructed. Engineers believe that its $177.8-\mathrm{mm}$ (7-in) thick pavement is too weak to carry trucks, although they allow buses on it. One reason the bans work is because alternative freeways are available to truck drivers.

There is also a truck avoidance policy in place for the Harbor Freeway (I-710) in Los Angeles during major reconstruction. It is a voluntary ban, not regulatory. CALTRANS reports that the reduction in trucks is negligible. Los Angeles also recently instituted a truck ban ordinance in the Wilmington (harbor) area that reduced the route options available to truck drivers.

Currently, another type of ban--a time-of-day restriction-is being considered by Los Angeles. In 1990, the city was prevented from restricting trucks from all freeways during peak periods, but it is currently proposing to restrict trucks from arterial streets, except in special cases, requiring that deliveries be made at night. Most businesses along these arteries and truck drivers operating on these streets believe that they will be hurt economically by this restriction. Other problems perceived with night deliveries include security and safety. Truck drivers maintain that they already avoid peak periods voluntarily as much as possible because the economics of being delayed by congested traffic causes them to be less competitive. Some officials have indicated there is still a possibility the ban will occur through provisions of the Clean Air Act. In the Urban Freeway Gridlock Study, Cambridge Systematics et al. predicted the effects of a traffic ban. ${ }^{(19)}$

San Francisco. In the Oakland area, McArthur Freeway or I-580, built in the 1960's, has a ban on all trucks over 4086 kg ( 4.5 tons) for several miles of its length. According to several CALTRANS sources, this was a political decision. All trucks are diverted to the Nimitz Freeway, now I-880, which is a six- and eight-lane freeway.

## Minneapolis/St. Paul

In Minneapolis/St. Paul, traffic signs encourage truck traffic to divert to the bypass rather than travel straight through the central business district area on more congested freeways. This action utilized voluntary compliance and was not a regulatory ban. Although the effects of this countermeasure have not been studied, local officials believe that the diversion has not been substantial.

## SYNTHESIS OF RESULTS

According to transportation engineers who work closely with truck diversions, accidents typically shift in equal proportions to the number of trucks which are diverted, with other factors being equal. Two diversions intended to shift through truck traffic to the circumferential freeway occurred in Cincinnati, Ohio and Atlanta, Georgia. For the location near Cincinnati, Ohio, the diversion order was expected to shift trucks from the interior Interstate highways to I-275 with no net change in accidents for the entire region. For the cut-in-the-hill segment, however, the diversion was expected to reduce truck involved accidents by approximately 9 percent.

No attempt has been made by GA DOT to quantify the benefits of the truck ban countermeasure or to assign cost savings to it, however, they did estimate that combination truck travel on interior freeways was reduced from 6 to 2 percent, or approximately 6,000 trucks per day. No detailed accident information exists for the period before December 1978 when this ban was initiated. Results of a limited study showed that only 5.4 percent of trucks violated the truck ban.

Two examples of freeways in Los Angeles that ban trucks due to insufficient design for heavy trucks are the Ventura Freeway and the Pasadena Freeway. Another truck ban is on the McArthur Freeway (I-580) in Oakland, California (where trucks are regional) to the Nimitz Freeway (I-880). These bans appear to have been based on political decisions.

In 1990, Los Angeles was prevented from restricting trucks from all freeways during peak periods. A recent study by Cambridge Systematics concluded that while peak-period truck bans on freeways would temporarily reduce congestion on core freeways, congestion would increase on parallel arterial routes. ${ }^{(19)}$ The city is now proposing to institute a peak period ban on arterials. This would force many businesses to receive shipments at night, which is perceived as an additional economic burden in addition to safety and security concerns.

Voluntary peak period truck bans are being promoted in several cities including Los Angeles, Minneapolis/St. Paul, and Washington, D.C. suburbs in Maryland. In the Los Angeles case, a voluntary truck avoidance policy is in effect because of major reconstruction of the Harbor Freeway (I-710). In the twin cities, the diversion is intended to remove trucks from the interior freeways in lieu of the circumferential freeway. Transportation officials in these locations all agree there is little or no obvious results from these voluntary bans. Truck drivers typically avoid peak periods as much as possible anyway due to a reduction in mobility during those periods.

### 7.0 REDUCTION OF SHOULDER PARKING

## INTRODUCTION

Another strategy for reducing truck accidents is reducing nonemergency shoulder parking. Highway shoulders are intended for use by motorists in emergency situations. Negligent and nonemergency parking of both trucks and other vehicles can contribute to accidents. This strategy assumes that if shoulders are used by motorists for emergency stopping only, a reduction in certain types of accidents could result.

## LITERATURE SOURCES

Agent and Pigman found that although the number of all accidents on limited access highways involving vehicles on shoulders was small ( 1.8 percent), the number of fatal accidents involving a vehicle on the shoulder was significant (11.1 percent). ${ }^{(21)}$ Tractor trailers were over- represented in shoulder accidents when compared to their involvement in all accidents. Twenty-five percent of vehicles involved in shoulder accidents were tractor trailers, with an even higher involvement during nighttime hours. An observational survey of shoulder vehicles indicated that a driver typically passes a vehicle stopped on the shoulder (in the direction of travel) every 8 miles. The percentage of tractor trailers observed in the survey was similar to the percentage involved in shoulder accidents.

A study conducted by the Bureau of Motor Carrier Safety and the FHWA involved commercial and noncommercial vehicles parked on the shoulders of highways. ${ }^{(22)}$ The majority of these accidents occurred on Interstate highways, with driver fatigue being the primary cause of the accident. Ninety percent of the accidents were rear-end collisions. Safety recommendations that resulted from the study included: contrasting pavement textures for shoulders that will produce a "rumble effect" to alert fatigued drivers, signs and information that encourage motorists to proceed to rest facilities in nonemergency situations, and pedestrian advisory information.

Because 10 fatalities occurred over a 5 -year period from vehicles parked on shoulders, the city of Columbus, Ohio has become more strict regarding the time period allowed for any vehicle to be parked on the right hand shoulder of a freeway. Effective in November 1989, the time period that a vehicle could remain on a shoulder, away from an interchange, was reduced from 12 hours to 3 hours. (Near an interchange or at specified "hazardous" locations, a vehicle is cited and towed immediately.) Under the current ordinance, a vehicle driver will be given a citation and towed at the owner's expense if the vehicle remains longer than the 3 -hour limit. The 3 -hour grace period is thought to be sufficient time for the driver to secure assistance and have the vehicle moved.

The MSHA analyzed parked vehicle shoulder accidents on all major routes. ${ }^{(23)}$ They found that of the 746 parked vehicle shoulder accidents on Interstate routes, 31 (or 4 percent) were fatal accidents, and of the 11,082 parked vehicle shoulder accidents on all other routes, 30 (or 0.3 percent) were fatal accidents. They also found that conditions involving parked
vehicle shoulder accidents are considerably different from statewide vehicle accidents. Some of the differences included:

- 0.8 percent of statewide accidents were fatal, compared to 4 percent of the parked vehicle shoulder accidents.
- 49 percent of statewide accidents involved injury, compared to 54 percent of the parked vehicle shoulder accidents.
- 34 percent of the statewide accidents occurred at night, compared to 54 percent of the parked vehicle shoulder accidents.
- 24 percent of the statewide accidents occurred when the pavement was wet, compared to 19 percent of parked vehicle shoulder accidents.
- 11 percent of statewide accidents involved alcohol, compared to 21 percent of parked vehicle shoulder accidents.

The analysis of accident data also showed that parked vehicle shoulder accidents were most likely to occur on Saturday (19 percent of the total), and between the hours of 12:00 am and 6:00 am ( 40 percent of the total). The number of these accidents that involved trucks parked on shoulders is not known.

## FIELD SOURCES

## Maryland

Representatives at MSHA stated that the issue of providing adequate rest area parking is very important. Currently, there is a shortage in parking at private truck stops. In the Laurel, Maryland area (northeast of Washington D.C., near Baltimore), shoulder parking has been a significant problem due to trucks. These trucks are probably waiting for the port at Baltimore to open. During a MSHA survey conducted at night, 50 to 60 tractor-trailers were parked along this particular length of freeway. Because of the high numbers of trucks parking on shoulders and the underutilization of park-and-ride lots during nighttime hours, Maryland began allowing trucks to use park-and-ride facilities as an alternative to parking on the shoulders.

The MSHA conducted a simple survey to determine truck usage of park-and-ride lots. In general, MSHA believes that truck drivers do not use the lots because of low enforcement of shoulder parking and because truck drivers are not informed regarding the availability of these lots. Officials at MSHA agreed with truck drivers that they need to improve the techniques used to provide this information. Signs provide information on when restrictions are imposed and not when the lots are open to trucks. The message used on these regulatory signs within parking areas is "NO TRUCKS 6 AM TO 10 PM."

## Michigan

Michigan DOT, State police, and the trucking industry are working together to reduce illegal truck parking on the shoulders of State highways. In the 4-year period from 1984 through 1988, 55 combination vehicles were hit by other vehicles while parked on freeway shoulders in Michigan. Much of the illegal parking is occurring in the vicinity of rest areas. The Michigan DOT district responsible for $200 \mathrm{~km}(124 \mathrm{mi})$ of I-94, the major east-west truck corridor between Detroit and Chicago, discovered that 28 of the total 55 shoulder accidents had occurred in their district. These accidents included one fatality and 12 injuries.

In January 1990, a task force was organized to address the problem of trucks parking on freeway shoulders and ramps, and parking too long at Michigan DOT Rest Areas. This task force consisted of representatives of the Michigan Truck Stop Owners Association, Michigan State Police (Motor Carrier Division), the Michigan Trucking Association, the FHWA, and various Michigan DOT personnel. Efforts of the task force led to additional enforcement of shoulder parking restrictions and a survey of all rest areas and other truck parking locations along the I-94 corridor.

Based on the survey results, the following recommendations were made: 1) stricter enforcement of shoulder parking restrictions, 2) limit the length of stay in freeway rest areas, and 3) Michigan DOT should provide information on appropriate overnight truck parking facilities at the rest areas and through press releases. ${ }^{(24)}$

## SYNTHESIS OF RESULTS

State and local jurisdictions are being faced with a growing problem with the number of commercial vehicles parked on freeway shoulders and ramps in nonemergency situations. Some agencies are becoming more restrictive in the amount of time trucks can park in rest areas and providing information signs regarding the locations of additional parking. In Columbus, Ohio, the city discovered that 10 fatalities had occurred over a 5 -year period from vehicles parked on shoulders. In November 1989, the time period that a vehicle could remain on the shoulder, away from an interchange, was reduced from 12 hours to 3 hours. (Near an interchange or at specified "hazardous" locations, a vehicle is cited and towed immediately.) In a recent study of the parking problem along I-94 in Michigan, recommendations included limiting the length of stay in freeway rest areas and providing information on appropriate overnight truck parking facilities.

### 8.0 URBAN TRUCK INSPECTION STATIONS

## INTRODUCTION

Another countermeasure that has been used as a strategy for reducing truck accidents is increased commercial vehicle roadside safety inspections, including the construction of urban inspection stations. Inspections of the operational and mechanical status of the truck and the driver may reduce accidents which are caused by mechanical problems or operatorrelated problems such as fatigue.

## LITERATURE SOURCES

No information was found in the literature which addressed implementation issues of urban truck inspection stations.

## FIELD SOURCES

## Capital Beltway

Three inspection stations are located near the Capital Beltway: at the I-95/I-495 interchange in Maryland, at the Route 210/I-95 interchange in Maryland, and the Van Dorn Street inspection facility in Virginia.

Maryland. Originally, I-95 was designed to go directly through the District of Columbia. This plan was abandoned, however, leaving some of the right-of-way and paved areas within the I-95/I-495 interchange north of downtown underutilized. A park-and-ride lot was developed for commuters in this area, but only a small percentage of its capacity was being used. As part of a more aggressive campaign to reduce truck accidents on the Capital Beltway, MSHA began using a portion of this paved lot for truck inspections, and occasionally for weight enforcement. Officials from MSHA stated that due to an increase in truck incidents on the Beltway, safety measures were implemented at the I-95/I-495 location beginning in 1988. In the past, Maryland used construction funds to build new inspection facilities and maintenance funds if minor maintenance of the facilities was needed, although major maintenance projects required construction monies.

Because of difficulties in building additional inspection stations, some agencies are adding personnel to existing sites. For example, Maryland's truck inspection forces have increased dramatically in the past several years with the recently increased emphasis on truck inspections. Several agencies are involved, including local and state police. Local police have sites where they can stop trucks and move them out of the traffic stream. Their focus is on intra-city delivery trucks, because over-the-road trucks are typically inspected elsewhere.

Along with the I-95/I-495 inspection station, another inspection location is at the interchange of the beltway with Maryland Route 210. Both locations require an officer to

## Section 8.0 Urban Truck Inspection Stations

pull the truck over and escort it into the station, which means that only a fairly small sample can be inspected.

Maryland maintains an inspection data base. They currently inspect 55,000 vehicles annually and expect this number to increase. They also have conducted special operations in Baltimore at tunnels and bridges. For full inspection of the vehicle and driver (MCSAP Level 1), they are now taking 42 percent of vehicles inspected out of service. This percentage has decreased from approximately 3 years ago when they were finding 53 percent which had defects serious enough to take them out of service.

Virginia. An inspection facility was built by VaDOT at the Van Dorn Street interchange on the Capital Beltway. Highway construction monies were used to build the facility, however, maintenance of the site comes from the maintenance budget. The total construction cost of the Van Dorn Inspection Station in 1987 was $\$ 962,000$. The State reduced its cost by utilizing an existing highway facility where right-of-way already existed and a portion of an existing ramp could be used. Another inspection facility is being considered for the Capital Beltway. Traffic volumes are very high near this location at over 200,000 vehicles per day, but the total current cost would be $\$ 3.5$ million, not counting sound walls which are now required. The State DOT admits that it just does not have the resources to construct this inspection station. The motoring public is very supportive of this countermeasure, because they feel safer if large vehicles are required to pass a safety inspection. As elsewhere, they are supportive as long as the inspection station is not near their homes.

Another measure of effectiveness of this program is in the number of vehicles taken out of service due to mechanical defects. During the 1990 calendar year, Virginia State Police inspected 3,400 trucks and took 1,400 or 40 percent of them out of service. Subjective comments regarding this measure of effectiveness were inconsistent. Some of the VaDOT personnel contend that because the percentage taken out of service used to be 60 percent and is now 40 percent, the situation must be improving. One pertinent factor to consider is the selection of vehicles to be inspected at the Van Dorn Street site is not random. For example, they do not inspect carriers with known effective safety programs because their resources are better spent elsewhere. Virginia State Police usually stop vehicles based on "probable cause." If they do not observe trucks with suspected or obvious violations, they stop vehicles at random (e.g. stop the tenth truck to pass their location). Because not all apprehensions are random, the percent taken out of service cannot be applied to the entire truck population. The out-of-service proportion would probably be somewhat less for all trucks.

Virginia sources made statements similar to personnel from other States regarding the unpopular aspects of constructing new inspection stations in urban areas. They predict that increases in their inspection program will be in the number of officers rather than the number of inspection stations. Virginia has less than 30 troopers statewide specifically assigned to Motor Carrier Enforcement, according to VA DOT personnel. Virginia uses Motor Carrier Safety Assistance Program (MCSAP) funds as seed money, but it is limited.

## Los Angeles, California

An urban inspection station was constructed by CALTRANS on I-405 (the San Diego Freeway) in the city of Carson. The California Highway Patrol (CHP) operates this facility and many other inspection facilities throughout the State. CALTRANS installed permanent scales on both sides of the freeway, but more space to perform inspections exists on the northbound side than on the southbound side. Improvements installed specifically for inspections included asphalt paving and striping; no buildings were constructed for inspections at this location. According to CALTRANS and CHP officials, recent construction costs for inspection stations which include large buildings with pits, office space, and bays sufficient for parking large combination vehicles is in the range of $\$ 8$ to $\$ 14$ million.

The operation at the I-405 station allows CHP troopers to first observe the vehicle in either of two lanes passing the CHP building (see figure 7). The outside lane is specified for unloaded trucks to drive slowly past the trooper building for observation, while the inside lane is equipped with scales for weighing loaded trucks. Troopers can select vehicles for inspection from either lane they choose. Neither lane uses weigh-in-motion (WIM) devices, however some sites use WIM for screening purposes to verify whether a truck is loaded or unloaded. The number of vehicles inspected in both directions in 1990 was 5,200 , and the proportion taken out of service was 27 percent. By comparison, the CHP inspected over 18,000 trucks in one direction of travel at a scale inspection facility on I-680.

The method officers used at I-405 to select trucks for inspection was to choose the "locals" because the Interstate traffic is inspected elsewhere. The officers look for obvious violations as the trucks pass in front of them either being weighed (loaded) or passing through the unloaded lane. Therefore, the number of trucks taken out of service is not necessarily representative of the entire truck population. The percentages for all trucks are probably lower than those noted above.

The inspection station on I-405 and others in California were constructed by CALTRANS. The money is from the same fund that is available for highway construction projects. Funding for maintaining inspection stations is from the highway maintenance fund. The cost of these urban inspection stations is highly variable, but one currently under construction (not in Los Angeles) is expected to cost $\$ 14$ million.

Some CALTRANS sources do not believe that the relatively large investment required to build inspection/weigh facilities in urban areas is worthwhile. They cite the large construction cost, plus the opportunities for bypassing the enforcement activity on numerous alternate routes. Historically, only 1 percent of vehicles weighed at these locations are overweight, while 20 percent of vehicles monitored using weigh-in-motion systems appear to violate weight laws.

## South Bound Truck Scale



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Figure 7. I-405 weigh/inspection facility.

Mobile Road Enforcement (MRE) officers use pickup trucks to inspect trucks at various locations, not necessarily at weigh/inspection stations. They might use widened shoulder locations if available. Locations are generally on non-freeway facilities, although there is one on I-40 that is an exception.

## SYNTHESIS OF RESULTS

Inspection of the mechanical condition of the truck and the operational status of the driver may reduce accidents which are caused by mechanical problems or operator-related problems such as fatigue. States included in this study which use urban inspection stations as a countermeasure to reduce truck accidents are Virginia, Maryland, and California.

Three inspection stations are located near the Capital Beltway: at the I-95/I-495 interchange in Maryland, at the Route 210/I-95 interchange in Maryland, and the Van Dorn Street inspection facility in Virginia. A portion of a Maryland park-and-ride lot, which was underutilized, has become a truck inspection station, and is occasionally used for weight enforcement. This location and a similar location at Maryland Route 210 require an officer to pull the truck over and escort it into the station, reduces the number of trucks that can be inspected. Maryland currently inspects 55,000 vehicles annually statewide, and they expect this number to increase. They are currently (1991) taking 42 percent of vehicles inspected out of service; this represents a decrease from 53 percent approximately 3 years ago (1988).

An inspection facility with a total construction cost of $\$ 962,000$ in 1987, was built by VA DOT at the Van Dorn Street interchange on the Capital Beltway. Another inspection facility is being considered for the Capital Beltway, but the total current cost would be $\$ 3.5$ million, not counting sound walls which are now required. Transportation officials in both Maryland and Virginia emphasized the difficulty in building new urban inspection stations. Other motorists wish to have trucks inspected, but proposals to build new urban stations almost always brings heavy opposition from local property owners. Future increases in inspection programs might be limited to increased personnel at existing sites.

An urban inspection station constructed by the CALTRANS on I-405 (the San Diego Freeway) in the city of Carson is operated by the California Highway Patrol. The current average cost of urban inspection stations in California is approximately $\$ 8$ million. Some CALTRANS sources do not believe this is a good investment in an urban environment due to the numerous bypass opportunities.

### 9.0 INCIDENT RESPONSE MANAGEMENT

## INTRODUCTION

Major truck incidents, including vehicular collisions, overturned trucks, spilled loads, and fires, which result in congestion and delay, have been portrayed in the media as contributing disproportionately to accidents and congestion on urban freeways. While incidents are a major source of congestion, they can be minimized by efficient clearing and diversion of traffic before motorists encounter the incident queue. Increasingly, incident management is used to minimize the effects of truck and automobile incidents on traffic flow.

Incident response programs are used in many urban areas throughout the Nation. Reduction of secondary accidents is a key safety objective in these programs. For the purpose of this study, contractual or other arrangements have been emphasized as a response for quickly dispatching tow trucks or even cranes to the accident site.

## LITERATURE SOURCES

Several studies have examined the effects of truck incidents on congestion and on using incident management concepts to minimize these effects. Teal in a study of Los Angeles County freeways, found that trucks appear to cause a disproportionate share of nonrecurrent congestion, and that the impact of truck incidents is disproportionately concentrated in peak periods. ${ }^{(25)}$ Reilly and Haven concluded that incident response teams, when properly equipped and trained, can have a dramatic positive impact on the consequences of truck incidents on California freeways. ${ }^{(26)}$

In a 1988 study for the California State Legislature, Cambridge Systematics, Inc. found that if an incident management program could feasibly reduce congestion and delay from truck-involved accidents and incidents, then it should be implemented in conjunction with a traffic management program. ${ }^{(19)}$ The program would involve providing traffic information to motorists, regulating speeds, enforcing safe truck operations, the addition of continuous-merge lanes at critical interchanges, and redesigning high-accident ramps.

An incident management study prepared by Cambridge Systematics, Inc. in 1990 for the ATA Trucking Research Institute found that the lack of a clear mandate is a major obstacle to developing effective incident management programs. ${ }^{(27)}$ Incidents are a special concern for trucking companies because of their direct impact on productivity, profitability, and public relations. Existing programs have often been ad hoc responses to major crises with responsibility for incident management distributed among various state and local agencies. Yet, case studies of programs in Chicago, Los Angeles, Fort Worth, Minneapolis, and New York/New Jersey, revealed that incident management is actually cost-effective, and effective models are available for developing and implementing comprehensive incident management programs.

The incident response strategies used in Seattle have reduced response and clearance time when freeway blockages occur. A study conducted at the University of Washington in the late 1980's praised the quickness of the incident response time in Seattle. ${ }^{(28)}$ An average of 10 minutes transpires between an accident occurrence and a State trooper arriving on the scene. The authors state that while the short amount of time is impressive, the time factor is still very costly in terms of lost vehicle-hours. The authors provide recommendations for future incident management strategies in three broadly classified areas: 1) education and awareness, 2) resource and personnel allocations and 3) detection and reporting. The report also includes detailed discussions on two recent incident management strategies used in the Seattle area: incident response storage sites and accident investigation sites. (Specific consideration on heavy truck accidents was not included in the study.) According to WSDOT sources, the average freeway clearance time for large trucks is now 1.5 hours, compared to 5 to 7 hours without the incident response team.

## FIELD SOURCES

## Capital Beltway

Maryland. Maryland has incident management teams for all Interstate highways. Each of the 23 counties has a Resident Maintenance Engineer (RME) who is responsible for the incident management plan. This individual is responsible for alternate route plans, signs, and other emergency equipment. Maryland also has a State Police Liaison Officer who is responsible for incident management. The State has a program called "CHART" which will eventually be capable of monitoring freeways through surveillance, communication, and control hardware. A project that combines video imaging, variable message signs, and Highway Advisory Radio (HAR) is underway.

The MSHA has taken an aggressive posture regarding clearing a roadway, except when hazardous materials or pending injuries are involved. Also, MSHA developed a Maintenance Policy (71.01-05.1--Revised, April 1990) that calls for the prompt reopening of the roadway to traffic. The policy states that "the RME in cooperation with the police officer in charge should reopen the roadway as soon as possible on an urgent basis." The policy also "recognizes that public safety is the highest priority and must be secured, especially if injuries or hazardous materials are involved. It is understood that damage to vehicle or cargo may occur as a result of clearing the roadway on an urgent basis. While reasonable attempts to avoid such damage should be taken, the highest priority is public safety."

Maryland does not currently have special contracts with cranes or large tow trucks. The State police maintain a list of available cranes and locations, and also use a rotation list to determine who is next contacted. Maryland is currently evaluating several types of towing contracts. Reducing response time is one of the primary objectives in the evaluation of new contracts. Developing a system of zones and hiring more than one towing contractor within each zone are being considered. The first contractor to arrive at the scene would be the one who is awarded the job. Contract penalties are also being considered if the tow rig does not
arrive within a certain period of time. In addition to evaluating special contractual arrangements, Maryland is also considering purchasing a heavy-duty tow truck that would be available for truck incidents.

Virginia. Removal and clearance of the roadway following an incident is the responsibility of the State police. They use push bumpers to move smaller vehicles from the roadway. Like Maryland, Virginia has also been studying the availability of heavy-duty tow trucks in the Washington D.C. area; they concluded that the private sector should provide the equipment. They maintain a list of private tow truck operators who are contacted on a rotational basis. Virginia has also initiated service patrols so that minor mechanical problems can be corrected.

The Virginia State Police also operate courtesy patrols that respond to minor incidents. A proposed action to facilitate quicker response time to incidents would include as part of a major construction contract the presence of wreckers to respond to incidents. Also being investigated is whether the road can legally be cleared immediately of spilled loads in order to quickly reopen it, even if this action further damages the load. At present, the normal procedure is to wait for law enforcement to arrive on the scene.

## Chicago, Illinois

In September 1961, a quick response unit was initiated to respond to traffic problems, and a parallel effort began to attempt to monitor freeway traffic conditions. The use of service patrols began by obtaining any available vehicles such as old patrol squad cars and pick-up trucks with push bumpers. This group was soon given the name "Minutemen" because of their quick response. The Emergency Traffic Patrol currently has 58 Minutemen that are on duty 24 hours a day, 7 days a week. The Minutemen, with their 35 Emergency Patrol Vehicles (EPV's), are trained to administer first aid, put out a small car fire, and carry out other actions to mitigate incidents. Towing is provided, but only to relocate vehicles to the nearest safe refuge off the freeway. Minutemen also provide assistance when motorists experience minor mechanical problems or when they run out of fuel or need coolant.

Elements of freeway surveillance, communication, and control, which are currently in place on the Chicago freeways include: the Minutemen with their EPV's (see figures 8 and 9), the Traffic Systems Center, and the Communications Center. The Traffic Systems Center monitors input from an extensive pavement sensor system ( 1,800 inductive loops on 190 km ( 118 mi ) of freeway and 95 ramp metering stations), controls messages displayed on the 12 changeable message signs and controls messages broadcast by the Highway Advisory Radio (HAR). The Communications Center, located at the Illinois Department of Transportation (IDOT) district office, receives cellular phone messages from the highly successful *999 program. This program allows cellular car phone users to call in free of charge and describe freeway conditions they are experiencing. The *999 calls are received at a rate of 10,000 to 13,000 calls per month. According to IDOT, this program, in combination with


Figure 8. Emergency patrol vehicle.


Figure 9. Heavy-duty tow truck.
the Minuteman program, all but alleviates the need for surveillance and communication devices such as call boxes and closed circuit television (CCTV).

The emergency traffic patrol fleet includes 35 EPV's that are the backbone of the system. The EPV is equipped with a public address system and multi-frequency radio for direct communication with DOT and State police. The vehicle fleet also includes nine light 4 by 4 's, three heavy-duty tow trucks, one crash crane, one tractor-retriever, a sand spreader, and a heavy rescue and extrication truck. Among the traffic control devices the fleet uses at incident sites are four portable, changeable message signs. The IDOT fleet also includes four heavy-duty tow trucks purchased at different times for handling specialized incidents, such as overturned combination vehicles. The IDOT fleet also has two specialized units that include an Emergency Sand Truck, used for fuel and engine oil spills, and a converted 1971 Kaiser Jeep military 6 by 6 truck tractor, used to tow abandoned trailers or to lift and tow semitrailers that have uncoupled from the tractor.

IDOT personnel are emphatic in stressing that conscientious, well-trained personnel are as important to getting the job done as having the right equipment. A new person hired as a Minuteman works approximately 2 months in on-the-job training supplemented with classroom training. Personnel assigned to this unit receive special training in all phases of Freeway Incident Management and specific operational techniques. To complement these primary activities, they are trained in: advanced first aid, CPR, fire fighting, basic auto extrication, State and city police coordination, radio communications, work zone protection, traffic control, heavy equipment use, and heavy recovery procedures. Heavy recovery procedures cover tank truck emergencies, hazardous materials handling and using air cushions to right an overturned vehicle.

The annual budget of the Minuteman operation is approximately $\$ 3.5$ million dollars. The replacement cost for the EPV's are $\$ 31,000$ for the chassis and $\$ 9,000$ to change over the tow assembly. IDOT uses a rotating purchase scheme where all 35 of the units are replaced over a 4 -year period. The newer heavy-duty tow trucks purchased by IDOT cost approximately $\$ 250,000$ each. The Minuteman operation has never used any Federal funds.

DOT has produced an effective incident management program. An informal study by an IDOT Bureau Chief using analytical calculations to determine the effects of freeway incident and freeway management programs found a reduction in secondary accidents of 18 percent and a 60 percent reduction in congestion. IDOT representatives state consistently that the Minutemen are the best public relations tools they have, by providing approximately 100,000 expressway motorist assists each year. A study prepared for the American Trucking Association found that the program returns about $\$ 17$ in benefits for each $\$ 1$ invested in the program. ${ }^{(27)}$

While local private tow operators contend that Minutemen operations negatively affect their business, the Minuteman's main goal is to clear the roadway quickly, relocating an involved vehicle to a removal location less than $0.8 \mathrm{~km}(1 / 2 \mathrm{mi})$ away. The owner is then allowed to contact a private tow operator to move the disabled vehicle to a location for
repairs. The Minutemen do not operate over the entire freeway system in Chicago, and only respond to areas outside their $160-\mathrm{km}(100-\mathrm{mi})$ length of freeway if the situation is quite serious or if a public agency requests them to assist.

## Fort Worth, Texas

The Texas Department of Transportation (TxDOT) and local governments decided that due to congestion and anticipated reconstruction projects on the Fort Worth freeway system, the development and implementation of a freeway traffic management system in the Fort Worth area would enhance current operations. The Fort Worth District prepared a comprehensive freeway traffic management plan that included staged implementation coinciding with reconstruction projects for the local freeways. This management plan incorporated the use of surveillance components to constantly monitor operational conditions on the freeway, an interactive control network with options to correct freeway conditions, a city-state command post, and an area-wide communications network.

For several years, the Fort Worth district of TxDOT has maintained an aggressive posture in clearing the roadway following an incident. For truck incidents, a concern of the driver and the owner of the truck is salvaging the load. Timely clearance of traffic lanes, however, means salvaging the load is less important than reducing motorist delay and secondary accidents which tend to increase with increasing closure time. Historically, motorist delay costs plus costs of secondary accidents are significantly higher than any additional damage that might occur to the salvageable part of the load. Typically, the load is substantially damaged already and appropriate handling assures minimal additional damage. Once the damaged vehicle and its load are moved out of the traffic lanes, and preferably completely off the freeway, the truck driver will have time to inventory the load.

In 1991, Texas took a proactive stance regarding the removal of obstructions from roadways and rights-of-way, by passing Senate Bill 312. This bill authorized the TxDOT (then State Department of Highways and Public Transportation) to remove, without consent of the owner or carrier, spilled cargo and personal property from any portion of the State highway system or rights-of-way. It also relieved the Department from liability for any damage resulting from removal of the property unless the removal or disposal was carried out recklessly or in a grossly negligent manner. Furthermore, it required the property owner or carrier to reimburse the Department for the costs of removal and subsequent disposition of the property.

A pre-appointed TxDOT official is responsible at an incident site for communicating traffic control needs at the site with other TxDOT personnel, and with law enforcement representatives. If a crane is needed to retrieve an overturned combination vehicle, the TxDOT official typically has information on their locations. Sometimes a crane is available from a highway construction project nearby and the TxDOT representative can request its use from the contractor, with an informal agreement to reimburse the contractor for costs involved.

TxDOT representatives relate positive results of their incident management program which aggressively clears the roadway following an incident. According to TxDOT sources, they are recovering approximately 75 to 80 percent of the costs they incur from incidents. This includes damage to their infrastructure, such as guardrail damage. Secondary accidents happen if roads are closed for very long. The Courtesy Patrol, operating 7 days a week, 365 days a year, is the best public relations tool TxDOT has, according to TxDOT representatives who receive comments by mail from those who have received assistance. The few negative comments they recall pertain to not having the proper parts to make a repair, or in reducing the amount of gasoline from 7.6 L to $3.8 \mathrm{~L}(2 \mathrm{gal}$ to 1 gal$)$. The cost of this program, which comes from the maintenance budget, is approximately $\$ 500,000$ per year. TxDOT also has a sand truck loaded and ready to respond to oil spills; this reduces the cleanup time from 2 to 4 hours to less than 1 hour.

## Los Angeles, California

Incident response techniques being used in Los Angeles, covering several hundred miles of freeway, are operated jointly by CHP and CALTRANS. Systems include a traffic operations center, major incident response teams, electronic surveillance and detection, closed circuit television (CCTV) cameras, changeable message signs, HAR, and a network of commercial radio stations and other media. Incident response involving heavy trucks includes the CHP's use of special criteria and a rotation list of heavy-duty tow truck operators.

CALTRANS incident response teams respond only to major incidents. Major incidents are defined as two or more lanes blocked for a time period of 2 hours or more. On mainlanes, if the situation is determined to be major, CALTRANS dispatches a sign truck which travels to the upstream end of the traffic queue and displays information for approaching traffic. Their purpose is to reduce secondary accidents and provide information to motorists regarding the incident, including alternate routes.

The incident response team approach is credited with gathering key players at the scene of an incident in a short amount of time. CALTRANS officials estimate a delay savings of approximately 500 vehicle-hours for each major incident and a reduction of one secondary accident for every two incidents in which response teams are used.

CALTRANS has for some time used calculations to determine the delay associated with an incident where all or part of the freeway remains closed. Costs are associated with historical delay values which are based on "density factors." Observations of queue length are used as input for a computer program that calculates the cost of accumulated delay. Reduction in secondary accidents could also be included, but is not.

## New Jersey Turnpike

Thirty garages are under contract to the NJTA to respond to incidents along the turnpike. State police responding to an incident contact the nearest garage that has a contract
with the NJTA for providing this service. NJTA does not require the garages to provide heavy-duty tow trucks which might be necessary to right an overturned combination vehicle, however, approximately 13 of the 30 garages have the capability of providing "heavy duty tow services."

Garages must meet several criteria to be eligible to contract with NJTA, including being equipped to handle a $36,000 \mathrm{~kg}(80,000 \mathrm{lb})$ tractor-trailer for a simple tow. The response of NJTA emergency crews varies when spilled loads block the freeway. The load is the responsibility of the driver, but if the driver is hurt the load then becomes the responsibility of State police.

## Pittsburgh, Pennsylvania

Heavy-duty tow trucks are stationed at major tunnels in the Pittsburgh area. The tunnel patrol at Fort Pitt consists of an on-call tow truck stationed at the southern end of the tunnel. PennDOT responds to an average of nine incidents per day in the tunnel. Most of these are simple situations, such as running out of fuel or flat tires that only require a quick tow to clear the traffic lane. The Fort Pitt tow truck is a heavy-duty diesel powered unit that can move large combination vehicles from within the tunnel, if the wheels are not locked. It is not powerful enough to right an overturned truck, however. The basic crew at the tunnel includes three persons. Two are stationed at the south end where the tow truck is parked and one at the north end. They are on 24 -hour call to respond to incidents, 7 days a week. With the high traffic demand that exists at the Fort Pitt Tunnel, it is important to clear the tunnel as quickly as possible following an incident. According to PennDOT records, the 1990 average daily traffic at the tunnel was 104,000 vpd. Each tunnel tube (direction) has only two lanes and no shoulders.

## Seattle, Washington

The Washington State Department of Transportation (WSDOT) operates an incident response system covering several freeways in the Seattle area. The system includes electronic surveillance and detection, an operations center and CCTV cameras. Variablemessage signs, highway advisory radios and commercial radio stations all provide information to the public on road conditions.

An incident response "van" uses a half-ton pickup chassis that supports an enclosed box for storing and transporting emergency gear to an incident site. It is a self-contained command center with communications equipment, flood lights, and specialized equipment for use in traffic control and mitigating the effects of a major incident. Some of the items stored in the van are: safety gear such as vests and hats, fire extinguisher, traffic cones, radios and other appropriate communications gear for control at the site, a high volume pump, large barrels for storing fuel pumped from truck fuel tanks, hazardous spill containment gear, a power blower to remove glass or other debris from travel lanes, and fuel tank sealant mastic. The pump is used for removing fuel from tanks of overturned trucks that might spill onto the roadway. The pump has a capacity of $416 \mathrm{~L}(110 \mathrm{gal})$ in 8 minutes.

The van is also specially equipped with exterior equipment. It has a wooden push bumper for removing small vehicles from travel lanes when they cannot move under their own power. It is equipped with four 1 million watt flood lights mounted on top of the van for incidents that occur during the hours of darkness. It also has an arrow board for traffic control.

Tampa, Florida

A Courtesy Bridge Patrol was initiated for the $5.3 \mathrm{~km}(3.3 \mathrm{mi})$ Howard Frankland Bridge on December 7, 1989 as a quick response to gubematorial pressures. The patrol operates during peak periods Monday through Friday. Typical hours are 7 a.m. to 10 a.m. and 4 p.m. to 7 p.m. Two heavy duty wreckers (SU class vehicle up to $22,700 \mathrm{~kg}$ ( 50,000 lb gross weight) operate on a 15 -minute sweep interval. The goal of the patrol is to clear an incident as quickly as possible.

Three formal systems are available to alert personnel to an incident on the structure: 1) roadside call boxes, 2) incident detectors, and 3) a 911 emergency number for cellular phone equipped vehicles. A fourth, informal system involves using a CB radio. A courtesy patrol operator stated that truckers are usually the first to report an incident on the bridge. Occasionally, the courtesy patrol vehicle will encounter a stalled vehicle on one of their sweeps before the CB radio reports it. The other systems are not used as frequently. The incident detectors on the bridge, used to sense stalled vehicles, consist primarily of loop detectors at approximately $0.4 \mathrm{~km}(1 / 4 \mathrm{mi})$ intervals. Input for the detection system is visually confirmed through eight television cameras placed along the bridge.

Another significant service provided by the courtesy patrol besides rendering aid to motorists is removing debris from the road. Examples of cleared debris include timber, power tools, camping and picnicking equipment, and sewage sludge. Small items are simply removed, while large loads, such as the sewage sludge, involve the courtesy patrol working with the Florida Department of Transportation (FL DOT) maintenance personnel to clean up the bridge.

The contract price for the Courtesy Patrol in 1991 was $\$ 141,440$ for a period of 12 months. No additional start-up or special equipment costs were involved. The benefits of this service are difficult to quantify, but public response to the courtesy patrols is very positive. It is believed to be one of the most effective public relations elements of the Tampa District's operations. To a large degree, this is the result of all the courtesy patrol services being free of charge.

The FL DOT operating personnel indicated that the only deficiency in the system is the short duration of operation. A significant number of incidents occur during the $10 \mathrm{a} . \mathrm{m}$. to 4 p.m. time period. Otherwise, FL DOT personnel are very pleased with the patrol.

## SYNTHESIS OF RESULTS

There are two primary issues involved in incident response management for large trucks. These are 1) providing a heavy-duty tow truck in a timely manner, and 2) clearing the roadway immediately of vehicles and/or spilled loads.

Heavy duty tow trucks are available from two sources - a few public agencies own tow trucks, but more commonly a responsible official at the incident scene (usually State police) requests privately owned tow trucks. The incident official typically selects a privately owned tow truck by selecting the next in line from a rotation list, usually broken down by zone within the urban area. Only a few public agencies have purchased tow trucks for incident response; two locations included in this study are Chicago and Pittsburgh. For the Howard Frankland bridge in Tampa, a 12-month contract with a private firm provides a courtesy patrol. This uses two roving tow trucks which are larger than most courtesy patrol vehicles, but are still limited in their ability to retrieve heavy trucks. While 20 to 30 courtesy patrols throughout the country own tow vehicles, almost all of them are limited in their capacity to handle large combination trucks, particularly those involved in rollovers.

IDOT in Chicago uses 35 EPV's on a 24-hour a day roving basis to patrol 160 freeway centerline km ( 100 mi ) 7 days per week. The tow trucks used as EPV's are similar to those used in Pittsburgh and Tampa. An additional investment besides the fleet of 35 EPV's which makes the IDOT (Minuteman) program unique is in the purchase of heavy-duty tow trucks to supplement EPV's. All other agencies must acquire heavy-duty tow trucks from the private sector.

IDOT has produced an effective incident management program, and the Minuteman contribution is one which is cost effective, according to a recent study sponsored by the American Trucking Association. Results indicate that the program returns $\$ 17$ in benefits for each $\$ 1$ invested. ${ }^{(27)}$ An informal study by an IDOT Bureau Chief using analytical calculations to determine the effects of freeway incident and freeway management programs found a reduction in secondary accidents of 18 percent and a 60 percent reduction in congestion. VA DOT sponsored a study of response times required by private tow truck operators in Virginia and found that a 20 -minute response time is usually required.

IDOT officials are emphatic in stressing that conscientious, well-trained personnel are as important to getting the job done as having the right equipment. Two important factors stand out from information gathered from several agencies. One is the need to have mature, experienced personnel at incident sites involving large trucks and the other is diagnosing the site-specific needs and immediately providing the proper equipment. A lack of either of these factors will significantly increase motorist delay near the site and increase the cost to the truck owner (or the insurance company).

Two States contacted in this study have been very aggressive in clearing the roadway following an incident. Timely clearance of traffic lanes often means salvaging the load is less important than reducing motorist delay and secondary accidents. Both Maryland and

Texas act quickly to clear the roadway, except when hazardous materials or pending injuries are involved. MSHA developed a Maintenance Policy (71.01-05.1-Revised, April 1990) that calls for the prompt reopening of the roadway to traffic. The policy states that "the RME [Resident Maintenance Engineer] in cooperation with the police officer in charge should reopen the roadway as soon as possible on an urgent basis." The policy also "recognizes that public safety is the highest priority and must be secured, especially if injuries or hazardous materials are involved.

Senate Bill 312, passed in 1990 by the Texas legislature, authorized TxDOT (then State Department of Highways and Public Transportation) to remove, without consent of the owner or carrier, spilled cargo and personal property from any portion of the State highway system or rights-of-way. The bill also relieved TxDOT from liability for any damage resulting from removal of the property unless the removal or disposal was carried out recklessly or in a grossly negligent manner. It requires the property owner or carrier to reimburse TxDOT for the costs of removal and subsequent disposition of the property.

Courtesy patrols have been implemented around the country to patrol freeway tunnels and/or bridges, construction zones, or other freeway segments where a roving patrol can be advantageous. Most of these patrols use vehicles such as pickup trucks or light-to-mediumduty tow trucks which are not equipped to handle difficult retrievals often required when large trucks are involved. These patrols, however, are still useful at large truck incidents when an experienced patrol operator can quickly identify the proper equipment needed and make arrangements to get it in a timely manner.

A frequently heard comment from all courtesy patrol operations was that this is the best public relations possible for their agency. Almost all of these programs are provided free of charge to the motorist in need. One exception is when 3.8 L or 7.6 L ( 1 or 2 gal ) of fuel are provided for which an invoice is sometimes issued, payable to the State treasury. A universal complaint heard from private tow truck operators in the vicinity of publicly owned operations is that the public entity is reducing their volume of business. The agencies, however, clear the wreckage and move it only a short distance to get traffic moving. From that point, the owner or law enforcement contacts a private tow truck operator.

### 10.0 DIFFERENTIAL SPEED LIMIT

## INTRODUCTION

Speed limits on many rural Interstate highways are now set at $105 \mathrm{~km} / \mathrm{h}(65 \mathrm{mi} / \mathrm{h})$, however, in urban areas, the regulatory speed limits are $90 \mathrm{~km} / \mathrm{h}(55 \mathrm{mi} / \mathrm{h})$. Most urban areas do not currently use differential speed limits. Maryland has, in the past, tried differential speed limits but decided against their use.

## LITERATURE SOURCES

The University of Maryland evaluated the effectiveness and desirability of differential speed limits (DSL) on the Maryland Interstate System. ${ }^{(29)}$ Vehicular speed and accident data were collected at 84 study sites, encompassing a variety of geometric designs and locations with and without truck DSL's. The study concluded that: compliance by all vehicles with posted speed limits is poor; compliance by trucks is dependent on the geometric design of the road and the existence of a DSL; and that no consistent and reliable relationship could be found among speed parameters, and accident rates.

Garber and Gadiraju conducted a study assessing the nature and extent of the effects of DSL on vehicle speeds and accident characteristics. ${ }^{(30)}$ The study used speed and accident data collected at test and control sites operating under DSL and non-DSL conditions respectively in California, Maryland, Virginia, and West Virginia. The authors found that the imposition of a differential speed limit had no significant effect on mean speeds of trucks or in reducing the rate of accidents. Yet, there was evidence that differential speed limits increase the interaction among vehicles and that certain types of accidents such as rear-end and sideswipe accidents may have higher rates on Interstate highways with an AADT less than 50,000 when DSL's are used.

## FIELD SOURCES

No agencies were found in telephone interviews or in field visits that currently utilize differential speed limits in urban settings.

## SYNTHESIS OF RESULTS

Neither the Maryland study nor the Garber study indicated any improvement in operational and safety factors with implementation of differential speed limits.

### 11.0 INCREASED ENFORCEMENT

## INTRODUCTION

Increased enforcement for trucks can occur by hiring additional personnel or by diverting personnel from other enforcement activities to concentrate on commercial vehicles. A diversion of existing forces occurred in Atlanta, and new officers were added in California and to the NJTA. To fully evaluate diversion of officers, their effects in areas of reduced activity must be considered.

## LITERATURE SOURCES

California used increased enforcement for a 12 -month period from January to December, 1987 to evaluate its effect on truck accidents. Specially marked patrol vehicles (SMPV's) were used to patrol five freeway segments to primarily enforce heavy truck laws. The study found that increased enforcement using specially marked patrol vehicles was successful in reducing the number of truck-at-fault accidents. Changes in truck-involved and truck-at-fault accidents were evaluated by the CHP using 1986 as the before period. Total results for all five test sites indicate a 3.5-percent reduction in truck-at-fault accidents (statistically significant at the 90 percent confidence level), compared to a 5.8 percent increase on non-test site freeway beats within the CHP Areas participating in the program. Injury (including fatal) truck-at-fault accidents dropped by 11.2 percent, compared to a reduction of only 0.4 percent on all non-test site freeway beats within CHP areas participating in the program. CHP estimated benefits from the accident reductions for 1 year to be approximately $\$ 5$ million, whereas the cost of the program was $\$ 1,556,355 .{ }^{(31)}$ The CHP recommended retaining the SMPV's for use on any highway segment within the State that meets specified criteria related to truck accidents or noncompliance with highway safety laws.

In a 1984 study conducted by McCasland and Stokes in Texas, six general classes of truck regulations and restrictions were examined in terms of their impacts on urban freeway safety and traffic operations. ${ }^{(32)}$ These regulations and restrictions included: lane restrictions; time-of-day restrictions; speed restrictions; route restrictions; driver licensing and certification programs; and increased enforcement of existing regulations. The authors concluded that only reduced speed limits for all vehicles, improvement of driver licensing/training, and incident management techniques appear capable of producing any substantial improvement in the safety and operational aspects of truck usage of urban freeways in Texas.

## FIELD SOURCES

## Atlanta, Georgia

GA DOT officials believe increased enforcement has been instrumental in reducing accidents involving large trucks. In 1986, trucks were involved in 45 percent of the
accidents resulting in fatalities in Georgia. Beginning January 15, 1987, traffic law enforcement.activity was increased substantially on I-285. The Georgia State Patrol assigned a special task force contingent of 18 officers to patrol I-285 7 days a week for 90 days beginning January 15, 1987. Special emphasis was placed on truck violations such as speeding, following too close, and improper lane changes. The additional enforcement was conducted by diverting existing manpower to focus on large trucks. No known additional costs were incurred in this effort. Obviously, benefits from this effort must be weighed against possible losses in other areas that were not as heavily enforced due to this concentrated effort.

After the first 45 days of this additional enforcement, GA DOT reported the following positive results:

- Speeds in the right lanes on I-285 decreased 9 percent even though speeds in other lanes increased.
- A reduction for all accidents (decreased by 18 percent) and for trucks (33 percent) as compared to projections for this same (short) time period.
- A reduction by 85 percent occurred for tractor-trailer overturn accidents or others resulting in considerable traffic impacts.
- Georgia State Patrol issued 572 citations involving trucks on I-285 during the first 45 days.

The additional enforcement of truck driver violations on I-285 was a short-term countermeasure lasting for 3 months. Georgia DOT compared accidents from part of the increased enforcement period (January-February, 1987) to two other 2-month periods: (January-February, 1986), and 2 months immediately preceding the enforcement period (November-December, 1986). Comparisons indicate reductions in the number of truckinvolved accidents for the test period of 13 to 14 percent compared to the other two periods. No specific information was provided on traffic volumes to allow an accident rate analysis, however, the average volume on Georgia Interstate highways increased by approximately 5 percent from 1986 to 1987. The reduction in accidents during this time period of increased enforcement is inconclusive because of the effects of other factors, such as the freeway reconstruction program, which was not controlled or accounted for in the calculations: yet, a reduction in truck accidents appears to have occurred.

## New Jersey Turnpike

NJTA conducted a study of enforcement activity on the turnpike in 1986 that resulted in an increase of 40 troopers. In the study, comparisons were made with the New York Thru-way, the Pennsylvania Tumpike, the Maryland Toll Road, and others. Because production rates in those other locations were better than NJTA, the authority was successful in adding more troopers. The State police in New Jersey have a special traffic office
assigned to reduce the number of accidents on the turnpike which concentrates on commercial vehicles.

Currently, the NJTA employs more State troopers per lane-kilometer (mile) than other jurisdictions in New Jersey. According to NJTA personnel, these troopers make more motor vehicle stops, investigate more accidents, and respond to more disabled vehicles than those in other jurisdictions. The NJTA is concentrating on maintaining safe speeds for commercial vehicles. They compile violations that commercial drivers have committed and then send the results to the New Jersey Motor Truck Association. The association, in turn, disseminates this information to members. The officer who issues a citation completes a separate form for the driver and the truck or bus company (owner), providing information on the nature of the offence. That information is input into a computer and, at the end of each day, a form letter is sent to the trucking or bus company informing them that their driver was cited for a specific violation.

To ensure continued success with enforcement efforts, NJTA traffic engineers and enforcement personnel meet monthly. In these meetings, engineers identify problem areas where they believe additional enforcement will be effective in reducing accident rates and/or compliance with laws. NJTA engineers believe this good working relationship is essential in maintaining the safest possible environment for motorists.

The NJTA, in cooperation with the New Jersey Motor Truck Association, the Office of Highway Safety, State police, and the New Jersey State Safety Council, offers "safety breaks." The NJTA provides information to motorists, sometimes in the form of a static display at service areas. In one case, in cooperation with the New Jersey Motor Truck Association, they provided a tractor-trailer to allow motorists to climb into the cab. They also brought a seat belt sled (the "convincer") to replicate a 13 to $16 \mathrm{~km} / \mathrm{h}$ ( 8 to $10 \mathrm{mi} / \mathrm{h}$ ) impact, and have shown safety films and distributed brochures. The "safety break" campaign has been well-received by the public. Operators of service areas offer free coffee and donuts to entice motorists to participate in the program. One of the programs the NJTA continues to sponsor is "Sharing the Road with Truckers." This program demonstrates how difficult it is to control a large combination vehicle and where the blind spots are.

## SYNTHESIS OF RESULTS

GA DOT found several positive results with a short-term ( 45 days) increase in enforcement. These included reductions in: speed ( 9 percent in right the lane), overall truck accidents ( 33 percent), and tractor-trailer overturning accidents ( 85 percent). Unfortunately, the reduction in accidents during this time period of increased enforcement is inconclusive because of the effects of other factors which were not controlled or accounted for in the calculations. Yet, a reduction in truck accidents appears to have occurred. It should be noted that these are truck-involved accidents; the effects on truck-at-fault accidents is not known.

California used increased enforcement for a 12-month period to evaluate its effect on truck accidents. Using SMPV's, they patrolled five freeway segments (three urbanized) to primarily enforce heavy truck laws. This program demonstrated significant reductions in total truck at fault accidents and in injury accidents during the test period. CHP estimated benefits from the accident reductions for 1 year to be approximately $\$ 5$ million, whereas the cost of the program was $\$ 1,556,355$.

The NJTA, which employs more State troopers per kilometer (mile) than other jurisdictions in New Jersey, is concentrating on maintaining safe speeds for commercial vehicles. When a truck or bus driver is apprehended for a traffic violation, the NJTA informs the truck company management. This allows the company's management to track their drivers' violations. The NJTA, following the lead of the Pennsylvania Tumpike Commission, is also involved in "safety breaks" at service areas.

The NJTA plans regular meetings between its engineering group and its enforcement group. They believe this good working relationship is essential in maintaining the safest possible environment for motorists. In these meetings, engineers identify problem areas where they believe additional enforcement will be effective in reducing accident rates and/or compliance with laws.

### 12.0 TALL BARRIERS

## INTRODUCTION

Three curved ramps included in this study use tall barriers (see Ramp Treatments, section 5.0) and one mainlane section uses a taller barrier for containment of large trucks and their loads. Two of the ramp treatments are in Detroit and the other is used on a ramp south of Pittsburgh. The mainlane treatment is located on the New Jersey Tumpike. Differences of the New Jersey application from the others are twofold: the height of this barrier is less at 1.07 m ( 42 in ) as compared to at least 1.83 m ( 72 in ) in the other applications, and it is used over a long distance as opposed to a short segment of roadway.

## LITERATURE SOURCES

The NJTA co-sponsored a research study to conduct full-scale testing of a $1.07-\mathrm{m}$ ( $42-\mathrm{in}$ ) tall barrier. In 1983, the barrier currently being used by NJTA was impacted by a loaded $36402 \mathrm{~kg}(80,180 \mathrm{lb})$ tractor-semitrailer at $84 \mathrm{~km} / \mathrm{h}(52.1 \mathrm{mi} / \mathrm{h})$ at an approach angle of 16.5 degrees. The five-axle tractor-semitrailer used a $12-\mathrm{m}(40-\mathrm{ft})$ box van loaded with sand bags distributed uniformly over the floor of the trailer. The composite center-of-gravity of van plus load was calculated to be at 1.64 m ( 64.4 in ) above the ground. The tractorsemitrailer was smoothly redirected with the trailer achieving a maximum roll angle of 52 degrees. The vehicle remained in contact with the barrier for approximately $46 \mathrm{~m}(150 \mathrm{ft})$, then veered away from the barrier at a 6 -degree angle. The vehicle did not roll over during the test and there was no measurable deflection of the barrier. ${ }^{(33)}$

## FIELD SOURCES

## Detroit, Michigan

One improvement at the northbound I-75 to I-75 connector removed the differing cross-slope rates and formed a constant superelevation rate of 7.4 percent over the full width of the ramp to the outside barrier (see figure 10). The other major improvement was construction of a tall barrier on the outside of the ramp curve to contain high center-ofgravity vehicles and loads that might be dumped on other ramps and the freeway below. The second ramp is a two-lane ramp on the I-94 (Ford Freeway), serving traffic in the westbound direction to southbound on I-75 (Chrysler Freeway). The improvement at this ramp included only the addition of a taller barrier similar to the other ramp for the purpose of containing trucks and their loads. Barriers at both ramps are $1.8 \mathrm{~m}(6 \mathrm{ft})$ high and their base thickness is $635 \mathrm{~mm}(2 \mathrm{ft}, 1 \mathrm{in}$ ). The improvements on this ramp were completed between 1977 and 1980, according to Michigan DOT.


Figure 10. Close-up of barrier on I-75 northbound.

According to a Michigan DOT traffic engineer, the problem at both ramps was practically identical. Both ramps were built with tight geometrics; one was built next to a large building that limited available right-of-way. Michigan DOT had installed extensive signing first in an attempt to reduce accidents, but results were insufficient. The typical truck incident involved rollover with a spilled cargo. According to a Michigan DOT engineer, only one truck had ever penetrated the shorter barrier prior to the installation of the $1.8 \mathrm{~m}(6-\mathrm{ft})$ barrier.

## New Jersey

The purpose for constructing the NJTA's $1.07-\mathrm{m}$ (42-in) high concrete barrier was to provide a more positive barrier to redirect or contain commercial vehicles while not increasing the risk for passenger vehicles impacting the barrier. The barrier was first used in 1984 to separate opposing directions of traffic; it is not used between parallel roadways where traffic is travelling in the same direction. In addition to being $254 \mathrm{~mm}(10 \mathrm{in})$ taller than the standard $813-\mathrm{mm}$ ( $32-\mathrm{in}$ ) barrier, it is also built stronger. Its thickness at the top is 305 mm (12 in) instead of the standard 152.4 mm ( 6 in ), and it is anchored more securely along the base. The cost of this barrier varies from $\$ 540,000$ to $\$ 600,000$ per $\mathrm{km}(\$ 900,000$ to $\$ 1$ million per mi). The cost of the previously used $813-\mathrm{mm}(32-\mathrm{in})$ barrier along the New Jersey Turnpike was not available for comparison.

According to NJTA personnel, this barrier has performed quite well in accomplishing the primary objective of containing all vehicles, including large combination vehicles. During the 5-year period between 1987 and 1991, out of the 55 trucks which struck the 1.07m (42-in) concrete median barrier, none penetrated into the opposite direction of traffic flow. Because of the positive results from this barrier, the NJTA has begun using this taller barrier throughout the turnpike instead of the shorter $813-\mathrm{mm}(32-\mathrm{in})$ barrier previously used. The authority expects to complete this installation by 1994.

## Pittsburgh, Pennsylvania

Several warning devices, additional superelevation, and a tall reinforced concrete barrier for containing cars and trucks were installed at the interchange of I-70/I-79 near Washington, Pennsylvania approximately $48 \mathrm{~km}(30 \mathrm{mi})$ south of Pittsburgh. PennDOT engineers reported that prior to the improvements several fatalities had occurred at the location.

The initial countermeasure for the ramp was to modify and increase the number of signs located on the approach to the ramp. Based on additional evaluations before and after installing the new signs, PennDOT investigated additional countermeasures, including alternative designs for barriers. A tall barrier, which would contain large combination vehicles as well as smaller vehicles, was selected. The tall barrier contract was awarded on January 21, 1985 and was completed on June 27, 1985.

The high wall project included construction of 204 m ( 669 linear ft ) of reinforced concrete barrier, installation of a safety guide rail, paving, drainage, and pavement markers. The barrier was $2.3 \mathrm{~m}(7.5 \mathrm{ft})$ tall, 0.46 m ( 18 in ) wide at the top, and 1.0 m ( 39.5 in ) wide at pavement level. The underground foundation for this barrier is reinforced concrete, 0.6 m ( 2.0 ft ) thick and $2.3 \mathrm{~m}(7.5 \mathrm{ft})$ wide, extending the full length of the barrier. The total cost of the high wall barrier project was $\$ 602,333$. Funding for this contract was 90 percent Federal and 10 percent State.

PennDOT provided before/after accident history, however, the after data were affected by a detour in place during 1989-1990 to rebuild the roadway. Evaluations of accidents included only truck-involved types expected to be reduced by the countermeasures implemented. Analysis of the after period of 1987 through 1990 revealed no accidents, whereas two to six truck accidents occurred during each year of the before period from 1980 through 1983. During the signing and tall barrier construction, traffic was also maintained and could be a factor in the number of accidents during that period.

## SYNTHESIS OF RESULTS

The physical dimensions vary for the four applications of tall barriers found in this study. The ramp applications are more massive than the mainlane application. The $1.07-\mathrm{m}$ ( $42-\mathrm{in}$ ) barrier is 0.3 m ( 12 in ) wide at the top and 0.8 m ( 33 in , minimum) wide at the base. The two ramps in Detroit used the same barrier design which was $1.8 \mathrm{~m}(6 \mathrm{ft})$ tall and 0.63

## Section 12.0 Tall Barriers

$\mathrm{m}(25 \mathrm{in})$ wide at the base. The barrier at I-70/I-79 south of Pittsburgh was $2.3 \mathrm{~m}(7.5 \mathrm{ft})$ tall, 0.46 m ( 18 in ) wide at the top, and 1.0 m ( 39.5 in ) wide at pavement level.

No cost information was available for the Detroit barrier. The total cost of the project near Pittsburgh, including reinforced concrete barrier, installation of a safety guide rail, paving, drainage, and pavement markers was $\$ 602,333$. The individual cost for the 204 m ( 669 linear ft ) of barrier was not available. Recent NJTA costs for the $1.07-\mathrm{m}$ ( $42-\mathrm{in}$ ) barrier have been between $\$ 540,000$ to $\$ 600,000$ million per kilometer ( $\$ 900,000$ to $\$ 1$ million per mile).

Representatives of agencies that use the barriers indicate they have been effective in containing large trucks and their loads. The NJTA reports that during the 5 -year period between 1987 and 1991, out of the 55 trucks which struck the 1.07 -m ( 42 -in) concrete median barrier, none penetrated into the opposite direction of traffic flow. No known truck accidents have occurred at the site near Pittsburgh since the barrier was added and the intensity of warning devices was increased. According to Michigan DOT sources, no trucks or their loads have penetrated the barriers installed in Detroit.

### 13.0 MAINLANE TREATMENTS

## INTRODUCTION

Mainlane treatments include: active and passive signing, truck climbing lanes, truck escape ramps, minor mainlane reconstruction, and shoulder improvements directly related to truck safety.

## LITERATURE SOURCES

The literature search revealed limited information on mainlane improvements. The only urban escape ramp discovered by the literature search was located in Pitsburgh.

Pittsburgh, Pennsylvania

Truck escape ramps are usually associated with rural areas, however one ramp is located near downtown Pittsburgh. Highway grades in the Pittsburgh area, coupled with high volume-to-capacity ratios and large volumes of heavy trucks increase the frequency of truck braking problems. In 1980, PennDOT engineers evaluated the runaway truck problem in the Pittsburgh area. They found that in the preceding 3 years, 63 runaway truck accidents occurred at 18 sites with steep grades. The grades ranged from 5 to 10.5 percent with lengths over $0.8 \mathrm{~km}(1 / 2 \mathrm{mi})$. One of these hills, known locally as Greentree Hill, had experienced 11 runaway accidents in 3 years. This $2.4-\mathrm{km}(1.5-\mathrm{mi})$ grade of 5 percent is located on the northbound approach to the Ft. Pitt Tunnel. Banksville Road merges from the right at the base of the hill just upstream of the Ft. Pitt Tunnel. The two main lanes on I279 plus two lanes from Banksville Road merge into two lanes just prior to the two-lane tunnel. This difficult merge, plus frequently stopped traffic, compound the length and grade problems near the bottom of Greentree Hill. ${ }^{(34,30)}$

One high visibility accident happened on Greentree Hill prior to the installation of the runaway ramp. It occurred because of brake failure while the truck was descending Greentree Hill. The truck driver negotiated the grade, proceeded through the Fort Pitt Tunnel, onto the Fort Pitt Bridge and then descended a ramp into the downtown area of Pittsburgh. The truck crashed into a crowded noontime city sidewalk, pinning victims against a building. Six injuries and four fatalities resulted. ${ }^{(36)}$ At the time of the four-fatality accident, PennDOT was designing a truck escape ramp according to the FHWA's Interim Guideline for Design of Emergency Escape Ramps. ${ }^{(37)}$

The original cost of the escape ramp was $\$ 597,178$. Considering the number of trucks using the escape ramp, and the severity typically associated with a runaway truck accident, it appears that the savings would outweigh the cost of the ramp. In 1980, when the effectiveness of the ramp was evaluated, PennDOT engineers estimated that at least 10 automobiles would have been involved for each runaway truck, had the ramp not been there. The PennDOT estimated cost savings was not available for review. Another cost associated with the ramp is the cost to the owner to retrieve the vehicle from the gravel pile. ${ }^{(36)}$

## FIELD SOURCES

## California

The Glendale Freeway has a climbing lane, but truck drivers usually avoid the freeway because of the grades and use more desirable alternatives; this extra lane serves as a fifth traffic lane for all traffic. According to CALTRANS engineers, problems occur when buses and delivery vans use the freeway because they often use the number three lane (third from the inside), so that faster moving vehicles pass at higher speeds on both sides of them. Motorists ascending the grade typically choose lanes based on their destination because the freeway terminates at its interchange with I-210 at the summit of this grade. The left three lanes merge with outbound (northwest) I-210.

Several truck accident countermeasures have also been implemented on the section of I-5 north of the I-5/Route 210 /Route 14 truck bypass, primarily because of long, steep grades. Because this is predominantly a rural area, the countermeasures are being included but not covered in detail. The mountainous topography along this stretch of I-5 has created the need for these countermeasures. Included are: a truck escape ramp, a truck speed limit, numerous truck warning signs, and a restriction of trucks to the right lane. This lane restriction is stringent because it only provides one lane for trucks. Observations of trucks in the ascending direction is that faster trucks are passing slower trucks by using the middle two of four available lanes. One additional countermeasure was implemented on a long grade, known locally as the "5-mile grade." The road was designed to follow the topography so that descending lanes were constructed wherever flatter slopes were available. The southbound lanes were built to the east of the northbound lanes along an alignment that was 0.64 $\mathrm{km}(0.4 \mathrm{mi})$ longer over its $8-\mathrm{km}(5-\mathrm{mi})$ length. Grade separated cross-overs were employed at the top and bottom of the grade for the southbound lanes.

## Pennsylvania Turnpike

The improvement at the Blue Mountain Tunnel eastbound exit included the same shoulder cross slope and drainage improvement as implemented at the Breezewood exit of the Pennsylvania Tumpike (See Ramp Treatments, section 5.0) (see figure 11). The tunnel was built with a horizontal curve at its east end for the eastbound direction. Trucks exiting the tunnel at high speeds had trouble negotiating the curve to the left. Upon running onto the shoulder and its negative superelevation, some overturned. A significant number of trucks and smaller vehicles were observed veering onto the shoulder.

On a mainlane curve to the left, superelevated sections slope to the inside of the curve (right to left as seen by motorists), but design standards allow the shoulders to slope downward to the outside of the curve (left to right as seen by motorists). When vehicles traversing a curve to the left veer onto this shoulder, their effective superelevation is decreased. A slot-drain became necessary with the new design to collect drainage across the shoulder. The accident problem was apparently caused by excessive speeds and not being
able to recover at the outer edge of the travel surface. After the improvements, more recovery area was available to vehicles by use of the shoulder.

Sketches provided by the turnpike commission show the existing maximum superelevation for this 5-degree curve at 7.87 percent on the mainlanes. Prior to improving the shoulder, a 1.8 percent negative cross-slope existed, resulting in an algebraic difference of 8.6 percent. Turnpike sources believe the improvements have significantly reduced the number of truck accidents at this location.


Figure 11. Eastbound exit from Blue Mountain Tunnel.

## Pittsburgh, Pennsylvania

Signs being used on the approach to Greentree Hill and the tunnels were used to inform truck drivers of the truck escape ramp. These static signs were installed in 1980 when the escape ramp was completed. The changeable message signs were already in place at that time. There are presently about 60 signs providing information to motorists in the Greentree Hill area on I-279. Of these, 23 signs give truck warnings and restrictions in the $3.3-\mathrm{km}(2-\mathrm{mi})$ segment of freeway.

Two of the approximately 60 signs are overhead changeable message signs, installed in 1981. The first upstream changeable message sign is positioned over the traffic lanes 3.2
km ( 2 mi ) in advance of the truck sandpile. The message typically displayed is a warning to truck drivers of the steep grade ahead. The second overhead changeable message sign is located 1.6 km ( 1 mi ) upstream from the sandpile.

## Portland, Oregon

The Terwilliger curve in Portland, Oregon occurs at or near MP 299 on Interstate 5. When this segment of I-5 was built in 1968, both the northbound and the southbound lanes in the so-called "Terwilliger Curve" were built with no superelevation. The degree of curvature (D) at the freeway centerline is $7^{\circ} 30^{\prime}$ (northbound and southbound directions are parallel). The roadway cross-section where the curve is located has three lanes in each direction. The design plans show that the cross-slope for both directions of traffic flow was 2 percent on the two inside lanes and 2.5 percent on the outside lane. Water drains across the pavement from the median to the outside for both directions of traffic flow. The southbound lanes, however, were built with 0 percent cross slope. During the summer of 1987, the superelevation was increased to a maximum of 5 percent within the curve. This was done by using an asphalt "wedge" to build up the pavement across its full width, with the depth increasing from the inside toward the outside of the curve.

The northbound curve to the right was preceded by a descending grade of approximately 3 percent for a distance of $1.83 \mathrm{~km}(1.14 \mathrm{mi})$, which added to the problem because of the tendency to accelerate. The southbound direction follows a 2 to 3 percent ascending grade for at least $2.13 \mathrm{~km}(1.33 \mathrm{mi})$ before the Terwilliger curve. The speed of trucks at the curve depends on several factors including their weight-to-horsepower ratio, whether they are loaded or empty, effects of other vehicles in the traffic stream, and the approach speed at the bottom of the grade. Observed truck speeds were in the range of 70 to $110 \mathrm{~km} / \mathrm{h}$ ( 45 to $70 \mathrm{mi} / \mathrm{h}$ ).

The superelevation improvement was completed in 1987. Another improvement included the addition of two " 50 MPH " black-on-yellow advisory speed plates mounted overhead in each direction. The signs included a large curved arrow over the top of the "50 MPH" (same sign face) indicating the direction of the curve to the left. The two signs are mounted with one over the inside lane and one over the outside lane.

Before the increase in superelevation, there were 26 accidents over 3 years and 5 months. These were only the types susceptible to being reduced by the superelevation. After the improvement, there were 14 accidents over a time period of 2 years, 4 months. Adjusting for the time periods, 7.6 truck accidents per year occurred in the before period, while only 6 truck accidents per year occurred in the after period. This suggests a reduction in truck accidents near 20 percent resulting from the superelevation improvement. Yet, this analysis must also recognize that nine accidents occurred in one of the after years, which equals the highest number of accidents in the before years, and that it does not account for exposure. More detailed information is needed before any conclusion on the effectiveness of the countermeasure can be made.

## Maine

Maine has installed active signs for use on freeway mainlanes for all traffic as a speed control device and in rural areas to inform truck drivers that they are approaching a stop or yield condition and/or where visibility is limited. For the urban freeway applications, the signs display the message "TRAVELLING TOO FAST" when a vehicle is travelling faster than $92 \mathrm{~km} / \mathrm{h}(57 \mathrm{mi} / \mathrm{h})$ in a $90 \mathrm{~km} / \mathrm{h}(55 \mathrm{mi} / \mathrm{h})$ zone. A study on the effectiveness of the signs showed speed reductions immediately after the site, however, 1.6 to 3.2 km ( 1 to 2 mi ) downstream speeds were approaching the original speeds. According to a former DOT employee who designed the system, the most important aspect of the signs was to increase motorist awareness that speeds were being monitored. These devices remained in place for 5 to 6 years during the 1980's.

## SYNTHESIS OF RESULTS

Mainlane treatments consist of passive and active devices, climbing lanes, superelevation improvements, improvements in shoulder cross-slope, and truck escape ramps. Some of these were also used on freeway ramps (see section 5:0). Treatments such as climbing lanes and escape ramps are typically considered rural applications, however, topography was a factor in these countermeasures and others in Pittsburgh and Los Angeles.

The only active device found on urban freeway mainlanes was used in Maine as an attempt to reduce vehicular speeds to the regulatory speed limit. Their application for this purpose was different from those used elsewhere for speed reduction upstream of curves on freeway ramps. The signs displayed the message "TRAVELLING TOO FAST" when a vehicle was travelling faster than $92 \mathrm{~km} / \mathrm{h}(57 \mathrm{mi} / \mathrm{h})(90 \mathrm{~km} / \mathrm{h}$ [ $55 \mathrm{mi} / \mathrm{h}]$ zone). A study on the effectiveness of the signs showed speed reductions immediately after the site, however, 1.6 to 3.2 km ( 1 to 2 mi ) downstream speeds were approaching the original speeds. This suggests that active devices should be considered for speed reductions at a certain point (mainlanes or ramps), but not for longer segments of freeways.

The improvement at the Blue Mountain Tunnel eastbound exit included the same shoulder cross slope and drainage improvement as implemented at the Breezewood exit of the turnpike (see section 5.0). At the tunnel exit, and to a lesser extent on the ramp exit from the mainlanes, the driver's view of the roadway ahead was obscured. The tunnel was built with a horizontal curve at its east end for the eastbound direction. Trucks exiting the tunnel at high speeds had trouble negotiating the curve to the left. Upon running onto the shoulder and its negative superelevation, some overturned. A significant number of trucks and smaller vehicles were observed veering onto the shoulder.

In 1980, PennDOT engineers evaluated the runaway truck problem in the Pittsburgh area. They found that in the preceding 3 years, 63 runaway truck accidents occurred at 18 sites with steep grades. The grades ranged from 5 to 10.5 percent with lengths over 0.8 km $(1 / 2 \mathrm{mi})$. One of these hills, known locally as Greentree Hill, had experienced 11 runaway accidents in 3 years. One difference in the Greentree Hill escape ramp and those found in
rural areas was in the approach speeds. On the downgrade approaching the tunnel, most trucks were travelling under $65 \mathrm{~km} / \mathrm{h}(40 \mathrm{mi} / \mathrm{h})$, according to evidence at the site and driver statements. This was due to the warning signs for trucks approaching the grade or the traffic congestion, or both.

The Terwilliger curve in Portland, Oregon on I-5 was built with no superelevation. The degree of curvature (D) at the freeway centerline is $7^{\circ} 30^{\prime}$. This mainlane improvement includes an increase in superelevation to a maximum of 5 percent within the curve using an asphalt "wedge." A similar treatment was used on ramps in Atlanta, Georgia (see section 5.0), where the maximum superelevation rate was increased in one case to 10 percent. Another improvement to the Terwilliger curve included the addition of two " 50 MPH " black-on-yellow advisory speed plates mounted overhead in each direction.

## Section 14.0 Issues to Consider for Future Data Collection Efforts

### 14.0 ISSUES TO CONSDER FOR FUTURE DATA COLLECTION EFFORTS

The type of data collection design to be performed varies from one countermeasure to another. Evaluating two examples is instructive for agencies who want to collect data. Two methods to be considered are before/after designs and the use of a concurrent "control group." The two countermeasures used to demonstrate the use of these two study designs are truck bans/diversions and incident response management.

The evaluation of truck bans and diversions necessarily falls into the category of a before/after design. These designs are limited due to the lack of control of intervening factors. These factors can be known or unknown, but their influence on measures of effectiveness are unmeasurable. Before/after designs can be improved with the inclusion of a control, however, identifying and using an adequate control is not always possible. It is necessary, therefore, to understand the limitations inherent in the methodology being used to evaluate any program.

There are potentially many reasons for implementing a truck ban/restriction. The benefits are decreased noise, improved traffic flow, and decreased incidence and/or severity of accidents. This discussion will concentrate on measuring the effects of truck restrictions on accident rates.

The data necessary for objective analysis include detailed information on traffic volumes and vehicle classifications. The accident information requires at a minimum, accident counts, types of vehicles involved, and locations of accidents (to include specifics regarding the lanes being restricted.) Additional information could include date and time of each accident, type of accident, cause of accident, severity of accident, damage costs and personal injuries.

The type and detail of the analysis depends on the amount of data available. In any before/after design, it is preferable that conditions remain stable during the interval of the study, however, in the absence of a controlled experimental setting, stable conditions are not guaranteed. Accident counts can be compared, with or without a control, or accident rates can be computed, using accurate traffic volume data.

Other measures of interest are hypothesized decreases in severity of accidents. Accident severity scales, cost figures, and personal injury data can be used to evaluate this hypothesis.

The objective and quantitative evaluation of incident management programs is difficult. Response times are generally not available. Some information can be obtained after the fact from police reports, but the data are not complete or necessarily representative. It can be assumed that extra effort in the form of personnel and equipment generally improves response time, however evaluation of the cost/benefit of various initiatives requires more quantitative analysis.

In the absence of data to represent conditions before establishment of an incident management program, only crude estimates of the benefits can be made. The evaluation of added initiatives after a system is in place is more feasible. For example, the benefits from the addition of a heavy-duty tow truck to clear large truck accidents could be evaluated. Comparisons of response and recovery times could be made if sufficient records were kept by the agencies involved.

The data necessary for an objective analysis include: type of incident, location of incident (shoulder or traffic lanes), vehicles involved, personnel responding (special patrol, police force, private towing company), date and time of the incident, time of the response, time of clearing, equipment used, and time to recover traffic flow. Defining the data items is not straightforward; for example, the time that the traffic flow returns to "normal." This example illustrates part of the difficulty in measuring the effects of an incident management program even when the collection of relevant data is regarded.

In addition to collecting data on the incidents that receive the attention of the incident management personnel, a comprehensive study must address the issue of unreported incidents. It is likely that the number and average duration of unreported incidents change with increased efforts by the program. Obtaining accurate measurements of these incidents may not be possible. This weakness should be addressed in reporting any analysis of the program.

A consideration in any before/after study is the influence of other uncontrolled factors on the results. A concurrent "control group" could be defined if an initiative were implemented in one area and not another. Adequacy of a control must be verified; the two areas must have similar characteristics. Having a control does not guarantee better comparisons, it is simply insurance against some types of intervening factors. Another means of protection against factors changing with time is to restrict the analysis to data collected within a short time interval. Restricting the length of the interval must, of course, be balanced against the time it takes to collect the data needed for an adequate comparison.

This research identified problems with existing data and information that agencies can provide. In many cases, missing detailed information was crucial in conducting a complete analysis. When an agency is uncertain about the implementation date, the before and after analysis periods are more widely separated, allowing intervening factors to have greater impact on the analysis. Another factor in accident investigations was the length of time agencies maintained detailed accident records. For some, it was 5 years, and for others it was longer. If a countermeasure was implemented 5 years ago, this may mean no before data. If the countermeasure was implemented 1 year ago, there will probably be insufficient after data. The quality of the accident data was also questionable in some cases, especially on freeway ramps. This was due primarily to enforcement officers omitting specific ramp information and the difficulty in establishing implementation dates, costs, and so forth if done by maintenance personnel. Due to the lack of control, there might have been other uncontrolled or missed factors that influenced accident rates in these analyses.

### 15.0 SUMMARY

Because of the excessive costs and delays, in addition to the injuries and fatalities resulting from truck accidents and incidents on urban freeways, several operating agencies have investigated and implemented countermeasures to reduce truck accidents on urban freeways. Some of the countermeasures, such as increased enforcement, are designed primarily for trucks. Others apply to all traffic with specific elements for trucks as when heavy duty tow trucks are used to retrieve overturned trucks as part of an incident management program.

The FHWA sponsored a 1986 survey to determine which States used lane restrictions. The most common reasons for their adoption of these restrictions were: 1) to improve operations (14 States); 2) to reduce accidents (8 States); 3) for pavement structural considerations ( 7 States); and 4) restrictions in construction zones (5 States). According to survey information, these justifications for employing lane use restrictions were not mutually exclusive among the total 26 States which used them. The field survey also indicated that, in most cases, restrictions were applied without detailed evaluation plans, including "before and after" studies. Little change in accident experience was noted under any of the restrictions. ${ }^{(2)}$

GA DOT adopted lane restrictions because trucks were over-involved in weaving and lane-changing accidents. The truck driver was determined to be at fault in 72 percent of the "changing lanes improperly" violations. In Atlanta and in Chicago, trucks were also observed travelling abreast across all available lanes, denying passing opportunities for other vehicles. Compliance of truck drivers appears to be directly related to their own passing opportunities and the enforcement level. Even though little is known regarding the effectiveness of this countermeasure, there is a common perception that its removal would be very unpopular. This is because many motorists feel safer with lane restrictions for trucks.

Separate truck facilities have been constructed in California, Oregon, and New Jersey for improving truck operations and safety. In California, truck bypass lanes were constructed primarily to reduce weaving problems at interchanges. On I-5 near Portland, a truck bypass was built to avoid a merge of slow-moving truck traffic on interior lanes with faster moving traffic entering the freeway from their right. The effectiveness of the California and Oregon facilities in reducing accidents has not been thoroughly evaluated. Accident rates on the New Jersey Turnpike are significantly different for the dual-dual cross-section when compared to the non-dualized sections. Records at NJTA indicate the truck accident rate for 1990 on the dual-dual portion was 114.0 accidents per 160 million vehicle km ( 100 million vehicle miles), compared to 176.7 for the non-dualized portion.

Ramp improvements in Georgia, Michigan, Maryland, Virginia, on the Pennsylvania Turnpike, and on the New Jersey Turnpike included adding active or passive signs, adding taller barrier, and minor reconstruction. The addition of passive warning devices was the most common countermeasure, perhaps due to its relatively low cost. Even if other countermeasures were implemented, they often followed installation of passive signs. Georgia DOT officials observed the following pattern of effectiveness for their active devices
using wig-wags. When first installed, speeds of most vehicles were reduced. After an initial familiarization period (the "novelty" effect), motorists became accustomed to their presence, and with their own perceived safe speed on the roadway, their speeds once again increased. With commuters, the time period is less than for unfamiliar motorists, but within a month or so familiarity tends to reduce the active device's effectiveness. Minor reconstruction of ramps has been used by agencies in Michigan, Georgia, Maryland, New Jersey, and Pennsylvania in an attempt to reduce truck accidents. Actions included increasing superelevation of the ramp, raising the shoulder cross-slope to match the ramp superelevation, and removing outside barrier curbs. No accident histories are available for evaluation.

According to transportation engineers who have observed the situation, truck diversions appear to simply shift truck accidents to the freeway(s) where they are diverted. Georgia DOT in Atlanta enacted an order restricting through trucks to the circumferential freeway instead of using a shorter path along interior freeways. No attempt has been made by GA DOT to quantify the benefits of the truck ban countermeasure or to assign cost savings to it; however, they did estimate that combination truck travel on interior freeways was reduced from 6 to 2 percent, or approximately 6,000 trucks per day.

Voluntary peak period truck bans are being promoted in several cities including Los Angeles, Minneapolis/St. Paul, and Washington, D.C. suburbs in Maryland. None of these have been closely scrutinized, however, the general feeling of local officials is that the shift in truck traffic was insignificant.

Attempts to quantify the shoulder parking problem in Kentucky by Agent and Pigman revealed that tractor trailers were over represented in shoulder accidents when compared to their involvement in all accidents. ${ }^{(21)}$ Twenty-five percent of vehicles involved in shoulder accidents were tractor trailers, with an even higher involvement during nighttime hours. In Columbus, Ohio, 10 fatalities over a 5 year period caused city officials to reduce the time a vehicle could legally remain on a freeway shoulder. Effective in November 1989, the time period that a vehicle could remain on the shoulder, away from an interchange, was reduced from 12 hours to 3 hours. (Near an interchange or at specified "hazardous" locations, a vehicle is cited and towed immediately.) A study in Michigan of shoulder parking revealed that during the 4-year period from 1984 through 1988, 55 combination vehicles were hit by other vehicles while parked on freeway shoulders. Recommendations included limiting the length of stay in freeway rest areas and providing information on appropriate overnight truck parking facilities. An urban solution being used in Maryland uses park-and-ride lots during nighttime hours for truck parking.

Urban inspection stations may reduce accidents that are caused by mechanical problems or operator-related problems such as fatigue. Inspection of the mechanical condition of the truck and the operational status of the driver helps correct problems before they are causal factors in accidents. Virginia, Maryland, and California use urban inspection stations as a countermeasure to reduce truck accidents. Three inspection stations are located in Maryland and Virginia near the Capital Beltway which circles Washington, D.C. The use of two Maryland park-and-ride lots for truck inspections is innovative, but only a relatively

## Section 15.0 Summary

small sample of trucks can be inspected. These facilities require officers to pull individual trucks over and escort them into the station.

Some major obstacles must be overcome to construct new inspection stations in urban areas. They are costly and the public usually opposes them. The 1991 cost of new inspection facilities in northern Virginia in the Washington, D.C. area was estimated at over $\$ 3.5$ million per facility. In 1987, Virginia spent only $\$ 962,000$ by utilizing an existing ramp and existing right-of-way at the Van Dorn Street interchange. In California urban areas, the current estimated cost is between $\$ 8$ million and $\$ 14$ million. Public opposition often occurs when an inspection station is being proposed within an urban area. Local property owners object to the noise, air pollution, and other environmental concerns. These outweigh their positive reactions to truck inspections in general.

There are two primary issues involved in incident response management for large trucks. These are 1) providing a heavy-duty tow truck in a timely manner, and 2) clearing the roadway immediately of vehicles and/or spilled loads.

Heavy duty tow trucks are available from two sources - a few public agencies own tow trucks but more commonly a responsible official at the incident scene (usually State police) requests privately owned tow trucks. In this case, the selection is made from a rotation list, usually broken down by zone within the urban area. IDOT in Chicago uses 35 EPV's patrolling constantly $160 \mathrm{~km}(100 \mathrm{mi})$ of urban freeway. The tow trucks used as EPV's are similar to those used in Pittsburgh and Tampa. An additional investment besides the fleet of 35 EPV's which makes the IDOT (Minuteman) program unique is the purchase of heavy-duty tow trucks to supplement EPV's. All other agencies must employ heavy-duty tow trucks from the private sector. IDOT officials are emphatic in stressing that conscientious, well-trained personnel are as important to getting the job done as having the right equipment. Two important factors stand out from information gathered from several agencies. One is the need to have mature, experienced personnel at incident sites involving large trucks and the other is diagnosing the site-specific needs and immediately providing the proper equipment. A shortcoming in either of these factors will significantly increase motorist delay near the site and increase the cost to the truck owner.

Two States participating in this study, Maryland and Texas, have been very aggressive in clearing the roadway following an incident. The MSHA developed a Maintenance Policy (71.01-05.1-Revised, April 1990) that calls for the prompt reopening of the roadway to traffic. In Texas, Senate Bill 312, passed in 1990, authorized the TxDOT to remove, without consent of the owner or carrier, spilled cargo and personal property from any portion of the State highway system or rights-of-way. It also relieved the TxDOT from liability for any damage resulting from removal of the property unless the removal or disposal was carried out recklessly or in a grossly negligent manner. Furthermore, it required the property owner or carrier to reimburse the TxDOT for the costs of removal and subsequent disposition of the property. Exceptions to quick clearance occur when hazardous materials or pending injuries are involved.

Increased enforcement yielded desirable results in California and Georgia. California used increased enforcement for a 12-month period from January to December 1987 to evaluate its effect on truck accidents. The study used a similar time period in 1986 for comparison. SMPV's were purchased to patrol five freeway segments (three urbanized) to primarily enforce heavy truck laws. Total results for all five test sites indicate a 3.5 percent reduction in truck-at-fault accidents (statistically significant at the 90 percent confidence level), compared to a 5.8 percent increase on non-test site freeway beats within the CHP areas participating in the program. ${ }^{(31)}$ Injury (including fatal) truck-at-fault accidents dropped by 11.2 percent, compared to a reduction of only 0.4 percent on all non-test site freeway beats within CHP areas participating in the program. CHP estimated benefits from the accident reductions for 1 year to be approximately $\$ 5$ million, whereas the cost of the program was $\$ 1,556,355$. The GA DOT found that increased enforcement resulted in several positive results over a short-term ( 45 days) period. These included reductions in: speed ( 9 percent in right the lane), overall truck accidents ( 33 percent), and tractor-trailer overturning accidents ( 85 percent). Unfortunately, the reduction in accidents during this time of increased enforcement is inconclusive because of other factors which were not controlled or accounted for in the evaluation.

Tall reinforced concrete barriers have been used to effectively contain large trucks and their loads. The NJTA installed a taller barrier in the median; Michigan DOT and PennDOT have installed tall barriers for shorter distances on ramps. The NJTA reports that during the 5 -year period between 1987 and 1991, out of the 55 trucks which struck the $1.07-\mathrm{m}(42-\mathrm{in})$ concrete median barrier, none penetrated into the opposite direction of traffic flow. No known accidents have occurred at the site near Pittsburgh since the barrier was added, and the intensity of warning devices was increased. No trucks or their loads are known to have penetrated the barriers installed in Detroit, as well.

A number of mainlane improvements have been installed in urban areas in California, Pennsylvania, Maine, and Oregon. These include active signs, a truck climbing lane, a mainlane shoulder cross-slope improvement, a truck escape ramp, and a superelevation improvement.

Active signs used in Maine display the message "TRAVELLING TOO FAST" when a vehicle is travelling faster than $92 \mathrm{~km} / \mathrm{h}(57 \mathrm{mi} / \mathrm{h})$ in a $90 \mathrm{~km} / \mathrm{h}(55 \mathrm{mi} / \mathrm{h})$ zone. A study on the effectiveness of the signs showed speed reductions immediately after the site, however, 1.6 to 3.2 km (one to two miles) downstream speeds were approaching the original speeds. There is a climbing lane on the Glendale Freeway in the Los Angeles area, but truck drivers usually avoid this freeway because of the grades and use more desirable alternatives. This extra lane serves as a fifth traffic lane for all traffic. PennDOT and the Pennsylvania Turnpike Authority implemented two mainlane improvements within their jurisdictions. The turnpike improvement at the Blue Mountain Tunnel eastbound exit included a shoulder crossslope and drainage improvement. The improvement raised the shoulder so that its crossslope matched the mainlane cross-slope on a horizontal curve to the left. Trucks exiting the tunnel at high speeds had trouble negotiating the curve which begins immediately at the end of a tunnel. When trucks veered onto the shoulder with its negative superelevation, some
overturned. The PennDOT improvement included construction of a truck escape ramp and several warning devices for trucks on a $2.4 \mathrm{~km}(1.5 \mathrm{mi})$ downgrade approaching the Fort Pitt Tunnel (Green Tree Hill) near downtown Pittsburgh. The Terwilliger curve on I-5 in Portland, Oregon was built in 1968 with no superelevation. The degree of curvature (D) at the freeway centerline is $7^{\circ} 30^{\prime}$. This mainlane improvement includes adding a "wedge" of asphalt to increase the superelevation to a maximum of 5 percent within the curve.

### 16.0 RECOMMENDATIONS FOR FUTURE RESEARCH

The information presented in this report is from a literature review, telephone interviews with representatives of selected agencies, and site visits. In most cases, implemented truck accident countermeasures were not thoroughly evaluated by the implementing agency to determine their effectiveness. Frequently, limited resources and funding hinder agencies from evaluating countermeasures.

Information on the actual rather than perceived effectiveness of the countermeasure, cost of the countermeasure, and transferability of the measure to different circumstances should be developed. If adequate resources and funding become available, future research efforts should be channelled into analyzing the most promising countermeasures identified in this research. Because of the problems associated with evaluating existing data, future research should focus on selecting sites or actions for new data collection under controlled conditions. This research identified countermeasures that "appear" to improve operations and reduce accidents, but further evaluation is needed.

One of the countermeasures investigated as part of this study, especially for ramps, was warning signs with advisory speeds. A weakness of the current speed advisory system is the discrepancy between performance characteristics of automobiles and trucks. One possibility might be the use of a dual system of advisory speeds - one for cars and one for trucks. Even if a dual system is not investigated, the current method of establishing advisory speeds on curves should be reevaluated. Observed speeds of automobiles and (unloaded) trucks on curves are significantly higher than the posted advisory speeds. Criteria for establishing when truck stability characteristics are significantly different from cars will be part of this activity. This should include truck driver eye height and wet versus dry pavement conditions.

Another countermeasure worth further evaluation is incident response management. One element that should be included is the reduction in response time by several scenarios of heavy-duty tow trucks. Included might be use of private tow trucks selected from a rotational list, contractual agreements that include response time requirements, and public ownership as practiced by IDOT's Minutemen. Evaluations of medium to large urban areas and regional representation should also be included in the evaluation, as well as local attitudes regarding quick clearance of the roadway.

Shoulder parking, especially by large trucks, also needs further evaluation. Parking demand for many rest areas throughout the country are already exceeding capacity during the early morning weekday hours. If the number of trucks continues to grow, the problem will worsen. Studies should evaluate the severity of the problem, and suggest solutions.

States or other entities considering future research should take two or three of the most promising countermeasures and perform a thorough 2 to 3 year evaluation of them. The studies should be conducted in States where the accident and traffic data base is sufficiently accurate to support this effort.

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