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RESEARCH REPORT

MARYLAND MOTOR CARRIER PROGRAM PERFORMANCE ENHANCEMENT

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16. Abstract

Using the inspection summary data (24-1 reports) from SHA for years 2006 to 2010 and inspection and violation files of Motor Carrier Management Information System (MCMIS) for the same years, the Maryland State Police (MSP) and Maryland Transportation Authority Police (MdTAP) roadside inspections were evaluated. The comparison with peer states and the national trend found that the roadside inspections of Maryland are effective. Specifically, Maryland conducted more inspections than many other states in terms of the absolute number of inspections and the number of inspections normalized by population and VMT. In addition, reduction in violations in Maryland was noticeable during these study years, a larger drop than the national average. This trend analysis suggests that population of safe trucks in Maryland has been increasing gradually, at rates higher than the national averages. This population of safe trucks may be the result of the effectiveness of prior inspection programs in the state and nationally. The Integer Programming resource allocation model successfully reallocated existing resources in a way to maximize benefits from avoided crashes. The modeling findings suggest that the current level of inspections, i.e. without resource reallocation, are quite effective and generate significant benefits to Maryland citizens. With resource reallocation, the benefits would increase significantly. Depending on scenarios, the percentage increase of additional benefits gained by resource reallocation ranges between 14.58% and 28.18% for the MSP roadside inspection program, and between 9.01% and 22.62% for the MdTAP roadside inspection program. A budget increase scenario was also considered. A budget increase of 10% using current inspection capacity, and assuming a 40% crash reduction coefficient, would result in MSP and MdTAP increasing benefits by 2.22% and 7.23% respectively. At the disaggregated level, the model recommends TWIS to conduct more level I and level II inspections, and fewer level III inspections. On the other hand, for MdTAP and MSP Roving County, an increase in level III inspections would have a significant impact on capturing potentially dangerous drivers who avoid fixed inspection locations on purpose.

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EXECUTIVE SUMMARY

The Maryland Motor Carrier Program (MMCP) involves the regulation of commercial vehicle safety, and size and weight inspections. It is a collaborative program based on federally provided safety standards and administered by various state agencies such as the Motor Carrier Division (MCD) of the Maryland State Highway Administration's (SHA) Office of Traffic and Safety (OOTS), Maryland State Police (MSP), Maryland Transportation Authority Police (MdTAP) and others. One of the safety programs is the roadside inspection program. The purpose of the program is to improve commercial vehicle safety to reduce crashes involving commercial vehicles. This study evaluated the effectiveness of the roadside inspection program and recommended strategies to improve the effectiveness.

Comparative Analysis

Using the inspection summary data (24-1 reports) from SHA for the years 2006 to 2010 and inspection and violation files from the Motor Carrier Management Information System (MCMIS) for the same years, the MSP and MdTAP roadside inspections were compared with peer states and the national average. The comparative analysis found that the roadside inspections in Maryland are effective. Specifically, Maryland conducted more inspections than many other states in terms of the absolute number of inspections (7^{th}) and the number of inspections normalized by population (10^{th}) and Vehicle Miles Traveled (VMT) (10^{th}). The comparison of five-year trends of Maryland inspection results with the national average trends again supported the higher effectiveness of the Maryland inspection programs. Nationally, the total number of violations and out-of-service (OOS) violations marginally decreased between 2006 and 2010. However, the total number of violations and OOS violations significantly decreased in Maryland. For example, the total violations decreased at annual rates between 0.1% and 1.4% nationally, which was much lower than Maryland's 1.4% to 6.02% decrease. For OOS violations, Maryland's decrease rates were between 2.61% and 14.09%, compared to the national trend of 3.2% to 6.7%. Across all metrics, the reduction in violations was much larger in Maryland than in the U.S. This trend analysis suggests that the population of safe trucks in Maryland has been increasing gradually, at rates higher than the national averages. This population of safe trucks may be the result of the effectiveness of prior inspection programs in the state and in adjoining regions.

Resource Allocation Model Analysis

The compiled data for year 2009, which had the most complete information, was used for evaluating the resource reallocation scenarios. Resources were reallocated in a way to generate maximum program benefits by reducing /preventing truck crashes, fatalities, and injuries. As expected, the resource allocation models behaved consistently; it reallocated more resources to high-return inspection levels and locations based on the trade-offs among Safety Measurement System (SMS) severity values, costs, benefits, and total numbers of inspections.

The modeling findings suggest that the current level of inspections (i.e., without resource reallocation) are quite effective and generate significant benefits to Marylanders, which suggest the high effectiveness of the roadside inspection programs of Maryland. For example, the MSP roadside inspection's return on $1 in budget spending was $4.19 at the 40% crash reduction coefficient, and $2.18 for MdTAP. The crash reduction coefficient captures the truck-involved crashes that would be prevented as a result of roadside inspection; i.e., inspections alone will not prevent present and future truck crashes.

Furthermore, the findings indicate that the roadside inspection programs of MSP and MdTAP can further improve their effectiveness and bring about more benefits by reallocating resources. Assuming crash reduction coefficients of 30%, 40%, and 50%, the percentage increase in additional benefits gained by resource reallocation ranges between 14.58% and 28.18% for the MSP roadside inspection program, and between 9.01% and 22.62% for the MdTAP roadside inspection program.

A budget increase scenario was also considered. Assuming an additional budget of 10% is available and a crash reduction coefficient of 40%, it was found that MSP and MdTAP would be able to increase benefits by 2.22% and 7.23% respectively within the current inspection capacity.

At the disaggregated level, the model recommends that Truck Weigh and Inspection Stations (TWIS) conduct more levels I and II inspections, and fewer level III inspections. On the other hand, for MdTAP and MSP Roving County, an increase in level III inspections is recommended, which would have a significant impact on capturing potentially dangerous drivers who avoid fixed inspection locations on purpose.

Implications for Implementation

From an implementation perspective, there are several points that need to be recognized for evaluating the findings for implementation. First, the definition of benefits generated by the inspection program should be understood clearly. As shown in the model formulation, the benefits are monetized benefits from preventing crashes. The costs include monetized loss to the victims and their family. Thus, the generated benefits from the model need to be understood as social benefits, not hard currency inflow to the program.

Second, the developed model is flexible. That is, crash reduction coefficients and upper/lower boundaries of the number of roadside inspections can be changed for re-running the model. Based on the domain expertise of the MSP and MdTAP roadside inspection personnel, various scenarios can be evaluated to find out the better resource reallocation options.

Third, decision making should be based on expertise. The model gives priorities to high severity violations. Due to this reason, for some TWIS, reduction or removal of levels IV, V and VI inspections is suggested. This is because, in general, violations from these levels had lower SMS severities. However, eliminating these levels is neither reasonable nor recommended. For example, level VI (enhanced NAS inspection for radioactive shipments) had never received serious violations in the data used for this study. This does not mean level VI inspections have low safety impact. In the case of level VI, a potential negative impact of noncompliance is too serious to afford no-action. This is why the model's findings need to be interpreted and implemented carefully based on domain expertise.

INTRODUCTION

Commensurate with the growth in Maryland's economy and population, trucks traveling on Maryland roadways would increase. The Maryland Department of Planning estimated (2012) that the Maryland population would reach nearly 7 million by 2040, an increase from 5.8 million in 2010. Measured in real gross state product (GSP),[1] the Maryland economy expanded by 19% between 2002 and 2012 (Bureau of Economic Analysis, US Department of Commerce 2012). Assuming the past growth rate holds for the future, Maryland's real GSP would increase to over $327 billion by 2022. That being the case, a dramatic increase in truck volumes in Maryland would be inevitable. The tonnage of goods moved using roadways in Maryland is likely to double between 2006 and 2025 (Cambridge Systematics 2009, 2-3).

A rapid growth in truck traffic on Maryland highways will have significant traffic implications. More conflicts between cars and trucks on already chronically congested Maryland roadways may occur, which could result in more fatal and severe injury crashes involving trucks. Of concern is that crashes involving trucks are more likely to result in fatal crashes. While trucks account for about 4 - 8% of vehicle volume on Interstates in Maryland (Maryland State Highway Administration 2013), they were involved in approximately 17% of fatal vehicle crashes that occurred on Interstates between 2008 and 2010 (Maryland State Highway Administration 2012)[2].

While private vehicle drivers are at fault for some truck-involved crashes, many of the crashes involving trucks could be prevented by safety inspection programs carried out in each state. In Maryland the Maryland Motor Carrier Program (MMCP) is responsible for safety inspection programs. MMCP in collaboration with the Maryland State Police (MSP) and the Maryland Transportation Authority Police (MdTAP) has led commercial vehicle[3] inspection programs. The success of such efforts has been well documented (Han and Pansare 2009, Bapna, Zaveri and Battle 2001, Bapna, Zaveri and Jaffr 2000, Bapna, Zaveri and Farkas 1998).

To continue its success, one of the most important tasks is to analyze the effectiveness of the program. The effectiveness is evaluated by measuring whether existing performance is good enough or whether room for improvement exists in order to accomplish the program goal of reducing fatal and injury crashes involving trucks.

Study Objectives

The goal of this study is to inform SHA, MDTA, and MSP about the effectiveness of the roadside inspection program in terms of the allocation of the limited resources. Using the inspection summary data (24-1 reports) from SHA for the years 2006 to 2010 and the roadside inspections database from the Motor Carrier Management Information System (MCMIS), resource allocation models were developed to find out ways to reallocate resources in a way to maximize program benefits (i.e., reduction in truck crashes, fatalities, and injuries). Integer programming was used for modeling. The study provides benefit estimation and suggests appropriate levels of roadside inspections.

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[1] The Bureau of Economic Analysis uses 2005 dollars for calculating real GSP to adjust inflation.
[2] The statistic was computed based on the data set provided by the Office of Traffic and Safety.
[3] Trucks, commercial vehicles, and commercial motor vehicles (CMV) are used interchangeably in this report.

Report Structure

The rest of the report is organized as follows. The next chapter provides a review of literature on roadside inspection programs, studies the association of trucks crashes and safety inspections, and effectiveness of safety inspection programs. Then, a detailed discussion on data collection, compilation, and limitations are provided, followed by a summary of the roadside inspection data. The resource allocation model is developed and described and the modeling results are reviewed. The report concludes with the summary of findings, study limitations, and future study suggestions.

REVIEW OF CURRENT PRACTICE AND LITERATURE

Maryland Motor Carrier Program (MMCP)

The MMCP involves the regulation of commercial vehicle safety, and size and weight inspections. It is a collaborative program based on federally provided safety standards and administered by various state agencies such as the Motor Carrier Division (MCD) of SHA's Office of Traffic and Safety (OOTS), Maryland State Police (MSP), Maryland Transportation Authority Police (MdTAP), and others.

The Motor Carrier Safety Assistance Program (MCSAP), authorized initially under the 1982 Surface Transportation Assistance Act, provides federal funds to states to cover 80% of the cost of inspections programs (Moses and Savage 1997). According to MCSAP, the purpose of the motor carrier program is to "reduce commercial motor vehicle (CMV) involved crashes, fatalities, and injuries through consistent, uniform, and effective CMV safety programs (FMCSA 2011)." It is believed that traffic safety is improved due to safety inspection programs that identify safety defects, driver deficiencies, and unsafe motor carrier practices and carry out corrective actions.

Review of the Current Practice: Commercial Vehicle Inspections in Maryland

At least three types of roadside inspections are conducted: inspections at truck weigh and inspection stations (TWIS), roving inspections using a portable scale, and inspections triggered as part of enforcement activity.

Maryland operates 17 TWISs – 13TWISs with permanent scales and four with portable scales (Table 1). Twelve TWISs are operated by the Commercial Vehicle Enforcement Division (CVED) of MSP, 10 of which have permanent scales. The Commercial Vehicle Safety Unit (CVSU) of MdTAP manages three TWISs with permanent scales and two TWIS with portable scales.

<u>Inspections at TWIS</u>

Bapna, Zaveri, and Battle (2001) provide a detailed description of the inspection process at a TWIS. The following paragraphs are extensively borrowed from that study. At the TWISs with permanent scales, drivers of commercial motor vehicles (goods delivery trucks and buses) are pulled into the station when a road sign signals them to do so. In general, two lanes are provided – one for by-passing and the other for weighing vehicles (Figure 1). If a vehicle is signaled to go through the bypass lane, it is not weighed and the driver is allowed to continue towards his or her destination. For safety considerations, vehicles are allowed to bypass the scale at times of heavy highway traffic.

When a vehicle enters the scale lane, it is weighed and visually inspected. At that point, there are several variables that determine whether a driver will be requested to pull into the inspection area to receive further inspection (Figure 2). Broadly, three categories of activities are conducted at a TWIS. First, a vehicle is weighed and a traffic citation is issued if the vehicle exceeds allowable weight limits. Second, a vehicle on the scale is inspected for any visual violations such as damaged tires, cracked windshield, etc. Based on the visual inspection, a vehicle may be further inspected, which can be level I, II, III, or IV inspection (Table 2). Lastly, a vehicle is often further inspected based on random selection by inspectors. A randomly selected vehicle will be subjected to one of the six inspection levels provided in Table 2.

Table 1. Maryland Truck Weigh and Inspection Stations

TWIS	Scale type	Agency in Charge
Cecilton, US301 southbound	Permanent	CVED
Conowingo, US1 northbound and southbound	Permanent	CVED
Delmar, US13 northbound and southbound	Permanent	CVED
Finzel, I68 eastbound	Permanent	CVED
Foy Hill, US40 eastbound	Permanent	CVED
Hyattstown, I270 northbound and southbound	Permanent	CVED
New Market, I70 eastbound	Permanent	CVED
Parkton, I83 southbound	Permanent	CVED
Upper Marlboro, US301 northbound and southbound	Permanent	CVED
West Friendship, I70 westbound	Permanent	CVED
I95/495 Park and Ride, College Park	Portable	CVED
Vienna, US50 eastbound	Portable	CVED
Perryville, I95 northbound and southbound	Permanent	CVSU
Thomas J. Hatem Memorial Bridge, US40 eastbound and westbound	Permanent	CVSU
William Preston Lane, Jr. Memorial Bridge, US50 eastbound and westbound	Permanent	CVSU
Baltimore Harbor Tunnel, I895 northbound and southbound	Portable	CVSU
Ft. McHenry Tunnel, 195 northbound and southbound	Portable	CVSU
Note: The table has been modified from the original version provided by the Motor Carrier Division contact.		
CVED - Commercial vehicle enforcement division		
CVSU - Commercial vehicle safety unit		

Figure 1. West Friendship TWIS Entrance

Figure 2. Inspections at TWIS

Table 2. Levels of Roadside Safety Inspections

Levels	Description
Level I	**North American Standard (NAS) Inspection:** examination of driver's license, medical examiners' certificate and waiver, if applicable, alcohol and drugs, driver's record of duty status as required, house of service, seat belt, vehicle inspection report, brake system, coupling devices, exhaust system, frame, fuel system, turn signals, brake lamps, tail lamps, head lamps, lamps on projecting loads, safe loading, steering mechanism, suspension, tires, van and open-top trailer bodies, wheels and rims, windshield wipers, emergency exits on buses and hazardous materials (HM) requirement, as applicable.
Level II	**Walk-Around Driver/Vehicle Inspection:** Only those examination items that can be inspected without physically getting under the vehicle.
Level III	**Driver-Only Inspection:** A roadside examination of the driver's license, medical certification and waiver, if applicable, driver's record of duty status as required, house of service, seat belt, vehicle inspection report, and HM requirements, as applicable.
Level IV	**Special inspection:** Typically include a one-time examination of a particular item, and normally made in support a study or to verify or refute a suspected trend.
Level V	**Vehicle-Only Inspection**: Vehicle inspection items specified in Level I inspection without a driver present.
Level VI	**Enhanced NAS inspection for radioactive shipments:** An inspection for select radiological shipments, which include inspection procedures, enhancements to the Level I inspection, radiological requirements, and the enhanced out-of-service criteria

Source: FMCSA, "North American Standard Driver/Vehicle Inspection Levels," http://www.fmcsa.dot.gov/safety-security/safety-initiatives/mcsap/insplevels.htm (Accessed June 1, 2011).

The inspection process can be conducted either manually or electronically through the ASPEN system, a computer application for collecting inspection information (Federal Motor Carrier Safety Administration n.d.). Manual inspections are conducted using Form MSP-24-32, which is filled out by the inspector. After the inspector completes the inspection report, it is manually checked before the reports are sent to MSP-CVED for processing in SAFETYNET, "a database management system for processing driver/vehicle inspections, crashes, compliance reviews, assignments, and complaints (Federal Motor Carrier Safety Administration n.d.)."

The electronic inspection reports are entered at roadside workstations or laptops using the ASPEN software. The USDOT number or the Interstate Commerce Commission (ICC) numbers of the vehicle enables ASPEN to remotely access the inspection selection system (ISS). ISS provides a comprehensive history of the carrier and other details such as the vehicle out-of-service (OOS) rate, driver OOS rate, safety fitness rating, inspections per power unit, inspections per driver, and total number of inspections. This information is used as grounds for conducting an inspection and updated weekly. Additional details on violations can also be accessed using ISS. The software highlights all potential problems with the carrier, making the inspection process easier for the inspector.

All inspections are conducted by certified inspectors in accordance with the North American Standard Inspection Procedures and North American Standard OOS Criteria (McCartt, et al. 2007). During the inspection, a vehicle and/or driver may be declared OOS due to issues that are likely to cause an accident or a breakdown (Federal Motor Carrier Safety Administration 2012). Vehicles and drivers placed on OOS cannot continue on their journey until all corrective actions required by the OOS notice have been completed (Federal Motor Carrier Safety Administration 2012).

Roving Inspection

CVED as well as CVSU can conduct roadside size and weight enforcement operations through the use of portable scales by roving crews. CVSU has roving crews present on both northbound and southbound lanes of the Baltimore Harbor tunnel as well as the Fort McHenry Tunnel. CVED operates portable scales at Park and Ride TWIS as well as the Vienna TWIS. Roving crews of civilian employees (safety inspectors and cadets) as well as troopers primarily enforce commercial vehicle regulations for vehicles and drivers that attempt to bypass fixed weigh stations in order to avoid being detected.

Review of Relevant Literature

To the authors' best knowledge, research on resource allocation for motor carrier programs is nonexistent. Thus, the study team focused on reviewing literature that provides theoretical, empirical, and/or factual support in establishing assumptions for the objective function for the resource allocation model proposed in the current study. With this in mind, the following sections are organized by topic areas.

Association between Roadside Inspection and Crash Avoidance

An important assumption in assessing the effectiveness of the motor carrier program is that the program is likely to help avoid truck-involved crashes, fatalities, and injuries. One of the earliest studies that examined the relationships between CMV inspections and crash avoidance was published by McDole in 1977 (Lantz 1993, 2). Using the truck-involved crash data from Michigan, Pennsylvania, Texas, the Bureau of Motor Carrier Safety, and the 1972 Truck Inventory and Use Survey (TIUS), the study found a strong relationship between quality vehicle maintenance and inspection procedures with decreased crashes related to defects (Lantz 1993, 2). A similar study conducted by researchers at the Pennsylvania State University (PSU) found an association between roadside inspections and crash reduction (Lantz 1993, 3). PSU found that driver-related violations were more related to potential crashes and recommended increased efforts in identifying, citing, and/or educating unsafe drivers in order to avoid potential crashes.

A more comprehensive study was conducted by Lantz (1993). Lantz examined the relationship between carriers' performance on roadside inspections and safety/compliance reviews (SR/CR), and their accident rates. 1,334 carriers that had 20 drivers or more and that had at least ten roadside inspections in 1990 and 1991 were examined. The study found that violation and OOS rates were positively related to an increase in reportable accident rates.

In summary, past studies have supported the positive impacts of roadside inspections on truck-involved crash prevention. This relationship is used as one of the study assumptions in building the resource allocation model.

Effectiveness of Roadside Inspection: Intervention Model

The effectiveness of the safety program is often measured by crash reduction. The Federal Motor Carrier Safety Administration (FMCSA) designed an intervention model to measure the effectiveness of roadside inspection and traffic enforcement (John A. Volpe National Transportation System Center 2004). FMCSA defined the program's effectiveness "in terms of safety, prevented crashes, and avoided fatalities and injuries." The model assumed that "roadside inspection and traffic enforcement directly and indirectly contribute to crash reduction" (John A. Volpe National Transportation System Center 2004, i). Another assumption of the model is that "observed deficiencies (OOS and non-OOS violations) discovered at the time of roadside inspections and/or traffic enforcements can be converted into crash risk probabilities and can be ranked into discrete risk categories" (John A. Volpe National Transportation System Center 2004, 5). Five predefined risk categories were used for assigning crash probabilities. The categories (often called Cycla Risk Category) were developed through "a synthesis of expert knowledge and judgment regarding the risks associated with different roadside violations (Cycla Corportation 1998)." The five categories are as follows:

- Risk Category 1—the violation is the potential single, immediate factor leading to a crash.
- Risk Category 2—the violation is the potential single, eventual factor leading to a crash.
- Risk Category 3—the violation is a potential contributing factor leading to a crash.
- Risk Category 4—the violation is an unlikely potential contributing factor leading to a crash.
- Risk Category 5—the violation has little or no connection to crashes.

Weights were assigned to each category based on the potential safety hazard; then avoided crashes, fatalities and injuries were computed. The latest FMCSA report estimated that 8,149 crashes, 275 fatalities, and 5,206 injuries were avoided in the U.S. as a result of roadside inspections (Gillham, Horton and Schwenk 2013).

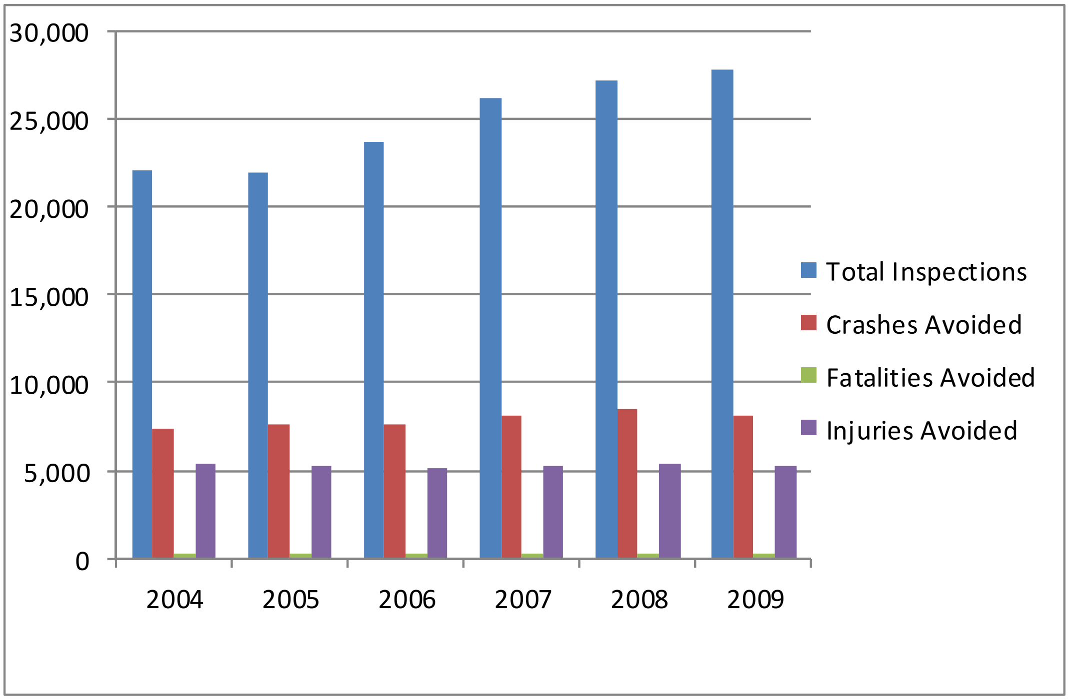
The intervention model study is probably the best study available on the effectiveness measurement of the inspection program. However, one important limitation should be noted. The study did not provide grounds to determine what would be an appropriate number of inspections with given resources. If the logic of the intervention model is followed, an agency must keep increasing the number of inspections to improve the effectiveness of the program which may not be possible due to limited resources.

Table 3 shows the total number of inspections in the U.S. between 2004 and 2009 and avoided crashes, fatalities, and injuries that were computed by the intervention model. A visual representation of the table is provided in Figure 3. As the total number of roadside inspections increases, more crashes and fatalities are avoided. Thus, more benefits of the program would be obtained by conducting more inspections. However, the marginal benefit from conducting an additional inspection decreases. Figure 4 presents avoided crashes, fatalities, and injuries per 1,000 inspections. While the total inspections increased by 26 % to nearly 2.8 million in 2009 from 2.2 million in 2004, avoided crashes per 1,000 inspections decreased to 2.92 in 2009 from the peak of 3.45 in 2005 when the least number of inspections were conducted during the six-year period. This does not mean that fewer inspections need to be conducted. This finding may imply that with the increase in inspection activities, fewer unsafe vehicles are on the road. More importantly, this finding is indicative of the need for a sound methodology to determine a best possible allocation of the limited resources to maximize program benefits. That is, if guidance on the number of inspections by different levels of inspection can be provided, the overall program benefits can be increased. This is what the current study has tried: that is, the allocation of the resources in a way to maximize roadside inspection program benefits.

Table 3. Total Inspections, and Avoided Crashes, Fatalities, and Injuries

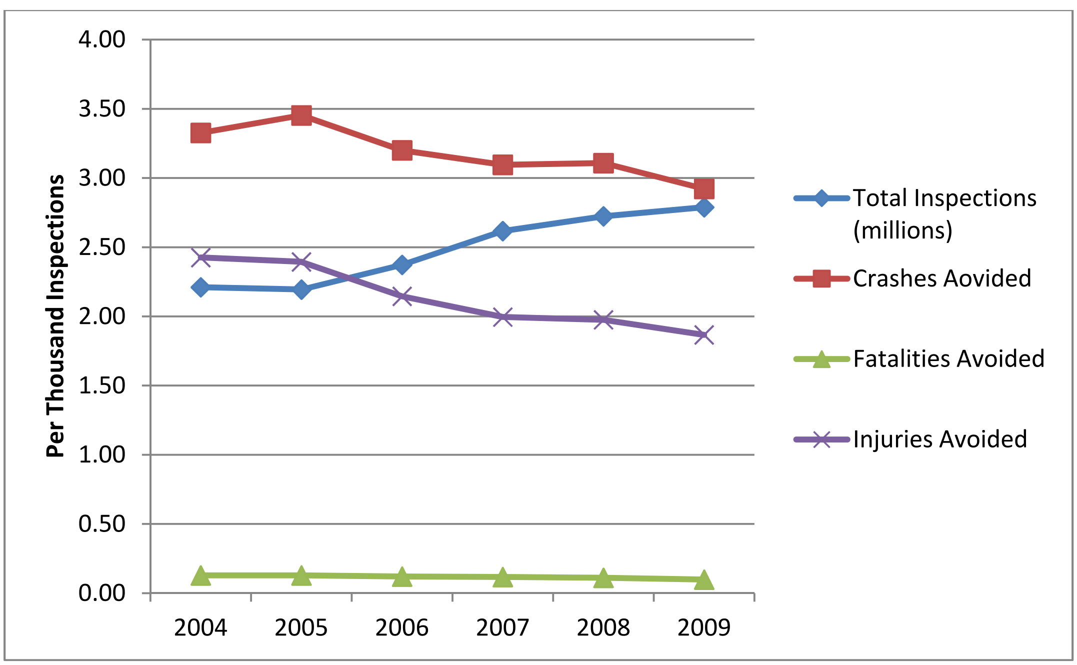
Year	Crashes Avoided	Fatalities Avoided	Injuries Avoided	Total Inspections (Hundreds)
2004	7,353	284	5,362	22,108
2005	7,575	282	5,252	21,940
2006	7,593	287	5,090	23,728
2007	8,101	307	5,222	26,169
2008	8,464	304	5,381	27,236
2009	8,149	275	5,206	27,887

Source: Modified based on the report by Gillham, Horton and Schwenk 2013



Source: Modified based on the report by Gillham, Horton and Schwenk 2013

Figure 3. Total Inspections, and Avoided Crashes, Fatalities, and Injuries



Source: Modified based on the report by Gillham, Horton and Schwenk 2013

Figure 4. Avoided Crashes, Fatalities, and Injuries: Per 1,000 Inspections

Effectiveness of the Program: Benefits and Costs

Another way to measure the effectiveness is benefit-cost analysis (BCA). This is an appropriate tool when the benefits and costs of a program can be quantified (Weimer and Vining 1999). In general, a BCA ratio of 1.0 is considered a bottom line to be considered as an economically viable project (Revelle, Whitlatch and Wright 2004).

Moses and Savage (1997) conducted one of the early studies assessing the benefits and costs of the motor carrier program. Using detailed audit and inspection information of 6,000 firms, the BCA for three federal motor carrier programs were assessed. The benefits of the roadside inspection were computed by applying accident risk percentage and accident cost to the reportable accidents. The authors defined reportable accidents as "more serious accidents involving a fatality, a serious injury, or more than $4,400 in property damage" (Moses and Savage 1997, 52). For the computation of benefits, violation types were divided into four categories: brake problems, other vehicle problems, driver impairment, and other driver problems. The computed benefits consist of avoided fatalities, injuries, property damage, traffic delay, business disruption, and the provision of high quality service. In addition, costs were computed in terms of inspection costs, government costs, other public funds, operating costs for firms, and deadweight loss. The study found that depending on the deterrent effect (i.e. the prevention of future occurrence of the same type of violation), the benefit-cost ratio ranged from 0.87 (with no deterrent effect), 1.64 (with 25% deterrent effect) to 1.94 (with 50% deterrent effect). In other words, when the deterrent effect is 50%, one dollar input to the program would yield $1.64. This study provides an important implication of the current study in terms of the impact of roadside inspection into the future. Using 7 years of the data, Moses and Savage (1997) determined that the deterrent effect of roadside inspection was 25%. The long-term effect could be higher. The survey by Lantz (1998) indicated that the deterrent effect could be higher. She found that that "about 70% of drivers agreed that roadside inspections improve safety for their company, and 43% of motor carrier managers agreed with the statement."

Resource Allocation Models

In the previous sections, studies evaluating the effectiveness of the roadside inspection program were reviewed. Those studies supported a notion that roadside inspections helped reduce crashes. However, one important question remained unanswered: At what level should roadside inspections be conducted? Given the limited resources allocated to roadside inspection programs, the number of inspections conducted by an agency cannot be increased infinitely. There should be a point where optimum or near optimum balance is reached so that the maximum amount of program benefits can be obtained. This is where the resource allocation model comes into consideration.

The resource allocation model deals with decision making in allocating limited resources among several activities. In general, resource allocation is determined based on mathematical programming techniques to find the optimum level of intensity of activities (Feldstein, Piot and Sundaresan 1973). As one of the most important roles of government, resource allocation is studied in most disciplines. It has also been widely applied to transportation resource allocation problems such as transit fleet management (Mishra, et al. 2013), pavement management (Medury and Madanat 2013), snow removal (Lindsey and Seely 2000), emergency service (Huang, Fan and Cheu 2006), intelligent transportation systems (Johnston, Ferreira and Bunker 2006), and many others.

While, to the best of the authors' knowledge, no study on resource allocation for roadside inspection has been conducted, at least one study is worth reviewing for the current study. Kar and Datta (2004) built a resource allocation model to prioritize safety planning activities. Using traffic crash data from Michigan and the crash cost information by severity, a model was developed using a linear program. The objective of the model was to allocate a limited safety planning budget in a way that more funds are distributed to the location with higher accident costs. Based on a linear programming technique, the objective function of the resource allocation model was to maximize the budget allocation to the areas with higher needs for safety improvement. This study gave the study team a more clear idea on how to build a model for roadside inspection resource allocation. That is, the objective of the model would be to maximize roadside inspection benefits by allocating more resources to the level and location of inspection that have more severe violations which have a higher likelihood of causing serious truck-involved crashes, bearing in mind the costs of allocating such resources.

Implications to the Current Study

The review of the current practice and relevant studies helped the study team refine the research methodology. First, relationships between truck-involved crashes and roadside inspections have been well established. Second, depending on the types of violations, potential crash risks are different. Thus, the violation types by inspection levels and their potential risk at each TWIS should be considered in building a resource allocation model. Third, using crash cost information, a resource allocation model can be built to help prioritize planning activities. Fourth, the deterrent effect of roadside inspection needs to be factored into the resource allocation modeling process. Moses and Savage (1997) used four levels of deterrent effect (0%, 25%, 50%, and 70%). Lastly, linear programming provides a good technique to find out the optimal level of resource allocation. Building on these findings, the study team developed a conceptual model, and data collection plan, which is discussed in the next section.

METHODOLOGY

This section discusses a conceptual model, data collection and compilation process, summary of the collected data, and resource allocation model building. It starts with the discussion of building a conceptual model that guided the data collection plan. Then, the description of the collected data is provided. Finally, the resource allocation model is introduced and the analysis steps are discussed.

Conceptual Modeling Frame

The development of a conceptual modeling framework was initiated at the proposal development stage and continued until the data collection and preliminary analysis were completed. The conceptual modeling framework enabled the study team to identify a list of desired data. As the study team reviewed more studies and new information from SHA became available, the conceptual model framework was refined.

A conceptual linear programming objective function was built as a maximization problem. Monetary costs (savings) of crashes avoided due to roadside inspection were considered as the inspection benefits. As a simple form, the objective function was formulated as below:

Obj. F. Z = Max ($\sum Benefits\ of\ CMV\ Inspections$ - $\sum Costs\ of\ CMV\ Inspections$)

s.t. $\sum Costs\ \leq MDOT's\ Budget\ for\ the\ Program$

Where

Benefits = monetary costs of avoided truck-involved crashes due to inspection activities

Costs = monetary costs per inspection

The model is based on the following assumptions made on the basis of careful literature review and the study team's educated judgment. They are as follows:

- Deterrent effects exist. That is, every vehicle inspection is believed to prevent a future accident
- There are direct and indirect associations between roadside inspections, violation types, and crashes;
- Crash severities are associated with types of driver and vehicle violations;
- Trucks and drivers with various safety issues are traveling on each roadway, which may result in different inspection levels and violations by TWIS;
- Truck populations in terms of safety ratings, maintenance, driver and vehicle qualities may vary by TWIS;
- TWIS are strategically located;
- The current inspection activities conform to the FMCSA provided guidelines, so the procedure itself is standardized; and,

- Budget is allocated in proportion to inspection hours at each TWIS, based on the assumption that the same unit cost per inspection hours, because, as mentioned in the above assumption, the inspection procedure is standardized.

Data Collection and Compilation

Refining the conceptual resource allocation model guided the study team in identifying data needs. Collecting the necessary data was a lengthy process. With assistance from SHA's Motor Carrier Program, MSP, and MdTAP, an initial data wish list was developed and sent to the contacts for further assistance. Table 4 shows data needs for benefits and costs and collected data after several months of data collection efforts. Each data set will be discussed further in the following sections. The detailed data wish list with questions is provided in appendix A.

Table 4. Data Needs and Collected Data

Input to the Model	Data Needs	Collected Data (Data Provider)
Benefits	Disaggregated inspection records	MCMIS Inspection Files (FMCSA)
	Truck involved crashes in Maryland	CMV crash data (SHA)
	Association between crash severity and inspection violation types	- Severity categories developed by FMCSA - Cycla Risk Category (FMCSA)
	Costs of crashes	CMV crash cost study (FMCSA)
Costs	Resources expended for roadside inspections	- Aggregated personnel hours spent by TWIS available in the 24-1 reports by inspection level (SHA) - Annual inspection-related budget (SHA and MdTPA)

Collected Data Sets

Inspection Summary Reports (24-1 Reports)

The inspection activity is conducted in collaboration with the SHA Motor Carrier Division, CVED, CVSU and other law enforcement agencies of local jurisdictions as well as the Public Service Commission (PSC).

Inspections conducted by various agencies are reported to CVED and CVSU. The reported inspection information is summarized as a database by the SHA Motor Carrier Division (MCD). A 24-1 report is a summary report that shows inspection activities by state, region, and agency. The 24-1 reports for the years 2006 through 2010 for the facilities managed by MSP and MdTAP were provided by a technical contact in MCD. An example copy of a 24-1 report is provided in appendix B. The report provides a detailed summary on the activities by facility. It includes personnel hours by various program activities (i.e., weight measurement system, inspection, safety audit, court time, training, etc.); the number of inspections by level; the number of vehicles weighed; and enforcement related summaries.

Unfortunately, not all information could be used for the study due to the following reasons. First, inspection data at the disaggregated level were not available, while the proposed resource allocation model required individual inspection records and corresponding violation types. The 24-1 reports available to the study team include an annual summary by agency, region, roving inspection locations, and TWIS. Second, changes in reporting formats over time prevented the study team from developing model based on all years in the data (Table 5). Third, due to the changes in facility type classifications over time, a detailed historical analysis by TWIS was not possible (Table 6). For these reasons, the most consistent information that could be comparable over time and useful for the current study is personnel inspection hours and the total number of inspections.

Table 5. Changes in Personnel Hour Reporting Categories in Form 24-1

	MCSP Hours													NMCSP Hours						
YEAR	INSP	AUD	SA	WT/MS	CT	ASSIST	TR	CV	CR	PC	TE	CRM	PM	WT/MS	CT	TR	APD	OPD	SHD	TE
2006-2008	√	√			√		√	√	0	√	√	√		√	√	√	√		√	
2009	√		√		√		√		√	√	√	√	√	√	√	√		√	√	√
2010	√		√	√	√	√	√		√	√	√	√	√	√	√	√		√	√	√

Table 6. Changes in Facility Classification in Form 24-1

Classification for	Year				
Summary Report	2006	2007	2008	2009	2010
Audits	√				
Audit/CR		√	√		√
Diesel	√				
Diesel/Noise		√	√		
Metro	√	√	√		
Northern	√	√	√		
Roving	√	√	√	√	√
TWIS	√	√	√	√	√

Table 7 presents the summary of total inspection hours, minutes taken per inspection, the number of inspections conducted by level, and the total number of inspections during the study period. The table was created based on the 24-1 summary reports. Please note that the 2010 data was not complete since the inspections conducted by roving crews were not available to the study team at the time of data collection. Between 2006 and 2009, the total number of inspections plateaued, showing a marginal decrease of 1 %. The total inspection hours, by contrast, showed a wider margin of decrease to almost 6 %. Therefore, minutes spent per inspection decreased by about one and a half minutes during the same time period. The decrease in time taken per inspection should be interpreted cautiously. A decrease in time per inspection may be a sign of the improved efficiency of the roadside inspection process. On the other hand, the decreasing trends of the number of level I and level II inspections and an increase in level III inspections could contribute to the average inspection time. The inspection level I is the most comprehensive inspection level that contains the examination of the driver and the vehicle. The average time per level I and level II inspections in Maryland in 2009 was approximately 29 minutes and 19 minutes, while level III inspections took only about 12 minutes on average.[4]

Figure 5 shows a graphical representation of changes in level of inspections conducted by year, which may explain the decrease in the average inspection time. Each bar on the figure is the proportion of each level by year as a percentage of total inspection of a corresponding year. Between 2006 and 2010, the percentage of level I inspections decreased by about 2 % (from 30 % to 28 %). Similarly, the proportion of level II inspections during the same time period dropped to 54 % of the total inspections in 2010 from 58 % in 2006. On the other hand, the driver-only inspections (level III) took a larger share in 2010 (17 % of the total inspections) than in 2006 (10 % of the total inspections). A relative importance of level III inspections seemed to be increased. Another way to look at this change is comparing the ratio of level I or level II inspections to level III inspections. In 2006, one level III inspection was conducted per every 2.9 level I inspections or every 5.8 level II inspections. By 2010, this ratio changed to one level III inspection per 1.6 level I and 3.2 level II inspections. This trend may be indicative of the shift of inspection emphasis to driver-related violations. This may be in line with a series of efforts by government agencies regarding driver's hours of service, distracted driving, and other human factors that may contribute to severe crashes.

Table 7. Inspection Hours and Number of Inspections by Level: 2006 – 2010 (For all inspection locations)

Year	Inspection hours (Hour)	Minutes per Inspection	Number of Inspections						
			Level I	Level II	Level III	Level IV	Level V	Level VI	Total Inspections
2006	93,988	41.09	40,571	79,862	13,875	2,813	127	-	137,248
2007	96,551	41.44	40,593	78,327	18,305	2,473	103	-	139,801
2008	92,429	39.96	39,580	80,239	17,908	923	126	-	138,776
2009	88,533	39.25	33,725	77,192	21,807	2,521	70	20	135,335
2010	71,251	39.78	29,837	58,414	18,091	1,117	17	1	107,477

[4] This calculation is based on the inspection file of the Motor Carrier Management Information System (MCMIS) of the Federal Motor Carrier Safety Administration (FMCSA) that was purchased for this study.

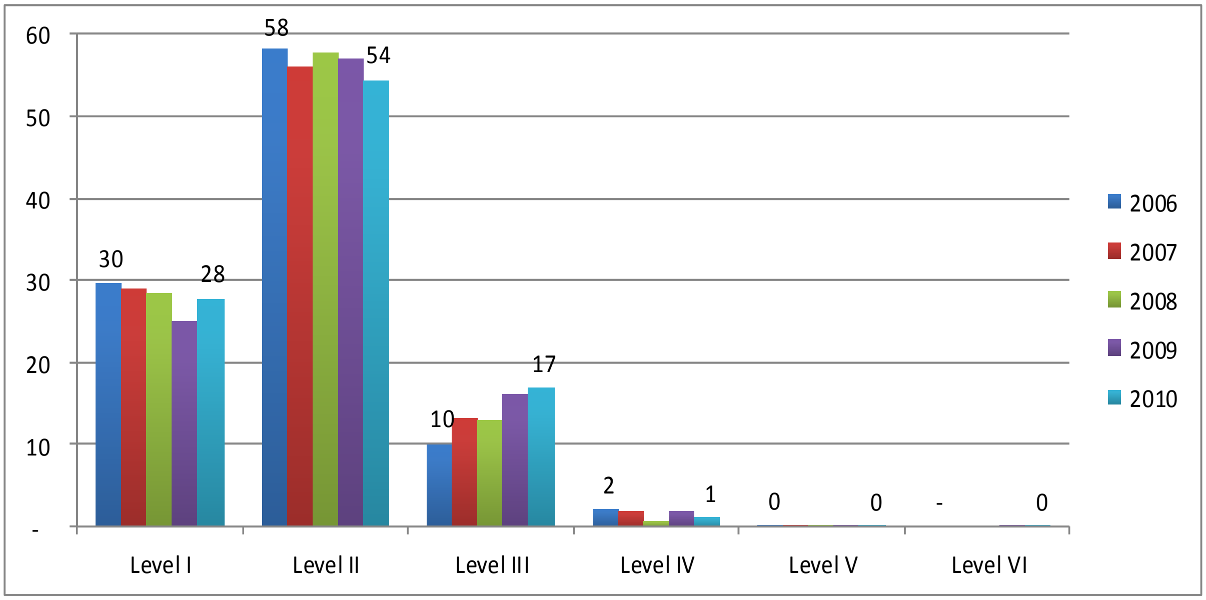


Figure 5. Percentage of Inspections by Level (2006-2010)

<u>Operational Budget Information</u>

One of the most important variables in the resource allocation model is the information on resources (e.g., budget) expended for the program of interest. The budget information provides a picture of the maximum level of resources that can be expended for inspection activities undertaken by MSP and MdTAP.

Operational budget information related to CVED and CVSU activities were provided to the study team. The budget summaries from the two agencies were provided with different granularities. CVED's budget included detailed line items summarized at the agency level, including 76 detailed line items summarized by 12 categories (e.g., salaries and wages, technical and special fees, communications, etc.). On the other hand, the budget from CVSU was an agency summary. Because of this difference, the total budget of each agency was used for the proposed resource allocation model, while not using detailed line items that may have direct relationships with inspections at TWIS.

<u>Inspection File of the Motor Carrier Management Information System (MCMIS)</u>

To complement the summary information of the 24-1 report, an inspection file available through MCMIS was purchased. MCMIS is a database maintained by FMCSA. It contains information on the safety fitness of commercial motor carriers (trucks & buses) and hazardous material (HM) shippers subject to the Federal Motor Carrier Safety Regulations (FMCSR) and the Hazardous Materials Regulations (HMR) (Federal Motor Carrier Safety Administration 2011a).

The publicly available inspection file consists of six tables: inspection, carrier, inspection unit, inspection violation, inspection shipper violation, and inspection study. The tables are based on the data from state and federal inspections on "interstate and intrastate motor carriers and shippers and transporters of hazardous materials," which are mostly conducted "at the roadside by state inspection personnel under the Motor Carrier Safety Assistance Program (MCSAP)" (Federal Motor Carrier Administration 2008, 3).

Of the six tables of the inspection file, the inspection and inspection violation tables are of most interest to the current study, since the two tables include the variables that are most relevant to the current study purpose. Variables of interest in the inspection table include the number of inspections by level, inspection locations, and time taken per inspection. The inspection violation table includes important variables such as types of violations and driver/vehicle out-of-service (OOS) violations. A vehicle and/or a driver will be placed "out-of-service (OOS)" if violations associated with the vehicle and/or the driver are severe enough to result in a high likelihood of an accident or breakdown (Federal Motor Carrier Administration 2008, 3). A summary of the MCMIS data is provided later in this report.

Safety Measurement System (SMS) Violation Severity Weight

Violations identified by inspectors have different safety implications; thus, they should be treated differently in modeling allocating resources. For example, violation code 390.21 is issued when no DOT number marking is printed on the cab. This violation alone may not be a big contributing factor compromising safety. However, a vehicle on the road with an inoperative/defective break (violation code 393.48A) is at a significantly higher risk compared to a driver using a radar detector (violation code 392.71).

To address different potential safety implications by violation categories, the Safety Measurement System (SMS) severity weight was used as a weighting scheme for assigning inspection activities by violation categories. The SMS severity weights were developed by the Volpe Center to meet the Compliance, Safety, and Accountability (CSA) Initiative of FMCSA with the primary goal of crash reduction for commercial motor vehicle (CMV) (Volpe Center 2010).

A number of resources are used to derive the behavior groups (BASIC) that are the basis for SMS: Large Truck Crash Causation Study (LTCCS); CSA Driver History Study; the existing FMCSA regulatory structure; and study conducted under FMCSA's Compliance Review Workgroup (CRWG), the predecessor to CSA (Volpe Center 2010). According to the Volpe study (2010, 2-1), BASICs are defined as six categories: (1) *Unsafe Driving BASIC, (2) Fatigued Driving (Hours-of-Service) BASIC, (3 Driver Fitness BASIC, (4) Controlled Substances/Alcohol BASIC*, (5*) Vehicle Maintenance BASIC, and (6) Cargo-Related BASIC.*

One of the key utility of SMS is the assignment of severity weight to various FMCSA violations. The SMS approach is based on statistics and observed relationship of violations with crashes. In the development and evaluation of SMS, statistical regression models were developed for correlation between violation rates in each violation group (e.g., tires, brakes) and crash involvement using data on roughly 250,000 drivers (Federal Motor Carrier Administration 2011b, 12). Of the 34 violations groups related to crash incidents, 27 (79 %) showed statistically significant relationships between high violation rates and greater crash occurrence (Federal Motor Carrier Administration 2011b, 12). For each of the six BASICs an SMS violation severity weight ranging from 1 to 10 has been published, where 10 corresponds to a severe violation (Volpe Center 2010).

Data Compilation Task

How Collected Data Were Put Together

The collected data were compiled in Microsoft Access and then exported to Microsoft Excel for further data manipulation. The most important data were the inspection table and violation table of MCMIS. The two tables are associated with a unique identifier: Inspection ID. Since it is possible that one inspection can result in multiple violations, a one-to-many merge from the inspection table into the violation table was performed. Table 8 shows a part of the merged table, Inspection-Violation Table. Each row in the table is one violation. Then, SMS severity weights were assigned to each violation code, which is discussed in the next section.

Table 8. Example of the Merged Inspection-Violation Table

Inspection ID	Inspection Violation ID	Violation Codes	
		Part Number	Section Number
30471755	112222743	391	41(a)
30471776	112222835	393	75(a)
30471776	112222836	393	95(a)
30472004	112223226	393	75(a)
30472004	112223227	393	45
30472006	112223228	391	11(b)(4)
30472531	112223653	393	9H
30472531	112223654	393	45(d)
30472531	112223655	396	3A1BOS
30472583	112223670	393	11
30472584	112223671	392	8
30472584	112223672	390	21(b)

Process for Updating SMS Severity Weights

For each of the inspections from MCMIS, for each of the violations, the violation code part number and section number were matched to the SMS code part and section numbers in order to obtain the SMS severity for that violation. Since there was no easy way to merge the two tables with multiple variables, a Java script was created. The script ran a search loop to find and assign an appropriate SMS severity for each violation. For OOS violations, the value 2 was added to the severity weight (Volpe Center 2010).

However, roughly 17 % of the violation records (i.e., rows in the inspection-violation table) did not have matching SMS severity weights. For the mismatching records, the SMS severity weights were imputed based on the clustering of similar violations in order to complete the data set. The process for updating the SMS severity weights is shown in Figure 6 and briefly described below.

Step 1. Identify if the first six numbers and characters (including the period between the part number and the section number) of the violation code part and section matches with at least one SMS code part and section that have the same first six numbers and characters. The severity weight attached to that missing section is assigned an average value of the severity weights of the first six matching characters. For example, the violation code 390.21(b) in MCMIS does not have a matching code in SMS. To impute a weight, the average SMS weight for the first six numbers and characters (i.e., 390.21) is searched. If the average SMS value for the code 390.21 is available, that value is assigned to the violation code 390.21(b). In addition, if 390.21(b) results in an OOS, additional weight of 2 is added.

If there was no match for the first five numbers the search for the next level was conducted in Step 2.

Step 2. Identify if the first five numbers and characters (including the period between the part number and the section number) matches with at least one SMS section that has the same first five characters (i.e., 390.2). The severity weight attached to that missing section is assigned an average value of the severity weights of the first five matching characters. For example, in the previous step, there was no match for 390.21 in SMS. The search of the first five numbers, 390.2, resulted in a match and its average severity is 5. Since 390.21(b) is not OOS violation, the average SMS severity value of 5 is assigned to the violation code.

Step 3. If there is still no match after the two steps, no severity weight is assigned to that missing MCMIS section. Fortunately, all data were successfully assigned SMS severity weights, by using this imputation algorithm.

Establishing Relationship between MCMIS and 24-1

As discussed before, the disaggregate records of inspections were merged with corresponding violations, and SMS severity weights were assigned to each violation. The next step was to establish a relationship between records in 24-1 reports and MCMIS. As discussed earlier, some of the information from 24-1 reports can be used to assign values to each TWIS. However, the inspection location names used in MCMIS did not match the TWIS names used in 24-1 reports. For some instances, no matching names were found. To find correct matches, the list of TWIS names and MCMIS names were created and compared one-by-one in consultation with the SHA technical contact and MdTAP contact.

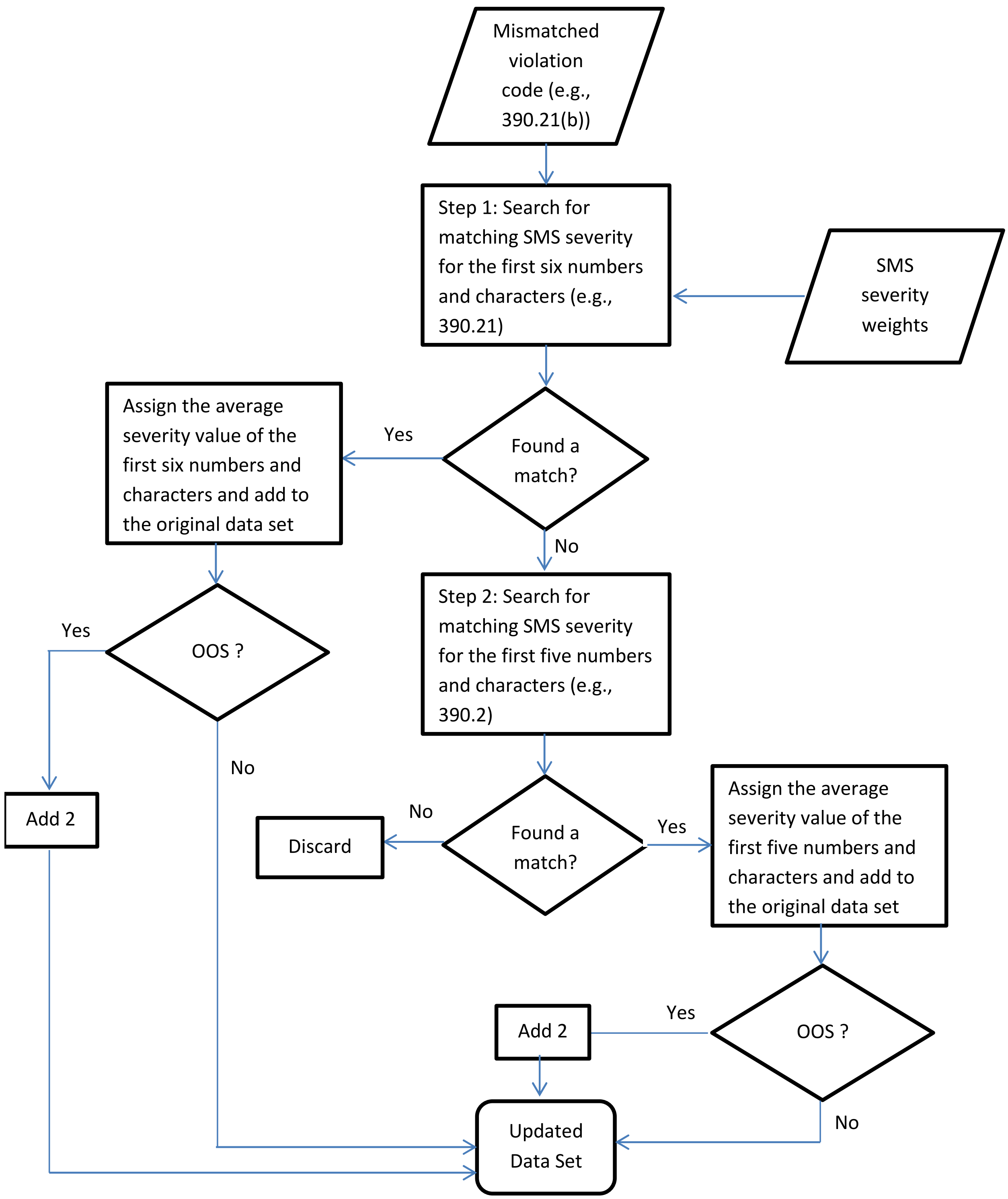


Figure 6. SMS Severity Weight Imputation to Mismatching Violation Code in MCMIS

The final comparison table is summarized in Table 9 that shows several issues identified. First, for the years 2006 through 2007, no matching inspection location names for MdTAP facilities could be found in MCMIS. A change in naming convention may have accounted for this. Second, the changes in reporting format of 24-1 reports did not match what was reported in MCMIS. For example, in 24-1 reports, in the Hyattstown South and North TWISs are reported separately. However in 2006 and 2008, only Hyattstown South was reported in 24-1 report. Since 2009 there has been no distinction between north and south. On the other hand, MCMIS reported inspection records by directional location of TWIS.

As seen in the table, all matching names were found for 2009 and 2010. Since the roving inspection information of 24-1 report for the year 2010 was not available to the study team, the most complete data available to the team was 2009. Therefore, the 2009 data was used for developing the resource allocation model.

Table 9. Comparison of Inspection Location Names

Agency	24-1 Name	MCMIS Name	Operating Status	Year				
				2006	2007	2008	2009	2010
MSP	CONOWINGO	R 1 N/B & S/B Darlington (two should be combined)	Permanent	√	√	√	√	√
MSP	DELMAR	RT 13 Salisbury (separated as NB and SB. Should be combined)	Permanent	√	√	√	√	√
MSP	I-83/PARKTON	I-83	Permanent	√	√	√	√	√
MSP	HYATTSTOWN SOUTH	I-270 SB	Permanent	√	√	√	√	√
MSP	HYATTSTOWN NORTH	I-270 NB	Permanent		√			
MSP	PARK AND RIDE	I-95 @ I-495 (PARK AND RIDE)	Permanent	√	√	√	√	√
MSP	UPPER MARLBORO	Almost same name; Loc Code 16, 17, and 18 in MCMIS need to be combined	Permanent	√	√	√	√	√
MSP	FINZEL	Same	Permanent	√	√	√	√	√
MSP	NEW MARKET	I-70 New Market	Permanent	√	√	√	√	√
MSP	WEST FRIENDSHIP	I-70 W Friendship	Permanent	√	√	√	√	√
MSP	Cecliton	US301 Cecilton	Permanent		√	√	√	√
MSP	FOY HILL	RT 40 EB Foy Hill	Permanent				√	√
MdTAP	I 95 NB JFK	I-95 Northbound	Permanent				√	√
MdTAP	I 95 SB JFK	I-95 Southbound	Permanent				√	√
MdTAP	I 95 SB FMT Toll Plaza	I-95 N/B FT	Roving				√	√
MdTAP	I 95 NB FMT Toll Plaza	I-95 S/B FT	Roving				√	√
MdTAP	Rt 50 EB Bay Bridge	RT 50 E/B Bay	Permanent				√	√
MdTAP	Rt 50 WB Bay Bridge	RT 50 W/B Bay	Permanent				√	√
MdTAP	Rt 40 EB Hatem	Rt 40 EB Hatem	Permanent				√	√
MdTAP	Rt 40 WB Hatem	Rt 40 WB Hatem	Permanent				√	√
MdTAP	I 895 NB BHT Toll Plaza	I 895 NB BHT Toll Plaza	Roving				√	√
MdTAP	I 895 SB BHT Toll Plaza	I 895 SB BHT Toll Plaza	Roving				√	√

Source: 24-1 reports and MCMIS Inspection Table

Summary of MCMIS: Where Maryland Is.

The following section provides a summary of MCMIS data between 2006 and 2010. The status of Maryland is compared with the national average and peer states.

Roadside Inspections

Total Number of Inspections

A total of 16.5 million inspections were conducted across the 50 states and the District of Columbia between 2006 and 2010. California conducted the most inspections (2,586,988), which accounted for nearly 16% of the total inspections conducted in the U.S., followed by Texas (1,837,898-11.17%) and New York (541,395-3.29%). It appears that the rankings are similar to population rankings. The large populous states tend to perform the most inspections; the less populated states perform the least number of inspections.

While Maryland was ranked 7th with 511,639 inspections (the red bar in Figure 7), the state was the 19th most populous state according to the 2010 Census.

Since different states have different areas, populations, road lengths and vehicle miles traveled (VMT), normalizing the number of inspections by the exposure value may provide more meaningful answers. While it may be ideal to normalize inspection frequency by the total trucks traveled in the corresponding state, such information is extremely hard to get, if not impossible. Instead 2010 Census Population and VMT were used as proxy values. It was assumed that the state population may be a proxy for freight delivery and hence more commercial vehicle trips on the road. More commercial vehicles on the road may be related to more inspections.

The number of inspections normalized by state population and VMT are presented in Figures 8 and 9. When inspections per population were calculated (Figure 8), New Mexico (0.30), Montana (0.21), and South Dakota (0.19) conducted the most inspections per population, while Hawaii (.02), Rhode Island (0.02), and Massachusetts (0.01) did the least inspections per population. The most populous states such as Texas, California, and New York were ranked 14th, 21st, and 16th. Maryland was ranked10th. Similar to the finding from Table 10, Maryland conducted more inspections than other states, after normalizing for the population.

When the number of inspections was normalized by VMT, the largest states, such as Texas (21.68), California (7.46), and New York (3.10) appeared on the top rank again (Figure 9), while smaller states were again at the bottom. Maryland's rank was still one of the highest.

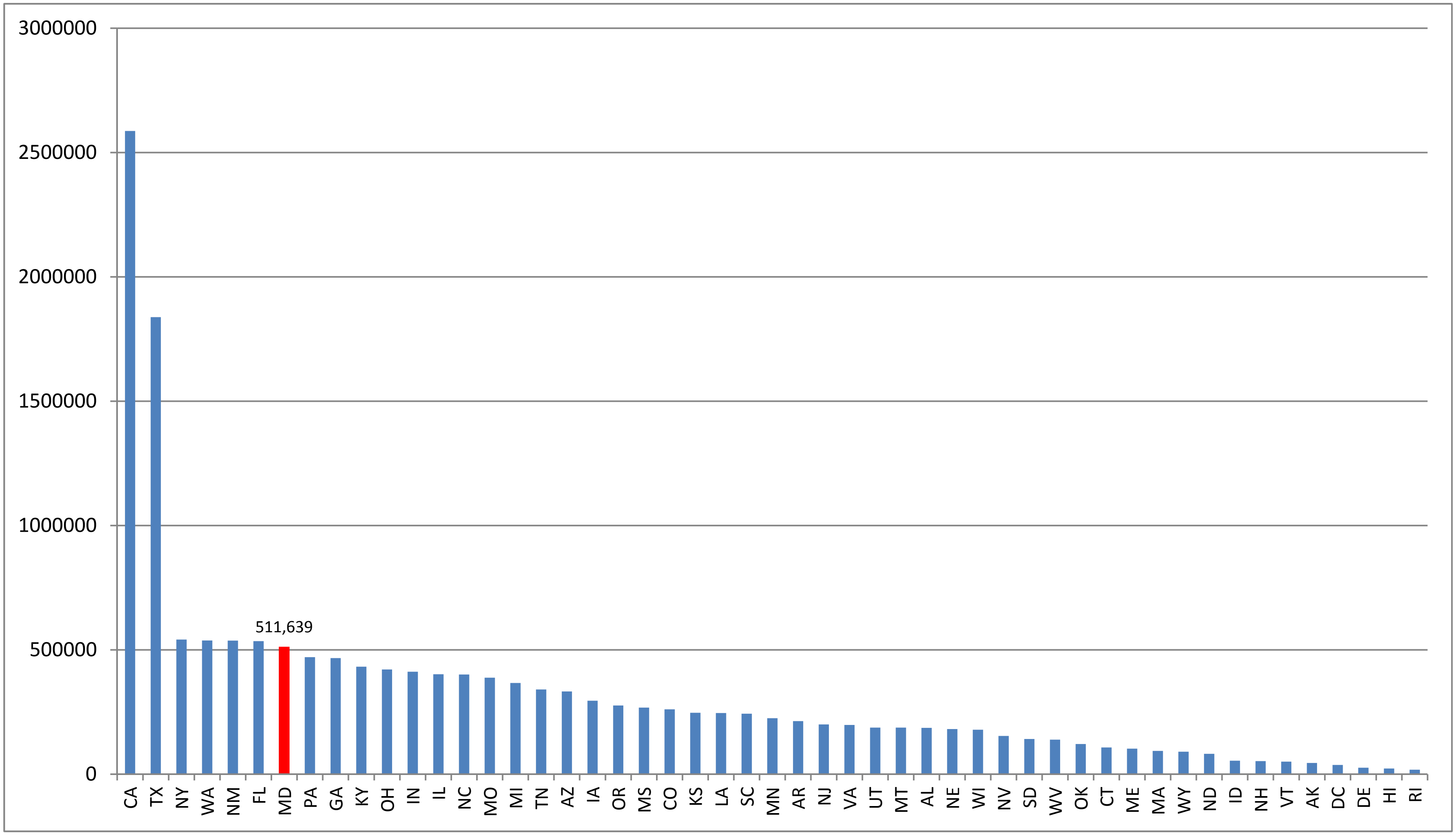
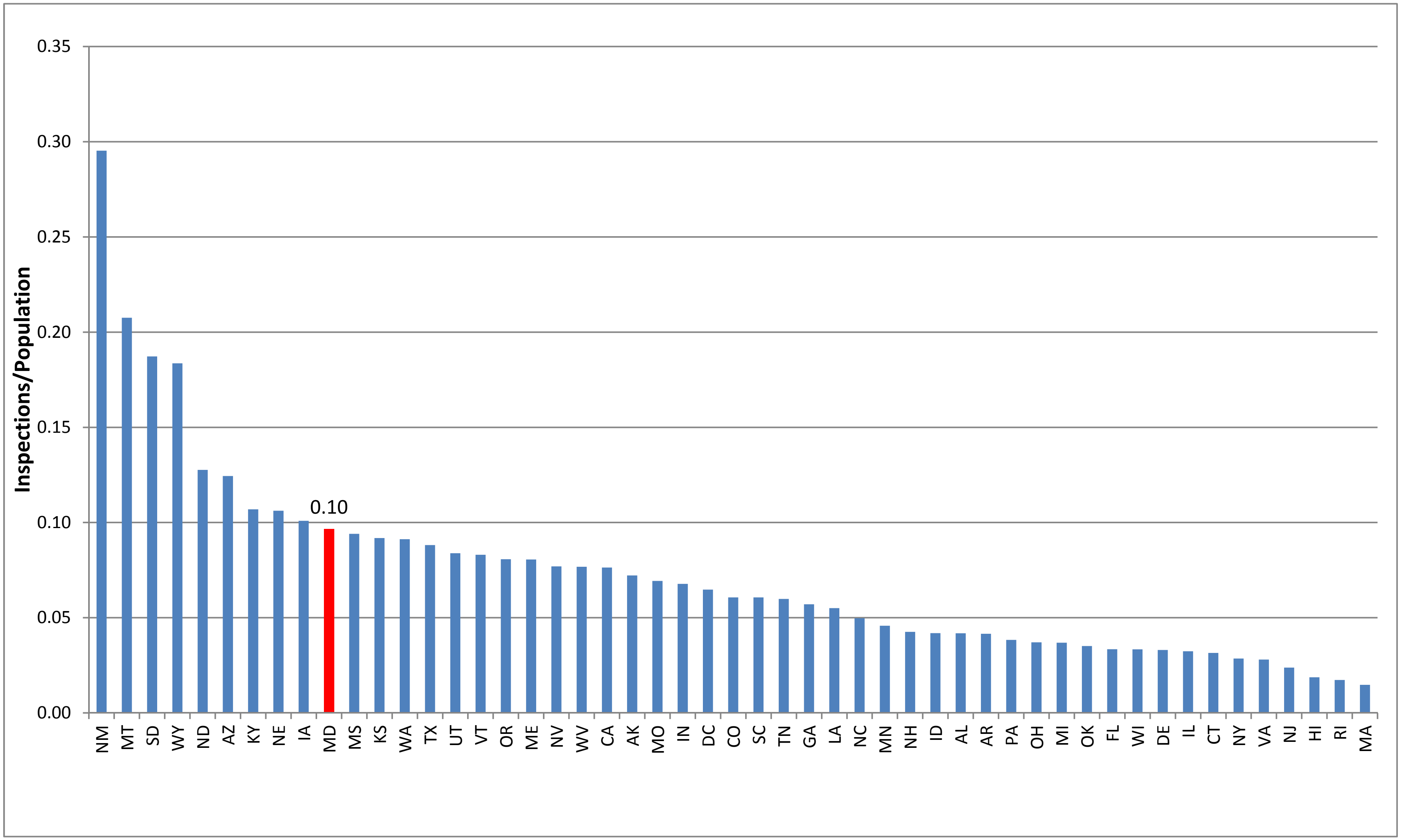
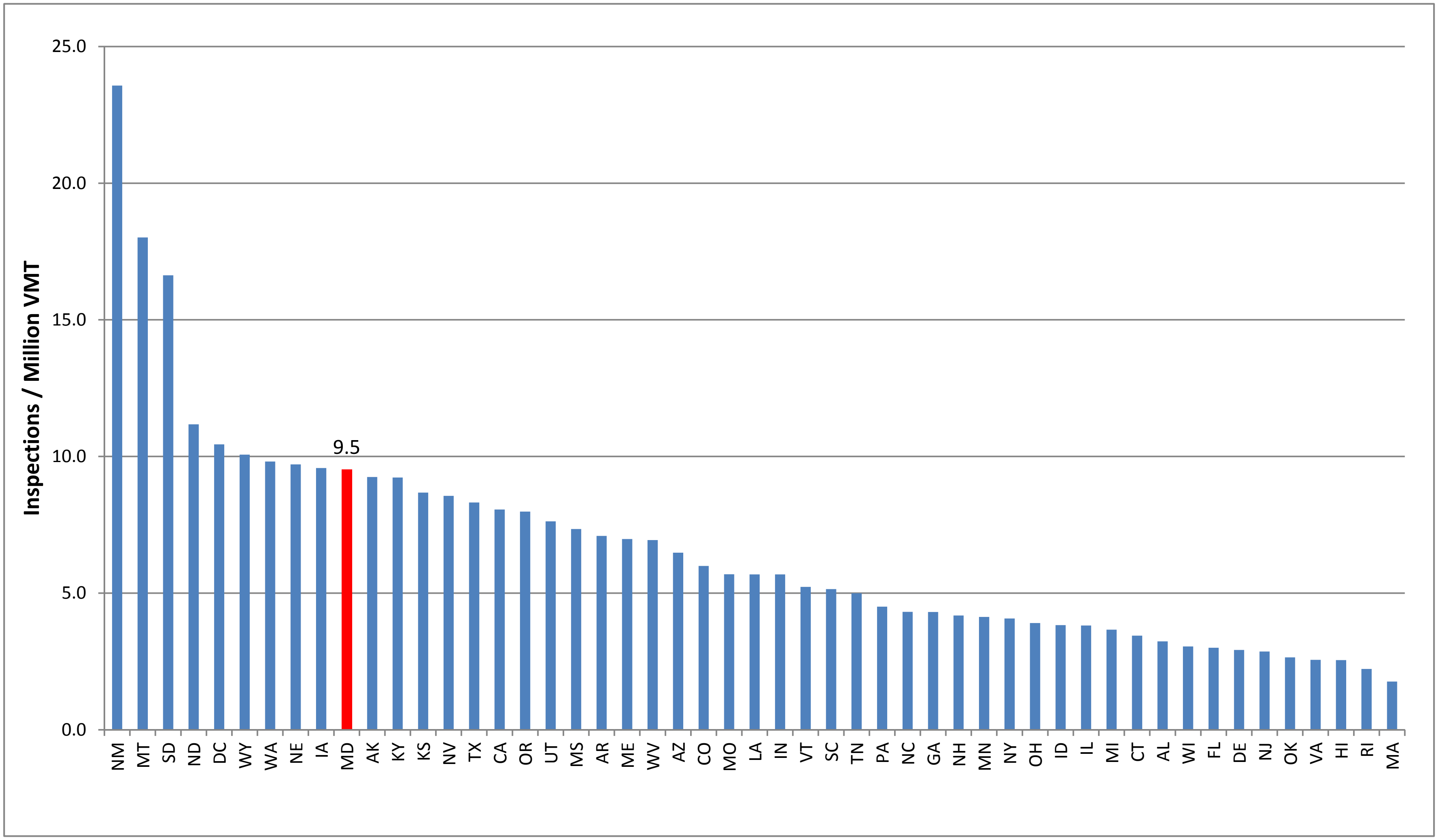


Figure 7. Total Number of Inspections by State (2006-2010)



Source: Population from 2010 Census

Figure 8. Number of Inspections per Population by State (2006-2010)



Source: VMT from FHWA Annual Statistics, 2011

Figure 9. Number of Inspections per Million VMT by State (2006-2010)

Number of Inspections by Level

There are six levels of inspections (levels I, II, III, IV, V, and VI) as described in Table 2. The majority of the inspections are level I, level II and level III. Of 16.5 million inspections conducted in the U.S. between 2006 and 2010, over 96% were levels I, II, or III inspections (Figure 10). Similarly, nearly 95% of inspections in Maryland were levels I, II, or III.

Level II inspections took the largest share of the total in the U.S.; however, the shares of levels I and III were slightly lower than that of level I. In Maryland, on the contrary, level II inspections alone accounted for over 50% of the total inspections, about 17% higher than the national average. Consequently, the shares of level I and level II inspections were lower than the national figures. Such differences between Maryland and the national average should not be of concern. The selection of inspection levels is probably determined by state-specific domain expertise, since each state may have different truck population, policy emphasis, and others. An in-depth review of a state-level data comparison shows that 12 states conducted even higher percentage of level II inspections than Maryland. For example, 70% of inspections conducted in Delaware were level II; and level I and level II inspections together accounted for only 28%. In California, the majority of the inspections were level I (57%), while level II inspections were only 7 % of the total. Moreover, for 21 states, the majority of inspections were level III inspections. Altogether, the state-level comparison suggests that state-specific factors may be a factor for selecting appropriate levels of inspections.

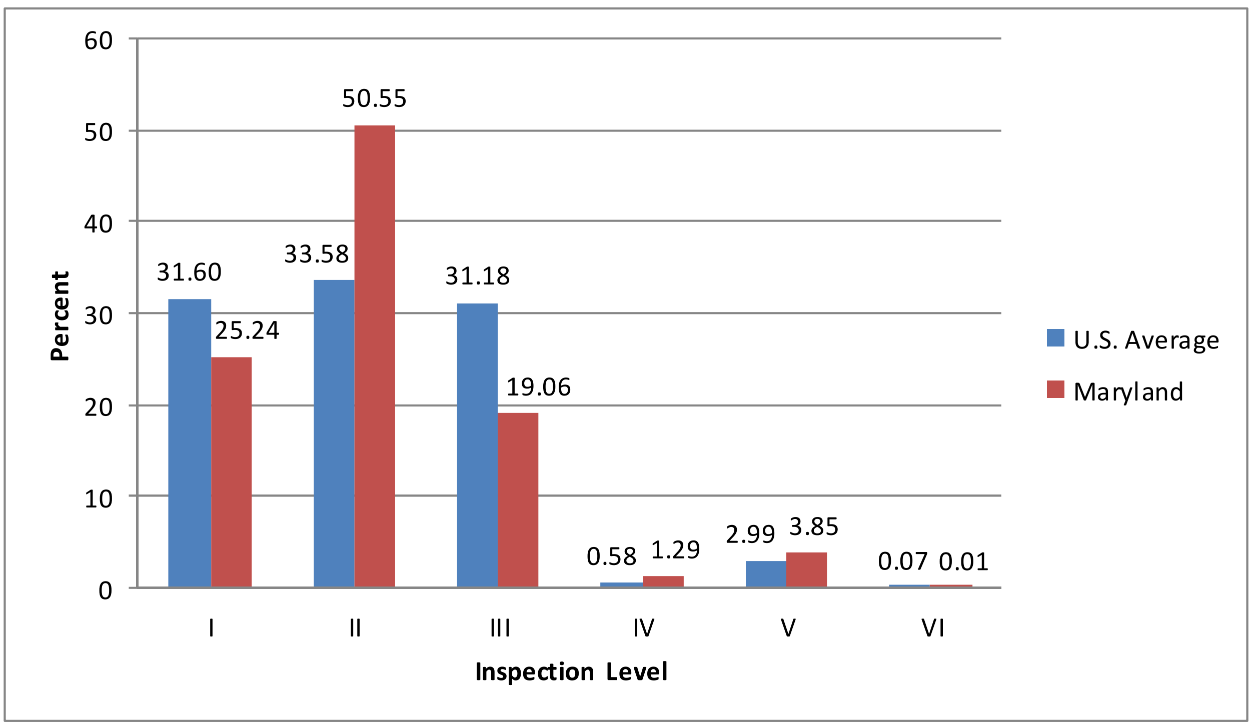


Figure 10. Percentage of Inspections by Level: U.S. Average vs. Maryland

While the share of each inspection level was different from the national average, the overall trend of inspections levels in Maryland was similar to the national average. Figures 11 and 12, respectively, display the changes in the share of each inspection level between 2006 and 2010 in the U.S. and Maryland. The shares of level I and level II inspections have decreased during the study period, while level III inspections increased from 27% of the total inspections in 2006 to 33% in 2010 (Figure 11). Likewise, Maryland saw decreasing trends of level I and level II inspections, while level III inspections jumped to 21% in 2010 from 15% in 2006 (Figure 12).

Reviewing the state-level data also shows that the share of level III inspections has increased in 38 states. This may reflect a recent emphasis on driver-related enforcement rules and policies such as hours of service regulations and distracted driving.

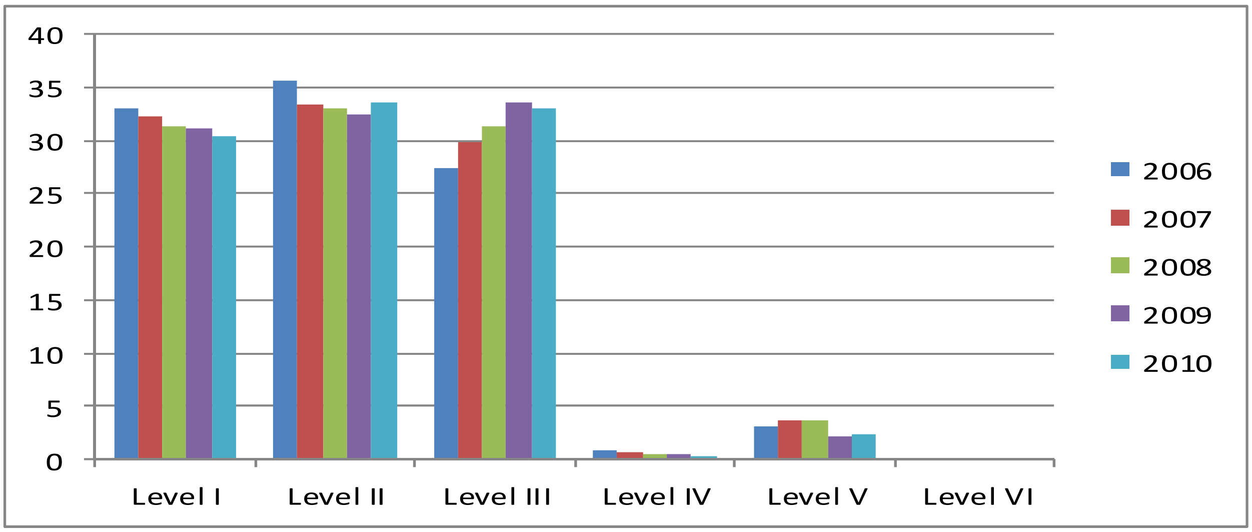


Figure 11. Changes in the Shares of Inspections by Level: U.S. Average

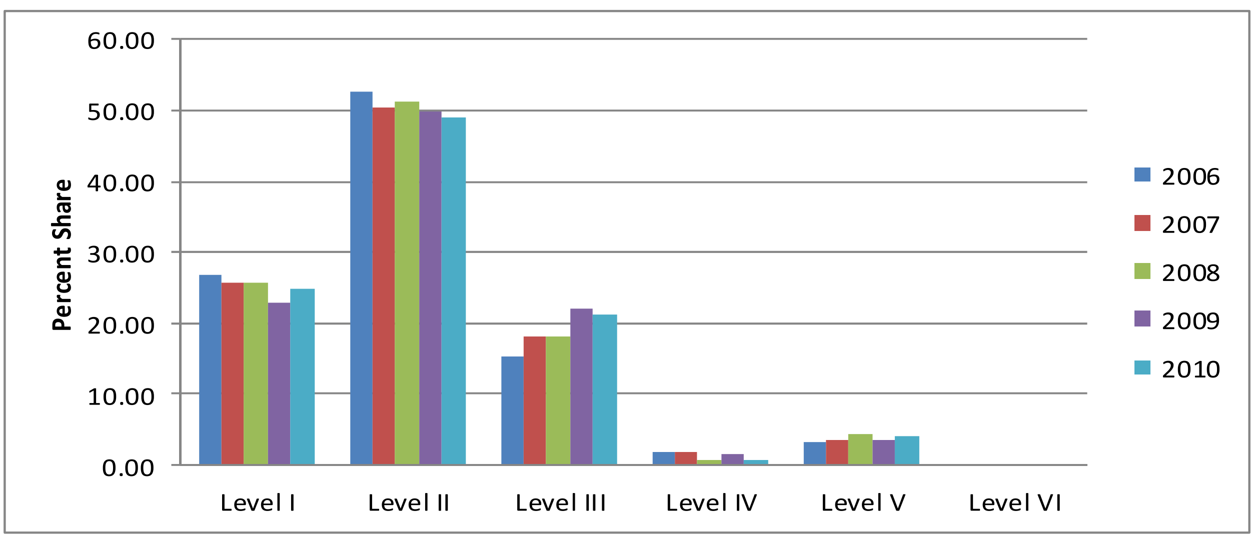


Figure 12. Changes in the Shares of Inspections by Level: Maryland

Inspection Time

The average inspection time by level in Maryland was compared to the national average (Figure 13). Except for level VI, which requires special care and extended time for inspection of radioactive shipments, the national average time per inspection ranged between 22 minutes (level III) and 37 minutes (level V). Inspections in Maryland took shorter than the national average for all levels but level VI. Of the first five levels, inspectors in Maryland spent the longest time for level I inspections (29 minutes) and the least for level III (17 minutes).

Was the average inspection time in Maryland significantly lower? If so, how much? A simple state-level comparison provided an answer. During the study period, only California and North Dakota spent less time for most levels of inspections than Maryland. While California inspectors spent more time on levels V and VI than Maryland, they spent less time for other inspections. In addition, North Dakota spent less time for the first five inspection levels. It is not clear as to why the inspections times were shorter in these states. As mentioned elsewhere in this document, domain expertise, local truck population characteristics, the use of technology and other factors should be examined in future studies to find out about the contributing factors.

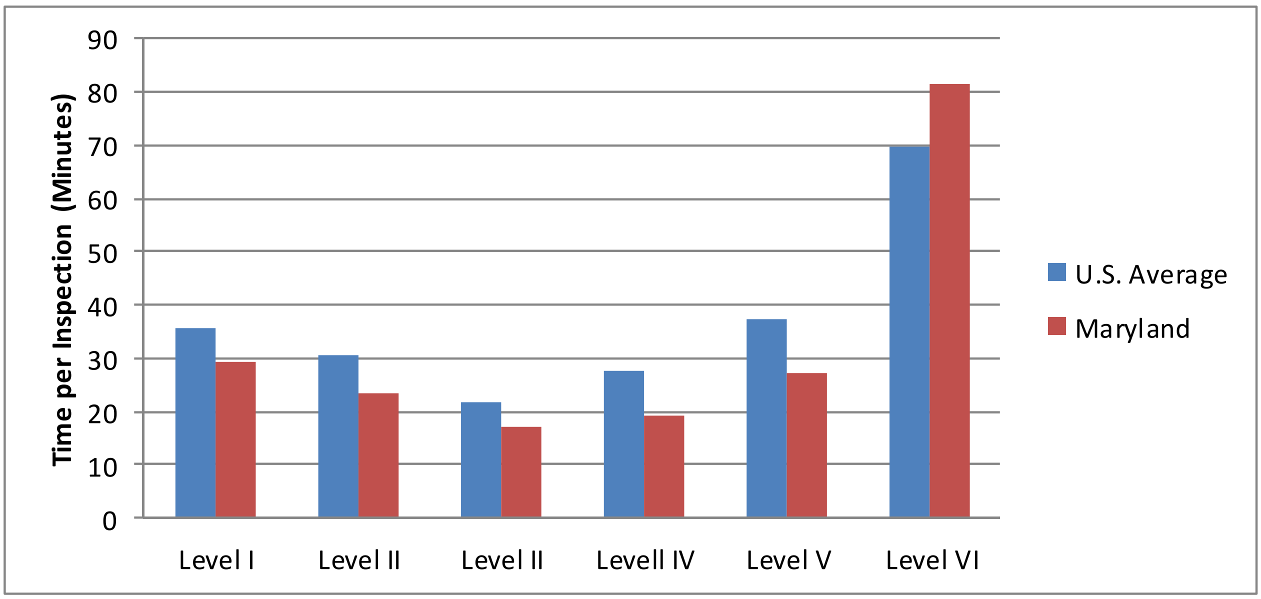


Figure 13. Average Inspection Times (Minutes): Maryland vs. U.S. Average (2006-2010)

Cited Violations

Over 35 million violations were detected by roadside inspections across the U.S. during the study period. The summary by state is presented in Figure 14. Texas alone issued over 7.6 million violation citations, which accounted for roughly 22% of the total violations identified nationwide. California was a distant second with 2.6 million violations, or 7% of the national total, followed by Washington (1.4 million), and New York (1.1 million). As one may expect, small states such as Delaware (49,142), and Hawaii (35,646) had the fewest number of violations. Maryland was ranked 12th with 875,455 cited violations.

The comparison of Figures 7 and 14 reveal that larger states generally conducted more inspections and issued more citations. However, this observation does not show another aspect of the picture, the number of violations per inspection. Each inspection may have none, one, or more violations. In an ideal situation with uniformly distributed distributions of trucks, safety ratings, populations, and other relevant factors, the violations per inspection should be simialar by state. However, the reality is that each state has hetergeneous population of commercial vehicles and other factors that may result in higher violation rates in some states and lower in others.

To this end, the average violations per inspection was computed (Figure 15). Texas topped the list again with 4.14 violations per inspection, followed by Connecticut (3.88) and Wisconsin (3.82). Interestingly, California was listed 50theven though it had the second largest number of violations and conducted the largest number of inspections in the nation. Like California, Maryland had only 1.71 violations on average (35th), while the state was 7th in the number of inspections and 12th in cited violations. Such changes in ranking were probably due to the higher percentage of inspections with no violations. Indeed, Figure 16 shows a somewhat similar trend to Table 15, assuring a relationship between the total number of inspections with no violation and the number of violations per inspection.

Out-of-Service (OOS) Violations

An inspection may result in one or more driver OOS or vehicles OOS. A driver and/or a vehicle are placed OOS when imminent risk factors are identified, due to high likelihood of an accident or a breakdown (Federal Motor Carrier Safety Administration 2012). Figure 17 shows the total number of OOS violations identified during the study period in each state and the District of Columbia. As expected, the three most populated states, also major trade gateways, were on top of the list. Maryland was sixth after Texas and California. Over 175,000 OOS violations were identified by roadside inspections in Maryland between 2006 and 2010.

Again, the population size, total inspections (Figure 7), total violations (Figure 14), and OOS violations (Figure 17) seem to be closely correlated. The correlations of the four variables are high, ranging from 69 to 94%. Nevertheless, given its populations size (ranked 19th in 2000), Maryland conducted more inspections (7th) and citied more violations (12th) and OOS violations (6th). Maryland could be an outliner in this sense.

However, examining OOS violations as a percentage of total inspections (Figure 18) provides a similar picture to Figures 15 and 16. That is, some big states such as Texas, New York, and California moved back in the rankings compared to the figures dealing with absolute number of inspections and violations, while small states like Connecticut, Delaware, and Idaho appear near the top of the rankings.

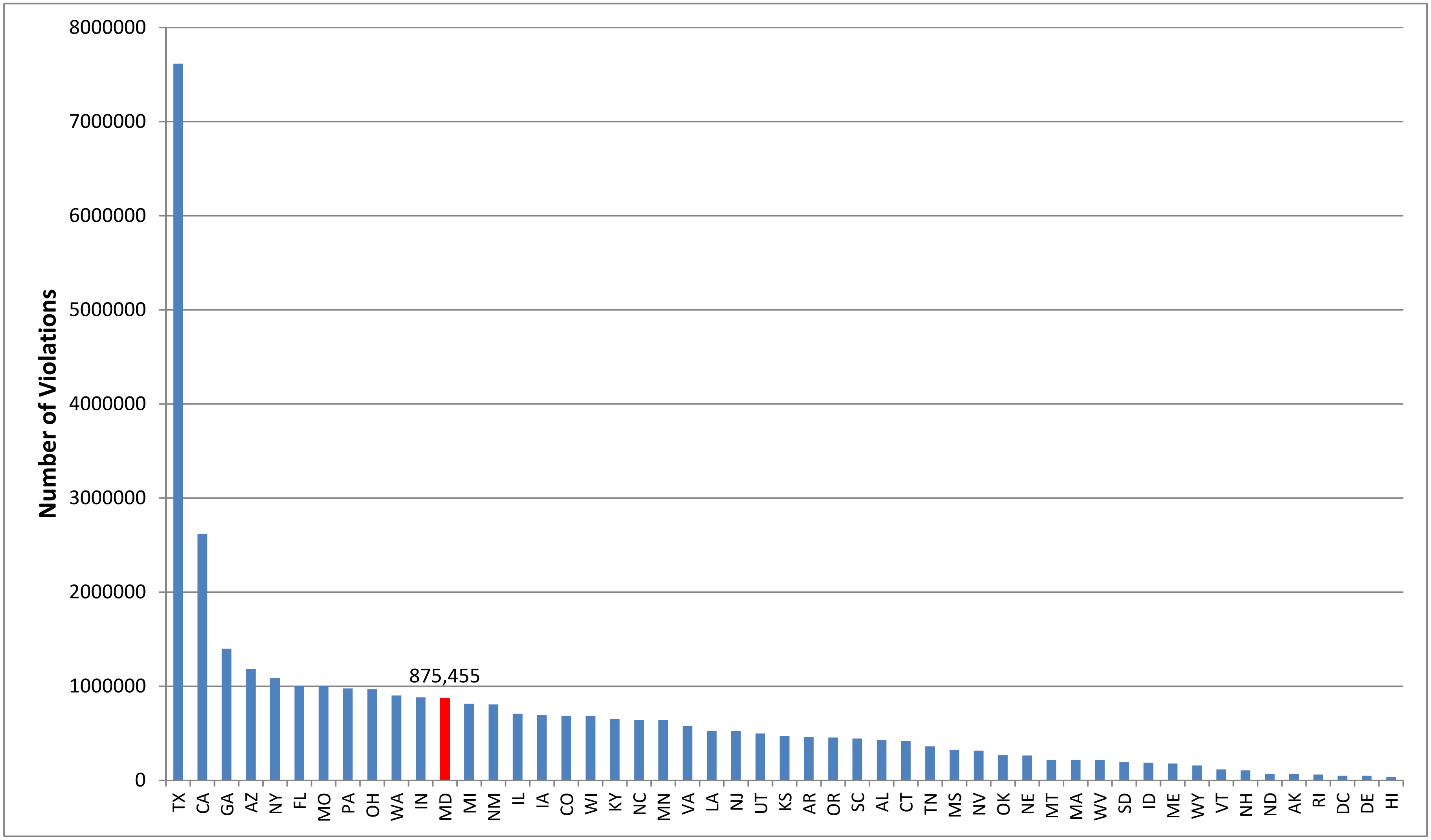


Figure 14. Total Number of Violations Cited by State (2006-2010

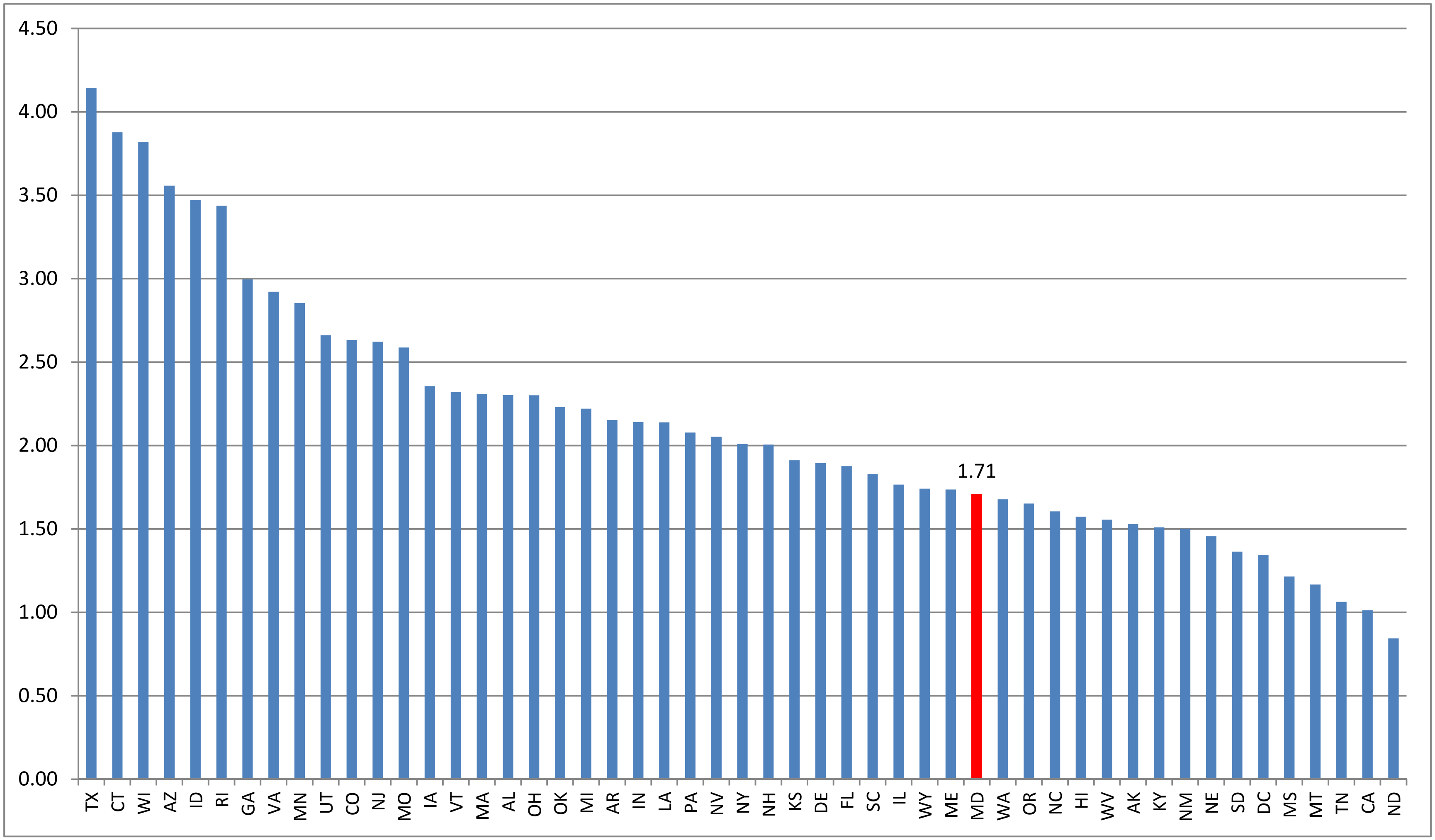


Figure 15. Average Number of Violations per Inspection by State (2006-2010)

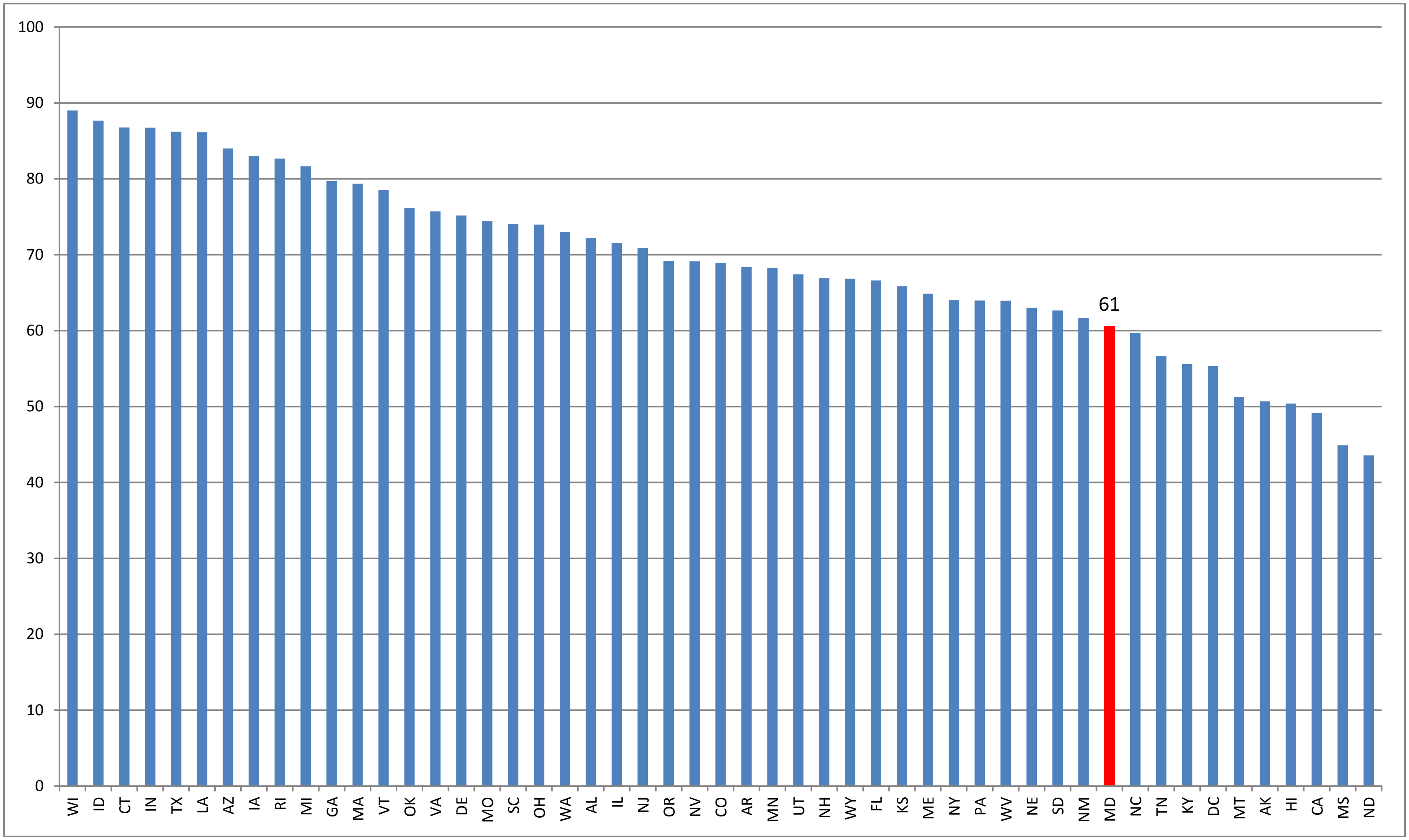


Figure 16. Percentage of Inspections Resulting in Violations by State (2006-2010)

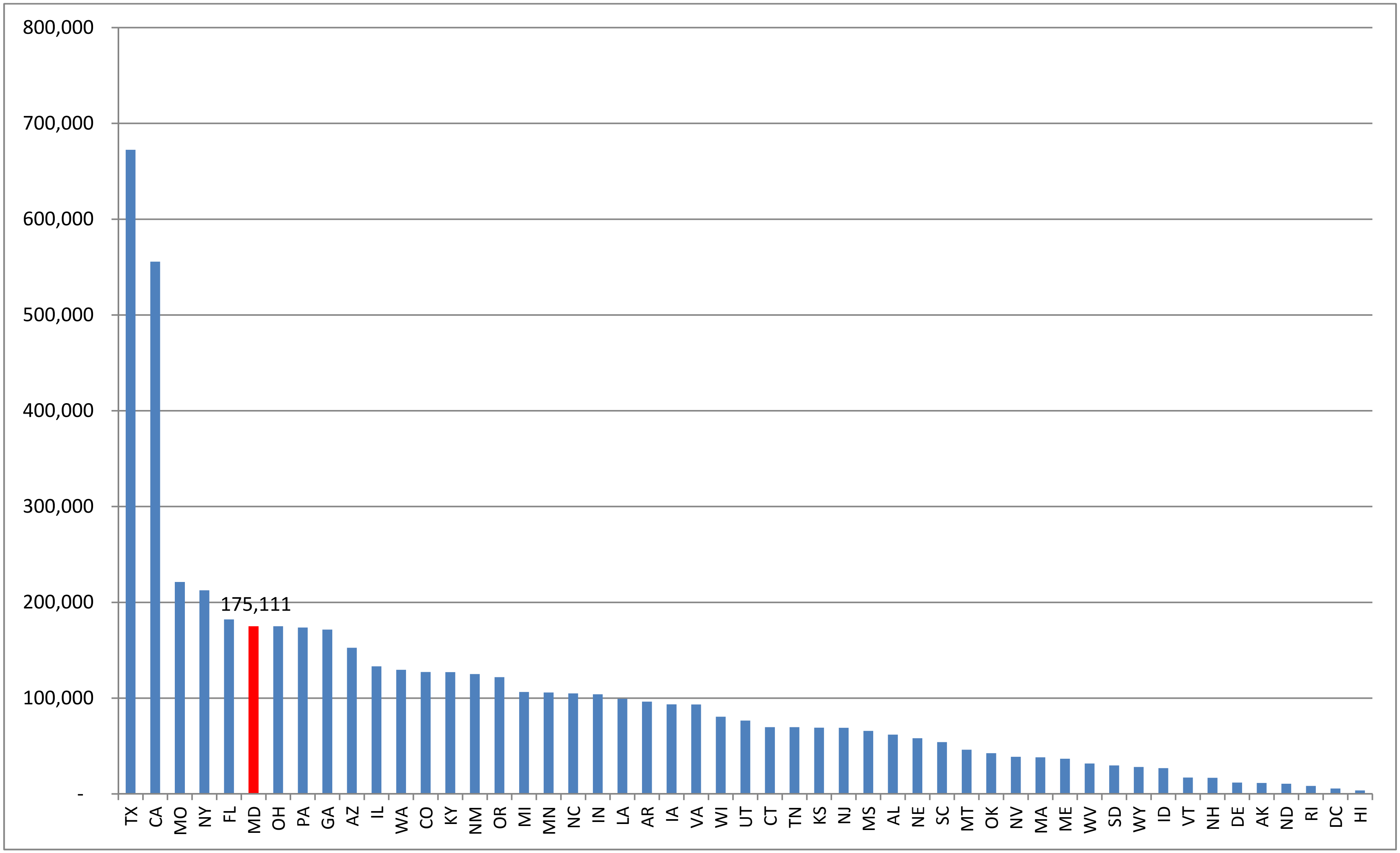


Figure 17. Total Number of OOS Violations by State (2006-2010)

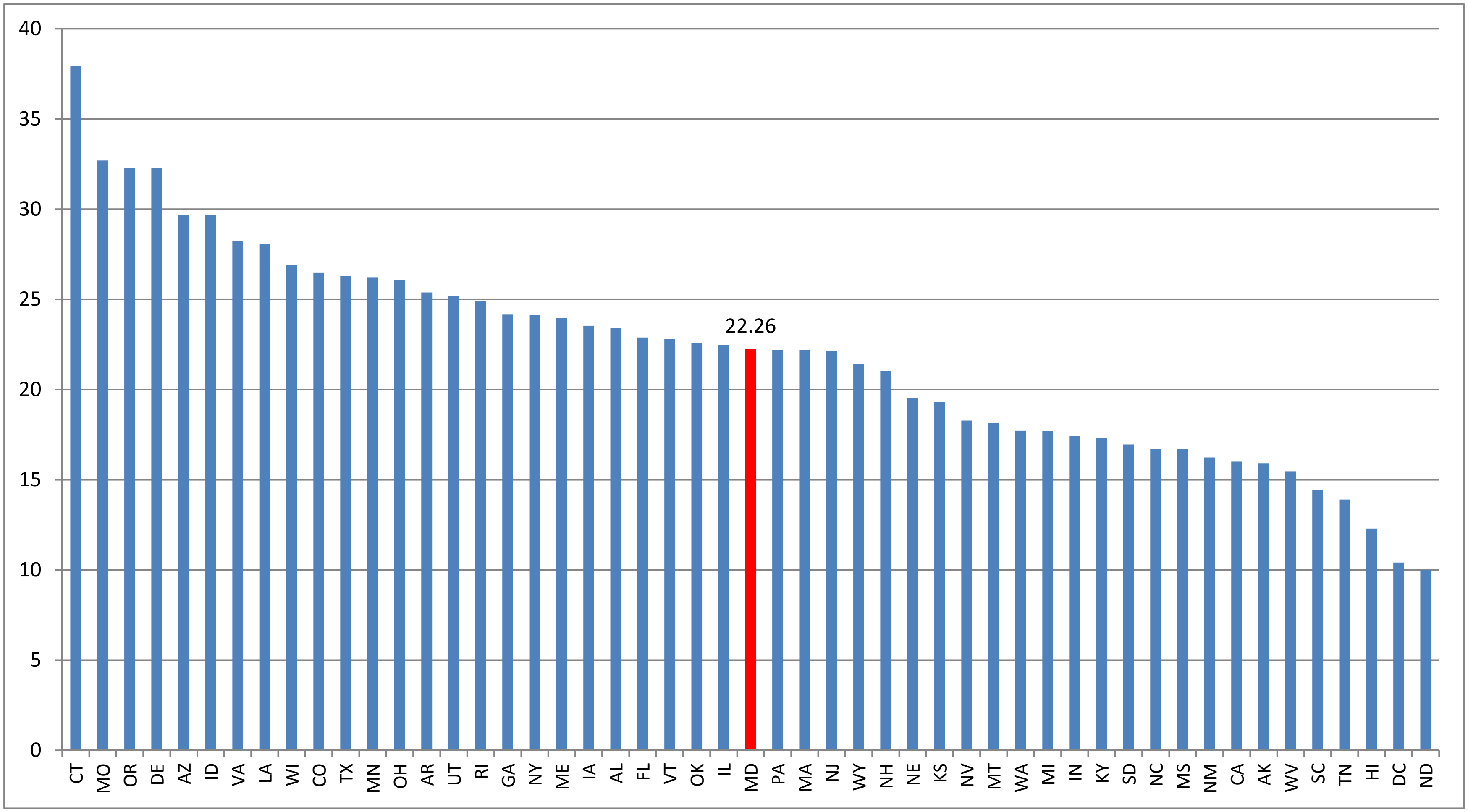


Figure 18. Percentage of Inspections Resulting in At Least One OOS by State (2006-2010)

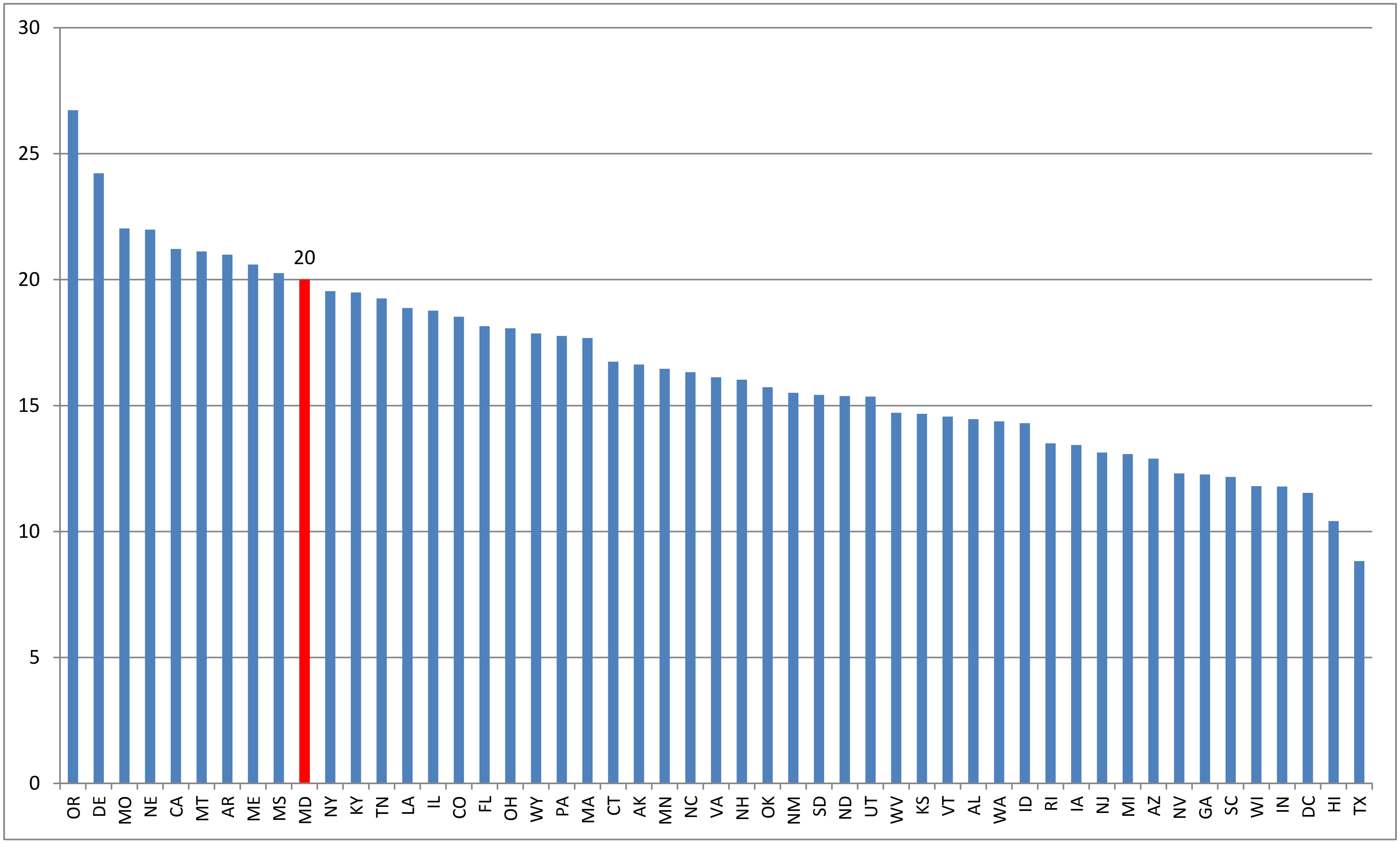


Figure 19. OOS as a Percentage of Total Violations by State (2006-2010)

Figure 19 presents the proportion of OOS violations as a percentage of total violations. This figure may imply the effectiveness of the inspections in terms of the identification of potentially hazardous commercial vehicles and/or drivers. Also, this figure may be an indication of the characteristics of general truck populations that were inspected in corresponding states. About 20% of violations resulted in driver or vehicle OOS in Maryland, which was the tenth highest in the country. While Maryland was ranked 35th in violations per inspection and 41st in the percentage of inspections resulting in violations, a relatively higher proportion of vehicles and drivers inspected in Maryland were placed OOS.

Summary

Comparative analyses of roadside inspection results were discussed in previous sections. Given the population, Maryland conducted more inspections and issued a higher number of violations and OOS than other states. The normalized data by population and VMT also showed that Maryland conducted many more inspections than peer states. In terms of the historical changes in the proportion of each level of inspection, Maryland was in line with the national trend: decreasing levels I and II inspections and increasing level III inspections. While over 50% of the inspections in Maryland were level I, significantly higher than the national average, an in-depth state level comparison showed that there was no consistent trend among states. Level I inspections were the most common in the majority of states, while 21 states conducted level III inspections most. In terms of the time taken per inspection, Maryland was one of the three states with the least time per inspection. Such efficiency did not seem to compromise the identification of immediate safety hazard. That is, OOS accounted for 20% of identified violations, which was the 10th highest among its counterparts. This can be translated into a higher effectiveness of the roadside inspections in Maryland.

Table 10. Percentage Change in number of inspections/violations in U.S. and Maryland from the Previous Year

	2006 to 2007		2007 to 2008		2008 to 2009		2009 to 2010	
	US	MD	US	MD	US	MD	US	MD
Total Number of Inspections	12.4	16.09	1.8	1.29	1.9	-0.98	0.4	-7.66
Total Number of Violations	5.9	8.81	-0.5	4.39	-1.4	-11.11	-0.1	-6.02
Percentage Inspections Resulting in Violations	-2.5	-3.82	-1.4	-1.89	-3.2	-10.17	-2.1	-0.56
Percentage Inspections Resulting in OOS	-3.8	-4.12	-3.2	-2.61	-6.7	-14.09	-5.2	0.97
Inspections With Driver OOS	7.1	20.9	-5.1	-14.73	-9.6	-20.58	-4.7	-10.8
Inspections With Vehicle OOS	5.7	7.44	-0.8	8.8	-9.3	-12.3	-6.9	-5.97

Table 10 provides additional metrics for comparing Maryland with the national average. While there has been an increase in the number of inspections nationally, in Maryland, the number of inspections has decreased from 2008 onwards. Similarly, the total number of violations has decreased more for Maryland during this period. Significantly, inspections with driver OOS and inspections with vehicle OOS have shown a greater decline in Maryland than those in the U.S. as a whole. Across all metrics, years 2008 – 2009 has shown a marked improvement in Maryland and nationally. Year after year, there is a marginal decrease in the number of violations, driver OOS and vehicle OOS violations in the U. S. In Maryland, however, the reduction in violations is more significant than the national average. This trend analysis suggests that the population of safe trucks in Maryland has been increasing gradually, at rates higher than the national averages. This population of safe trucks may be the result of the effectiveness of prior inspection programs in the state and adjoining regions.

Yet, the comaprative analysis leads to several questions: Do the states with a lower percentage of violations have safer truck population than other states? Why do certain states have higher number of violations per inspection? Why does Maryland have fewer number of violations per inspection? Does this mean that trucks in Maryland are safer than those in other states? The answers could vary. The differences may be due to differences in productivity and expertise of state roadside inspectors. However, considering that roadside inpections is a standardized process guided by federal rules, the procedural differences among states should be small, which, however, still needs to be evaluated. Another possibility would be different truck populations led to higher rates of violation. Lastly, the use of different technologies may result in different violation rates per inspection. For example, the use of CVISN or PrePass transponders allow inspectors to focus on commercial vehicles without the transponders, which may result in different types of inspections, and types/numbers of violations. Unfotunately, with the data available to the study team, it is not clear whether or not the lower violations in Maryland, for example, were due to safer trucks, different tecnologies, and/or productivity and experience. An in-depth comparative study can shed light on the findings, which is beyond the scope of the current study.

Description of Inspections in Maryland: MCMIS 2009 Data

This section discusses the characteristics of roadside inspections conducted in Maryland based on the 2009 MCMIS data. As stated earlier, year 2009 is the only year that MCMIS and 24-1 summaries are consistent with each other.

Location Description

Before providing the summary of the data, a brief discussion is warranted on matching inspection location names in 24-1 reports with MCMIS. The inspection table in MCMIS includes 69 locations; however, the 24-1 reports include fewer locations than MCMIS. Locations had to be renamed based on the 24-1 reports that are used by SHA. The list of MCMIS location names was sent to SHA and MdTAP contacts to assure that the assignment of the names were done correctly. The location name comparison between MCMIS and 24-1 reports are provided in Appendix C.

Table 11 presents roadside inspection locations considered in the resource allocation modeling task. The list includes 12 locations operated by MSP and 8 locations under MdTAP jurisdiction. In MSP's case, ten locations are existing TWIS and two locations are MSP Roving and MSP Roving County. In consultation with the technical contacts, it was determined that roadside inspections conducted in the City of Baltimore and most counties in Maryland should be categorized as roving inspections. For data management purposes, the City of Baltimore was named as MSP Roving, and inspections in counties as MSP roving county. Similarly, inspections locations of MdTAP consist of existing six TWIS, MdTAP Roving, and MdTAP Roving County.

Table 11. Inspection Locations for Resource Allocation Modeling

Location Names	Agency in Charge
Cecilton Conowingo Delmar Finzel Hyattstown I-83/Parkton MSP Roving New Market Park and Ride Upper Marlboro West Friendship MSP Roving County	MSP
I 895 NB BHT Toll Plaza I 895 SB BHT Toll Plaza I 95 NB FMT Toll Plaza I 95 NB JFK I 95 SB JFK Rt 50 EB Bay Bridge MDTAP Roving MDTAP Roving County	MdTAP

Summary of Inspections by Agency and Location

In 2009, the base year for the resource allocation model, a total of 108,938 inspections were conducted in Maryland. A breakdown by location types are provided in Table 12. In terms of location type, the most inspections (a total of 60,373) were conducted in TWIS of MSP, followed by inspections at TWIS of MdTAP, and roving inspections of MSP, and MdTAP. At the individual TWIS level, Finzel TWIS carried out most inspections, nearly 10,000. In addition, Hyattstown, New Market, Park and Ride, and I-95 SB JFK were the locations with a higher number of inspections than other locations.

Table 12. Number of Inspections by Location, 2009

Agency	Location Type	Location Name	Number of Inspections
MSP	TWIS	Cecilton	2,762
		Conowingo	2,357
		Delmar	4,562
		Finzel	9,992
		Hyattstown	8,154
		I-83/Parkton	5,529
		New Market	7,789
		Park and Ride	8,006
		Upper Marlboro	5,357
		West Friendship	5,865
		MSP TWIS Subtotal	60,373
	Roving	MSP Roving	1,596
		MSP Roving County	22,899
		Roving Subtotal	24,495
MSP Total			84,868
MdTAP	TWIS	I 895 NB BHT Toll Plaza	3,029
		I 895 SB BHT Toll Plaza	2,222
		I 95 NB FMT Toll Plaza	1,961
		I 95 NB JFK	3,250
		I 95 SB JFK	6,319
		Rt 50 EB Bay Bridge	2,573
		MdTAP TWIS Subtotal	19,354
	Roving	MDTAP Roving	4,662
		MDTAP Roving County	54
		Roving Subtotal	4,716
MdTAP Total			24,070
Grand Total			**108,938**

Table 13. Percentage of Inspections by Level, 2009

Agency	Location Type	Location Name	Level I	Level II	Level III	Level IV	Level V	Level VI
MSP	TWIS	Cecilton	15.21	75.31	9.49	0.00	0.00	0.00
		Conowingo	45.52	38.91	12.86	2.72	0.00	0.00
		Delmar	24.79	66.18	6.64	2.39	0.00	0.00
		Finzel	19.33	21.54	58.02	1.12	0.00	0.00
		Hyattstown	22.37	49.31	26.28	2.02	0.01	0.00
		I-83/Parkton	27.36	30.95	39.99	1.70	0.00	0.00
		New Market	21.61	25.82	51.73	0.83	0.01	0.00
		Park and Ride	5.76	67.40	25.02	1.74	0.09	0.00
		Upper Marlboro	13.50	75.19	7.97	3.34	0.00	0.00
		West Friendship	22.28	48.35	24.14	5.22	0.00	0.00
		MSP TWIS Subtotal	19.99	46.66	31.30	2.04	0.01	0.00
	Roving	MSP Roving	15.60	70.74	12.84	0.81	0.00	0.00
		MSP Roving County	23.68	61.85	5.79	0.44	8.23	0.01
		Roving Subtotal	23.15	62.43	6.25	0.46	7.70	0.01
MSP Total			20.90	51.21	24.07	1.59	2.23	0.00
MdTAP	TWIS	I 895 NB BHT Toll Plaza	22.55	58.77	18.55	0.10	0.03	0.00
		I 895 SB BHT Toll Plaza	14.81	53.78	17.37	0.14	13.91	0.00
		I 95 NB FMT Toll Plaza	25.50	58.34	16.17	0.00	0.00	0.00
		I 95 NB JFK	57.66	28.49	11.78	2.06	0.00	0.00
		I 95 SB JFK	43.90	37.36	16.05	2.69	0.00	0.00
		Rt 50 EB Bay Bridge	14.54	72.29	12.13	1.05	0.00	0.00
		MdTAP TWIS Subtotal	33.76	47.88	15.37	1.40	1.60	0.00
	Roving	MDTAP Roving	15.96	61.78	13.56	0.75	7.72	0.24
		MDTAP Roving County	5.56	37.04	57.41	0.00	0.00	0.00
		Roving Subtotal	15.84	61.49	14.06	0.74	7.63	0.23
MdTAP Total		30.25	50.54	15.11	1.27	2.78	0.05	
Grand Total			**22.97**	**51.07**	**22.09**	**1.52**	**2.35**	**0.01**

Table 13 summarizes the data by inspection level. In 2009, the most frequently conducted inspections in Maryland were level II inspections, which account for 51% of the total inspections. Level I and level III inspections were carried out at similar proportions. While MSP TWIS and MdTAP TWS conducted similar proportions of level II inspections (47% and 48%, respectively), the proportion of level III inspections was a lot higher in MdTAP TWIS than for MSP. At the individual location level, the proportions of inspection levels vary. Generally, the most dominant inspection type was level II; 10 of 16 TWIS and 3 of 4 roving locations conducted such inspections. In three locations (Conowingo, I-95 NB JFK, and I-95 NB JFK), level I inspections took the highest share of the total inspections. Level III inspections were most frequently conducted in Finzel, I-83/Parkton, and New Market. Different proportions of inspection by location is probably related to operational decisions based on domain expertise of MSP and MdTAP inspection-related personnel, which would be constrained by characteristics of individual locations, resources, and other factors.

Average Time Taken per Inspection by Agency and TWIS

The average time taken per inspection by agency and TWIS are compared below. Figure 20 compares the average inspection time by agency and location type. In general, inspections at MdTAP locations took longer than those conducted at MSP facilities. Level I inspections took an average of 26.6 minutes in MSP locations. However, the same level of inspections took nearly 11 minutes more in MdTAP facilities. Differences for other levels ranged from 4 to 9 minutes. Level V inspections in MdTAP locations were done marginally faster than in MSP locations, with less than a minute difference. While the time difference of level VI inspections is even more significant than level I inspections, the average values cannot be compared. This is because very few level VI inspections were conducted in 2009. MSP and MdTAP conducted only three, and eleven level VI inspections, respectively.

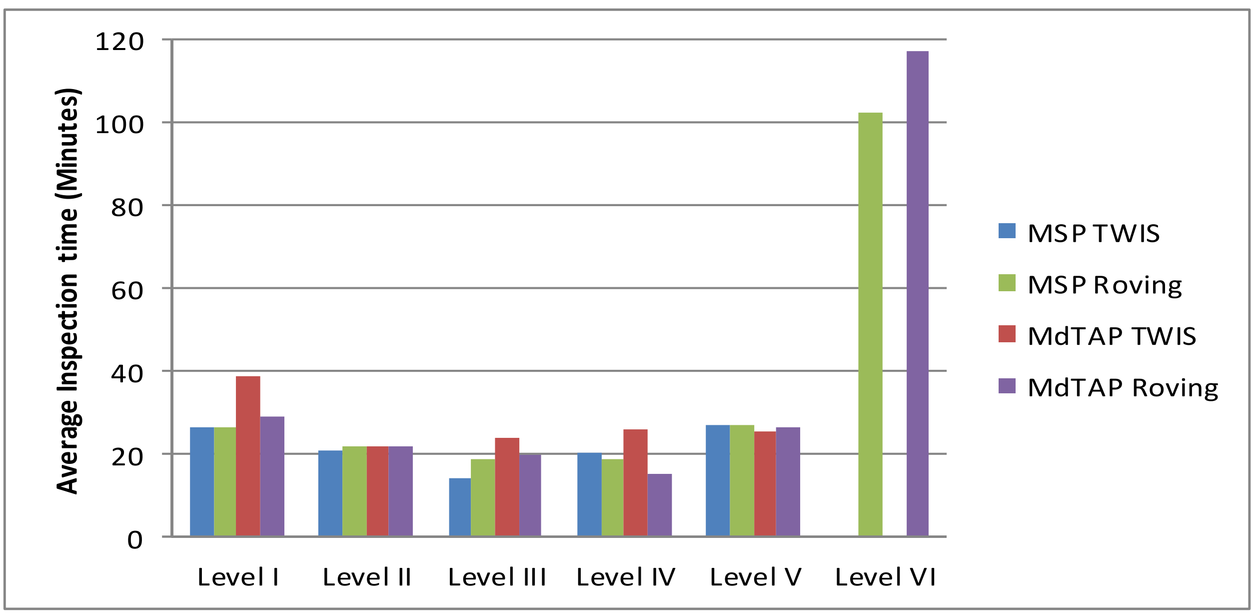


Figure 20. Average Inspection Times (Minutes): Maryland vs. U.S. Average (2006-2010)

The average inspection time differences by agencies were again confirmed by comparing the TWISs. Table 14 compares the ranks of average inspection time by TWIS and inspection level. Since there was at least one TWIS that did not perform levels IV, V, and VI, only the first three levels of inspections were ranked. It appears that there is a general trend in the ranking of the inspection times for the two agencies. TWIS with better rankings (that is, shorter time per inspections) in one level tend to have better rankings in the other levels. Based on the average ranking, West Friendship TWIS had the shortest average inspection times, followed by Upper Marlboro and Conowingo. All six MdTAP TWIS are at the bottom of the table. This finding may not imply efficiency differences among TWISs. According to several discussions with MSP and MdTAP roadside inspection officers, and the SHA technical contact, some roadside inspectors move around different TWIS locations. Further, the operation hours varied by TWIS and strategic locations of TWIS may capture truck samples from different population groups at specific TWIS location and time. Altogether, it may imply that roadside inspection operation in each location is effectively based on professional judgment and population of safe trucks.

Table 14. Rankings of Average Inspection Time by Level and TWIS, 2009

TWIS	Level I	Level II	Level III	Avg. Rank	Agency
West Friendship	3	1	2	2.0	MSP
Upper Marlboro	1	3	4	2.7	MSP
Conowingo	2	2	7	3.7	MSP
New Market	4	5	5	4.7	MSP
Finzel	6	6	3	5.0	MSP
Delmar	8	9	1	6.0	MSP
I-83/Parkton	5	4	12	7.0	MSP
Park and Ride	7	8	9	8.0	MSP
Cecilton	9	10	6	8.3	MSP
Hyattstown	10	7	8	8.3	MSP
Rt 50 EB Bay Bridge	11	11	10	10.7	MdTAP
I 895 SB BHT Toll Plaza	16	13	11	13.3	MdTAP
I 95 SB JFK	13	12	15	13.3	MdTAP
I 95 NB JFK	12	14	16	14.0	MdTAP
I 95 NB FMT Toll Plaza	14	15	14	14.3	MdTAP
I 895 NB BHT Toll Plaza	15	16	13	14.7	MdTAP

Summary of the Number of Violations by Agency and Location

The total number of violations, driver and vehicle OOS violations are summarized in Table 15. In 2009, 175,947 violations were issued in Maryland. In other words, every inspection identified an average of 1.62 violations. MSP alone issued 126,868 violations, which were 72% of the total violations. It should be noted that MSP conducted roughly 78% of inspections in the same year. That is, MSP carried out more inspections, but issued fewer violations than MdTAP. Indeed, violations per inspection of MSP were lower than that of MdTAP (1.49 vs. 2.04). On the other hand, the proportion of OOS as a percentage of total violations was similar between agencies.

At TWIS level, the difference in violations per inspection is even larger than the agency level comparison. On average, every inspection in MSP TWIS identified 1.34 violations, which was significantly lower than 2.09 violations per inspection in MdTAP facilities. At the individual levels, again, some of the MdTAP TWIS, such as 1-95 SB JFK, Rt. 50 EB Bay Bridge, and I-95 NB JFK, cited more violations than other TWIS. Further, I-95 SB JFK also had the highest OOS rates; 26.5 % of violations were either driver or vehicle OOS violations.

Table 15. Numbers of Violations by Agency and Location, 2009

Agency	Location Type	Location Name	Violations	Violations per Inspection	Total OOS	% of Violations with OOS
MSP	TWIS	Cecilton	4196	1.52	1055	25.14
		Conowingo	5589	2.37	643	11.50
		Delmar	9243	2.03	1861	20.13
		Finzel	11065	1.11	2680	24.22
		Hyattstown	11801	1.45	2141	18.14
		I-83/Parkton	8570	1.55	2103	24.54
		New Market	7919	1.02	1425	17.99
		Park and Ride	7609	0.95	2339	30.74
		Upper Marlboro	5541	1.03	936	16.89
		West Friendship	9161	1.56	1197	13.07
		MSP TWIS Total	80,694	1.34	16,380	20.30
	Roving	MSP Roving	2109	1.32	383	18.16
		MSP Roving County	44063	1.92	7594	17.23
		Roving Total	46172	1.88	7977	17.28
MSP Total			126,866	1.49	24,357	19.20
MdTAP	TWIS	I 895 NB BHT Toll Plaza	5866	1.94	763	13.01
		I 895 SB BHT Toll Plaza	3058	1.38	371	12.13
		I 95 NB FMT Toll Plaza	3212	1.64	566	17.62
		I 95 NB JFK	7232	2.23	1751	24.21
		I 95 SB JFK	15092	2.39	4004	26.53
		Rt 50 EB Bay Bridge	5986	2.33	567	9.47
		MdTAP TWIS Total	40,446	2.09	8,022	19.83
	Roving	MDTAP Roving	8508	1.82	1778	20.90
		MDTAP Roving County	127	2.35	27	21.26
		Roving Total	8635	1.83	1805	20.90
MdTAP Total			49,081	2.04	9,827	20.02
Grand Total			**175,947**	**1.62**	**34,184**	**19.43**

Summary

In the previous section, it was found that inspections in MdTAP TWIS took longer than those in MSP. One may suspect that the higher number of violations per inspection in MdTAP, as found earlier, may be a contributing factor behind longer average inspection time. To verify this, average time per inspection was calculated and tabulated by agency and the issuance of violation (Table 16). Indeed, inspections resulting in violations increased the average inspection time significantly. For MSP, the average inspection time increased by 85% when inspections resulted in violations. The same is true for MdTAP. Average inspection time increased by 50 %. However, this figure shows that average inspection time of MdTAP was longer than MSP, regardless of the existence of violations. In sum, the above discussions led to a conclusion that operational characteristics, truck populations, and other factors of MdTAP are different from those of MSP. Therefore, these differences warranted a separate resource allocation model for both of these agencies.

Table 16. Average Inspection Time With and Without Violations

	Inspections with No Violations	Inspections with at least One Violation
MSP TWIS	13.99	25.94
MdTAP TWIS	24.74	36.86

Resource Allocation Model

Resource allocation models to maximize benefits of roadside inspection are described in the following sections. For the modeling task, the 2009 data were used. In 2009, most of the locations covered by MCMIS have been covered by 24-1 forms. Therefore, due to completeness of data collected in 2009, the year 2009 is being treated as the base year for this task.

Objective Function

Building on the knowledge gathered in the previous steps, resource allocation models for MSP and MdTAP roadside inspection programs were built using a linear programming (LP) technique. LP is an optimization technique that has been extensively used in resource allocation problems. It gives solutions to maximization or minimization problems under resource constraints.

The objective of the resource allocation model is the maximization of benefits from roadside inspection. As discussed earlier, the benefit of roadside inspections was defined as monetary values of avoided fatalities and injuries from commercial vehicle related crashes due to roadside inspections. The cost was defined as monetary value per inspection. The objective function searches the optimal number of inspections by inspection level that maximizes inspection benefits given resource constraint.

Since the missing information, that is, the optimal number of inspections, cannot be divided into decimals, an integer programming (IP) was employed. IP is also a linear programming technique employed when some or all of the variables must be nonnegative integers (Winston 1994). The integer programming formulation is as follows:

$$Z = Maximize \sum_{i=1}^{n} \sum_{j=1}^{m} \left(C_1 S_{ij} - C_{2ij}\right) * N_{ij}$$

Where,

i = Inspection location
j = level of inspection
C_1 = Monetary value of crashes avoided by inspection
Sij = Average SMS severity weight per inspection level j at location i
C_{2ij} = Costs per inspection by level 'j' at location i
N_{ij} = Number of inspections by level j at location i

s.t.

$$\sum C_{2ij} N_{ij} \leq Inspection\ Budget$$

$$80\%\ of\ current\ inspecion\ total\ by\ j\ at\ i \leq N_{ij} \leq 120\%\ of\ current\ inspection\ total\ by\ j\ at\ i$$

$\boldsymbol{N_{ij}} \geq 0$, integer

This model is based on the following assumptions.

- Deterrent effects exist. That is, every vehicle inspection is believed to prevent a future accident;
- There are direct and indirect associations between roadside inspections and crashes;
- Crash severities are associated with types of driver and vehicle violations;
- Trucks and drivers with various safety concerns are plying on each roadway, which may result in different inspection and violations results by TWIS;
- Truck populations in terms of safety ratings, maintenance, driver and vehicle qualities may vary by TWIS;
- TWIS are strategically located;
- The current inspection activities conform to the FMCSA provided-guidelines, so the procedure itself is standardized; and,
- Budget is allocated in proportion to inspection hours at each TWIS, with the assumption that the same unit cost per inspection hours, because, as mentioned in the above assumption, the inspection procedure is standardized.

The objective function considered potentially different characteristics by inspection location. First, severity (Sij) per each violation by inspection level and location was factored into the objective function to account for differences in violation characteristics found at each inspection location. Second, time taken per inspection by level and location of inspection, C_{2ij}, were monetized using inspection time information from MCMIS, personnel hours from 24-1 reports, and budget information provided by MSP and MdTAP. Time taken per inspection was considered a proxy for productivity of each inspection location that presumably varies by location. In addition, the lower bound and upper bound of the optimal number of inspections were set as a constraint. This constraint is for preventing all resources from being allocated to only a few inspection locations that generate higher benefits than other locations. The limit of 20% was set arbitrarily and can be changed depending on users' professional judgment. More details of each of the components are provided in the following section.

Benefits and Costs of Inspection by Locations

Costs of Inspections: C_{2ij}

Cost per inspection was developed by monetizing time taken per inspection and allocating it to each TWIS for each inspection level. Ideally, the information for dollar values expended per inspection hour needed to be used. However, the lack of such data led the team to devise a conversion factor to calculate the cost per inspection.

First, the average time per inspection by level was computed using MCMIS. The MCMIS time is a net inspection time; that is, it is the difference between inspection start time and end time. As mentioned already, costs per minute (or hour) of inspection was not available. Second, to calculate time costs, personnel hours from 24-1 reports were used. The total expenditure of the agency was divided by the total personnel hours that yielded a fixed number for each agency: \$4.28 for MSP and \$4.97 for MdTAP. In doing this calculation, it was assumed that the budget was allocated to each location in proportion to the total inspections conducted. Third, MCMIS time needs to be converted to a 24-1 equivalent time. Costs per inspection just computed should not be directly applied to MCMIS time to derive costs per inspection. This is because that while MCMIS time was specifically for inspection duration, personnel hours from 24-1 reports were gross time that included direct inspection activity hours as well as other supporting hours. Therefore, at each inspection location, a conversion factor was used to convert MCMIS inspection time into 24-1 time, called the 24-1 equivalent inspection time. Conversion factor for each location was calculated as the 24-1 time divided by MCMIS time. This conversion factor was then multiplied by MCMIS time to obtain the 24-1 equivalent inspection time. The formula for cost per inspection by location and level was derived using the following formula.

$$Cost\ Per\ Inspection\ (C2ij) = \frac{Total\ Expenditure\ of\ the\ Agency}{Total\ Inspection\ Minutes\ in\ 24-1} * (24 - 1\ \text{Equivalent Inspection Time})$$

Benefits of Inspections: $C_1 S_{ij}$

Benefits of inspections ($C_1 S_{ij}$) is basically costs of truck-involved crashes weighted by violation severity. A linear relationship between the number of inspections conducted and total costs of avoided crashes was assumed. In other words, $C_1 S_{ij}$ is interpreted as benefits from avoiding crashes. $C_1 S_{ij}$ consists of two parts: C_1 and S_{ij}.

The first part is C_1, constant value of crash costs per unit severity (i.e., benefits from avoided crashes), which can be computed as follows:

$$Benefit\ Per\ Inspection = \frac{Total\ Costs\ of\ Crashes\ involving\ Trucks}{Total\ Severity\ observed\ in\ the\ Inspections}$$

Total costs of crashes involving trucks, the numerator of the above formula, was calculated based on the 2009 truck crashes by severity provided by SHA, and the truck crash cost study by Zaloshnja and Miller (2007). The truck crash cost study provides the estimates of unit costs of highway crashes involving trucks. The total crash costs per victim are all costs over the victims' expected life span. The costs per victim include medical costs, emergency service costs, property damage costs, lost productivity, and monetized value of the pain, suffering, and quality of life of the victim's family. All values of the report were calculated in 2005 values. Thus, a 3% annual inflation rate was applied to the costs from the study to convert the costs into 2009 dollars. Then, the total number of truck-involved crashes by severity was multiplied to the crash costs. The calculated crash costs are presented in Table 17.

Table 17. Costs of Truck-Involved Crashes, 2009

Crash Severity	Number of Truck Crashes in 2009	Truck Crash Costs (2009 dollars)	Total Costs (2009 dollars)
Killed	59	4,056,917	239,358,089
Incapacitating injury	193	591,105	114,083,235
Non-incapacitating injury	629	202,955	127,658,774
Possible injury	805	88,032	70,865,496
No injury	4,320	17,011	73,487,261
			625,452,855.28

Source: Recalculation based on (Zaloshnja and Miller 2007)

The total severity observed in the inspections, the denominator of the above formula, is the sum of the severities assigned to violations. The process was discussed earlier. Now, using total crash costs and total severity, crash cost per severity, C_1, can be obtained.

The second part of the inspection benefits, $C_1 S_{ij}$, is the average severity per inspection by level and location, denoted as S_{ij}. It is calculated using the following formula.

$$Average\ Severity\ Per\ Inspection = \frac{Total\ Severity\ by\ location\ by\ level}{Number\ of\ Inspections\ by\ location\ by\ level}$$

The numerator is the sum of SMS severity weight assigned to violation by level and location of inspection, based on the procedure described earlier. The denominator is the number of inspections. The total severity and average severity by inspection location and level are provided in Appendix D.

Resource Allocation Scenarios

In the above mentioned resource allocation model, it is assumed that every crash can be prevented by an inspection. This assumption is not realistic since there are many reasons for truck crashes and inspections alone cannot eliminate all of them. Inspections have both a short-term effect on preventing crashes and a long-term effect on decreasing crashes. The contribution of an inspection in preventing truck crashes also needs to be incorporated in the model for resource allocation. This contribution is modeled as a crash reduction coefficient. The net impact of this coefficient is to decrease the benefit per inspection compared to the naïve model benefit per inspection as shown in the previous page.

Resource allocation models were built and run separately for each agency, using “Solver” available in Microsoft Excel 2010. Solver is an easy-to-use tool that conducts what-if analysis to find an optimal solution for an objective function. Four scenarios were considered for each agency.

- Scenario 1 – 30% of crash reduction coefficient
- Scenario 2 - 40% of crash reduction coefficient
- Scenario 3 – 50% of crash reduction coefficient
- Scenario 4 – 10% budget increase using scenario 2 as a base

The first three scenarios were constructed to account for the percentage of a long-term crash reduction impacts as a result of roadside inspections. The percentage value was named “crash reduction coefficient.” The coefficient can have a value between 0 and 1: a crash reduction coefficient of zero means no crash reduction effect, and one means 100 percent crash prevention as a result of roadside inspection. In other words, the crash reduction coefficient tries to capture the amount of truck-involved crashes that would be prevented as a result of roadside inspection. This coefficient is critical for reasonable allocation of resources. While the crash reduction effect of inspections has been well supported (Gillham, Horton and Schwenk 2013, Moses and Savage 1997, B. Lantz 1993), not all truck-involved crashes are preventable by roadside inspections.

To make the model close to reality, the question is the magnitude of the crash prevention effect. There would be some immediate prevention effect such as the benefit of driver and/or vehicle OOS citations that are issued for violations which prevents those safety hazards from potentially resulting in a crash. Mid and long-term prevention effects would exist as well. First, when more trucks get inspected, the roadways would have more safe trucks. Second, some drivers, truckers, and firms with commercial fleets may voluntarily improve safety performance in order to avoid any penalties and other costs as economic consequences of noncompliance. Such behavioral change is called “deterrent effect.” Moses and Savage (1997) estimated with economic reasoning that the deterrent effect of roadside inspections would be at least 25% of direct impact. Considering short-term crash prevention and mid-to-long term behavioral changes, the scenarios presented above seem reasonable given resources available to the study team.

The last scenario was to examine the impacts of a budget increase by 10%, using scenario 2 as a base.[5] Reallocations of additional resources were analyzed. Ideally, additional resources should be allocated to the location and level with higher potential benefits, if there is additional room for improvement.

[5] After multiple runs of the resource allocation model scenarios, the study team found that scenario 2 allocated resources reasonably well.

RESEARCH FINDINGS

This section discusses the results of the resource allocation models by scenario. By comparing scenarios, the reallocation of given resources (the 2009 budget for MSP and MdTAP), and the additional benefits generated as a result of reallocation are discussed. In addition, how well the resource allocation model performed is evaluated. It is important to note that the 2009 inspection data were used for resource allocation modeling.

Total Benefit Reallocation by Crash Reduction Coefficient Scenarios

To achieve a goal of benefit maximization, the resource allocation model based on IP technique was run. The most important output from the model was total benefits generated as a result of reallocation of the pre-set resources (budgets from the two agencies). Existing resources were redistributed in a way that more resources were assigned to the inspection levels and locations that identified more violations with higher average SMS severity. In doing so, levels of inspection at locations with higher SMS severity were assigned more resources to conduct more inspections, but up to the upper limit (20%). The output from this process is presented in Table 18. The total benefits estimated by each scenario are provided along with the 2009 budgets. First of all, the size of the total benefits is very sensitive depending on the assumption of crash avoidance. Scenario 1 estimated the total benefits of $27 million for MSP and $8.5 million for MdTAP. An increase of crash reduction coefficient by 10% (scenario 2) boosted the total benefits by 130% for MSP and 149% for MdTAP. Subsequently, an additional 10% crash reduction coefficient (scenario 3) raised the total benefits to $106.5 million (a 70% increase) for MSP, and $38.4 million (an 80% increase) for MdTAP. Overall, significant benefits were generated per dollar expended for roadside inspection. For example, for scenario 2, every $1 spent would generate a benefit of $4.98 for MSP and $2.41 for MdTAP. The last scenario examined the impact of a budget increase using scenario 2 as a base on total benefits. It was estimated that a budget increase of 10% resulted in a 2% increase in total benefits of the MSP program and a 7% increase in total benefits of the MdTAP program.

Table 18. Inspection Benefits by Resource Allocation by Scenarios

	2009 Budget ($)	Total Benefits by Scenarios ($)			
		Crash Association Assumption			Scenario 4 - 10% Budget Increase (scenario 2 as base)
		Scenario 1 - 30% crash avoidance	Scenario 2 - 40% crash avoidance	Scenario 3 - 50% crash avoidance	
MSP	12,546,899	27,024,426	62,526,966	106,485,250	63,916,497
MdTAP	8,867,228	8,564,127	21,349,693	38,355,492	22,893,429

It is worthwhile to note that at the 30% crash reduction coefficient (scenario 1), the benefits of inspections ($8.564 million) for MdTAP are lower than the costs ($8.867 million). Thus, using this scenario would suggest that it is economically not worthwhile for MdTAP to conduct any inspections. This is clearly an incorrect ratio to use since we assume that MdTAP has a rational inspection program. The study team suspects that the crash avoidance ratio is certainly more than 30% and use scenario 2 as the conservative base scenario for inspection benefits. Scenario 4 uses this base scenario of determining the impact of a 10% increase in the budget. Each of the scenarios will be further compared in the following section.

Robustness of Total Inspection Benefits Reallocation by Crash Reduction Coefficient

This section discusses whether the resource allocation model works as expected. Since the average costs, severity, and numbers of inspections are fixed variables, models should behave in a way that consistently allocates resources to high-return inspection levels and locations after evaluating the trade-offs among SMS severity value and total number of inspections. Table 19 shows 10 inspection location-level pairs that generated the top 10 benefits for each of scenarios 2 and 3.

For MSP, the same levels and inspection locations were listed in both scenarios. The only difference was that the level II of Hyattstown and level I of West Friendship swapped the rankings. The model recommends increasing the number of inspections for all 10 locations. Additional allocation of resources to levels I and II inspections at MSP Roving County is recommended when no additional resources are available. For MdTAP, additional level I and II inspections are recommended. For this agency, the top 9 benefits are produced by the same location and inspection level. It is also interesting to note that for MdTAP, scenario 2 suggested that five location-level pairs need to decrease the number of inspections. These are the location-level pairs either with relatively lower SMS severity or with lower number of inspections in 2009. This suggestion is a result of the trade-off between levels by location, SMS severity, and total number of inspections in order to generate maximum benefits at each agency level, not at the TWIS level. Overall, the resource allocation model behaved consistently with the assumption, allocating resources to levels and locations with higher inspection benefits.

Table 19. Top 10 Allocations by Agency

(a) MSP

Scenario 2						scenario 3				
Location	Level	Avg. SMS Severity	Current inspections	Optimal Inspection	Benefits	Location	Level	Current inspections	Optimal Inspection	Benefits
MSP Roving County	II	8.62	14164	16996	15,634,016	MSP Roving County	II	14164	16996	27,076,227
MSP Roving County	I	8.31	5422	6506	5,272,066	MSP Roving County	I	5422	6506	9,493,778
FINZEL	I	17.12	1931	2317	4,870,924	FINZEL	I	1931	2317	7,968,824
Park and Ride	II	5.29	5396	6475	3,388,192	Park and Ride	II	5396	6468	6,059,312
Hyattstown	I	12.95	1824	2188	3,317,833	Hyattstown	I	1824	2188	5,530,791
I-83/Parkton	I	14.9	1513	1815	3,253,351	I-83/Parkton	I	1513	1815	5,365,841
Delmar	II	7.59	3019	3622	3,140,212	Delmar	II	3019	3622	5,287,515
West Friendsip	I	13.87	1307	1568	2,535,280	Hyattstown	II	4021	4825	4,323,418
Hyattstown	II	4.98	4021	4825	2,447,085	West Friendsip	I	1307	1568	4,233,534
New Market	I	10.41	1683	2019	2,320,703	New Market	I	1683	2019	3,961,911

(b) MdTAP

Scenario 2						scenario 3				
Location	Level	Avg. SMS Severity	Current inspections	Optimal Inspection	Benefits	Location	Level	Current inspections	Optimal Inspection	Benefits
I 95 SB JFK	I	15.12	2774	3328	5,311,282	I 95 SB JFK	I	2774	3328	9,242,475
MDTAP Roving	II	9.19	2880	3456	3,652,375	MDTAP Roving	II	2880	3456	6,133,852
I 95 NB JFK	I	12.17	1874	2248	2,634,302	I 95 NB JFK	I	1874	2248	4,771,663
Rt 50 EB Bay Bridge	II	10.58	1860	2232	2,436,865	Rt 50 EB Bay Bridge	II	1860	2232	4,281,781
I 95 SB JFK	II	8.61	2361	2310	1,808,388	I 95 SB JFK	II	2361	2309	3,359,377
I 895 NB BHT Toll Plaza	II	6.74	1780	1424	872,000	I 895 NB BHT Toll Plaza	II	1780	1424	1,622,701
MDTAP Roving	I	8.42	744	892	779,632	MDTAP Roving	I	744	892	1,366,644
I 895 NB BHT Toll Plaza	I	8.84	683	819	671,369	I 895 NB BHT Toll Plaza	I	683	819	1,237,214
I 95 NB FMT Toll Plaza	II	7.21	1144	915	591,476	I 95 NB FMT Toll Plaza	II	1144	915	1,106,475
Rt 50 EB Bay Bridge	I	11.23	374	448	513,552	I 95 NB JFK	II	926	740	927,343

Size of Additional Benefits of Resource Allocation Model Scenarios

While the previous section detailed benefits of reallocating resources, the interesting question is the additional benefits from reallocating the resources. Table 20 shows that resource reallocation generated additional benefits for all scenarios for both agencies.

Scenario 2 assumed a crash reduction coefficient of 40%. Without resource reallocation, 84,868 roadside inspections by MSP generated over $52.5 million in benefits. After executing the resource allocation model, the model resulted in a solution with total benefits of $62.5 million (an increase by 19.06%), with fewer roadside inspections. The same scenario raised total benefits by 10.49% for MdTAP, also with fewer roadside inspections. A similar trend was found in other scenarios.

Table 20. Additional Benefits Generated by Resource Reallocation

(a) MSP

	Scenario 1 (30%)		Scenario 2 (40%)		Scenario 3 (50%)	
	Current	Reallocation	Current	Reallocation	Current	Reallocation
Benefits	21,083,779	27,024,426	52,518,194	62,526,966	92,933,872	106,485,250
% Additional benefits		28.18		19.06		14.58
Number of Inspections	84,868	78,322	84,868	83,019	84,868	84,916
% change of inspections		(7.71)		(2.18)		0.06

(b) MdTAP

	Scenario 1 (30%)		Scenario 2 (40%)		Scenario 3 (50%)	
	Current	Reallocation	Current	Reallocation	Current	Reallocation
Benefits	6,984,405	8,564,127	19,322,211	21,349,693	35,185,105	38,355,492
% Additional benefits		22.62		10.49		9.01
Number of Inspections	24,070	23,555	24,070	23,690	24,070	23,691
% change of inspections		(2.14)		(1.58)		(1.57)

Additionally, this table provides at least two implications: one for the agencies performance, and the other for the performance of the resource allocation model. First, in 2009, without the resource reallocation model run, the roadside inspection programs of both agencies generated large benefits in comparison to the budget. With the 40% crash reduction assumption, the MSP roadside inspections generated benefits of $52.5 million “without” reallocation. In other words, every $1 spent in roadside inspections generated benefits of $4.19. In the case of MdTAP, an $8.9 million budget generated benefits of $19.3 million, resulting in over $2.18 benefits per $1 spent.

Second, the resource allocation worked very well as intended in that existing resources are efficiently reallocated to generate maximum benefits with fewer or similar number of total inspections, compared to the number of inspections conducted in 2009 (as shown for MSP in fifth and sixth rows of Table 20). As mentioned earlier, this is a result of trade-offs by which resources are allocated to the high impact location-level pairs first that generate more benefits.

Effect of Budget Increase

The analysis of additional budget on the impact of inspection benefits is discussed here. A 10% budget increase in scenario 4 raised total benefits by 2% (from $62.5 million to $63.9 million) for MSP and 7% for MdTAP (Table 21). These increases are the marginal benefit of a 10% budget increase. In theory, additional resources (i.e. budget) can be added as long as the marginal benefit is equal to or greater than the marginal costs. For MSP (MdTAP), the ratio of marginal benefits to marginal costs exceeds 1, with a value of 2.22 (7.23). The resource reallocation model recommends greater marginal benefits by increasing the budget for MdTAP compared to MSP.

Table 22 shows the inspection location-level pairs that would benefit from the 10% budget increase. Compared to Table 19 that showed top 10 reallocations, the additional budget is allocated to new location-level pairs. While levels I and II were given priority in Table 19, with the additional resources, the reallocation was focused on mostly level III, as well as level II and IV for some locations.

Table 21. Impact of a 10% Budget Increase

	Scenario 2 - 40% crash avoidance	Scenario 4 - 10% Budget Increase (40% Crash contribution)
MSP	62,526,966	63,916,497
	Additional Benefit Increase	2.22
MdTAP	21,349,693	22,893,429
	Additional Benefit Increase	7.23

Table 22. Allocation of Additional 10% Budget Increase

(a) MSP

Location	Level	Current inspections	Optimal Inspection	Additional Benefits
UPPER MARLBORO	2	4028	4833	512,378
I-83/PARKTON	3	2211	2653	279,832
CECLITON	2	2080	2496	179,672
MSP Roving	2	1129	1354	171,919
NEW MARKET	3	4029	4834	89,607
WEST FREINDSHIP	3	1416	1699	47,810
HYATTSTOWN	3	2143	2571	40,728
CECLITON	3	262	314	17,390
UPPER MARLBORO	4	179	214	16,419
CONOWINGO	3	303	363	12,691
DELMAR	3	303	363	10,096
NEW MARKET	4	65	78	9,195
MSP Roving	3	205	246	1,793
Total		18353	22018	1,389,531

(b) MdTAP

Location	Level	Current inspections	Optimal Inspection	Additional Benefits
I 895 NB BHT Toll Pla	2	1780	2136	436,000
I 95 SB JFK	2	2361	2833	409,432
I 95 NB FMT Toll Plaz	2	1144	1372	295,415
I 95 NB JFK	2	926	1020	176,692
I 895 SB BHT Toll Plaz	1	329	393	92,517
MDTAP Roving	3	632	758	82,165
Rt 50 EB Bay Bridge	3	312	374	50,911
MDTAP Roving Coun	3	31	36	3,244
Total		7515	8922	1,546,375

Impacts on Individual Inspection Locations

This section briefly discusses the reallocation model's recommendation to individual location-level pairs. Instead of examining all twenty locations one by one, interesting findings on reallocation of the number of inspections by level is discussed here. Modeling output for individual facilities is described in detail in Appendix E. In general, an increase in levels I and II inspections and a decrease in level III inspections were recommended by the resource reallocation model. This result is somewhat surprising because of the recent Maryland and national trends of increasing level III inspections. Between 2006 and 2010, the share of level III inspections increased in Maryland as well as in the U.S. At the same time, level I and II inspections decreased both in Maryland and the U.S. The recommendations of the resource allocation model to decrease level III inspections is due to the nature of the resource allocation model: reallocating resources to the inspection level with higher SMS severity based on the costs on inspection. The average SMS severity weight of level III inspection is 2.53, much lower than level I and II severity weights. This logic was also applied to level IV, V, and VI for some TWIS.

Table 23. Average SMS Severity Weights by Inspection Level

Inspection Level	Average SMS Severity
I	11.94
II	6.68
III	2.53
IV	5.48
V	1.97
VI	NA

It should be noted that an increase of level III inspections was recommended for MSP Roving County and MdTAP Roving County. However, not all scenarios provided the same recommendation. For MSP, scenarios 2 (40%), 3 (50%), and 4 (10% budget increase) suggested the increase. For MdTAP, scenario 4 resulted in the same recommendation. Additionally, scenario 4 recommended an increase of level III inspections at the I-83/Parkton and Rt 50 EB Bay Bridge TWIS. The reason for this recommendation is again related to the average SMS severity. That is, more resources are allocated to the inspection level with higher average SMS severity. While the average SMS severity for level III is 2.53 (Table 23), the average values for MSP Roving County, MdTAP Roving County, I-83/Parkton and Rt. Ro EB Bay Bridge have higher average SMS severity values of 3.01, 6.52, 3.95, 4.54, respectively.

An especially interesting aspect of this finding is the reallocation of more resources to MSP Roving County and MdTAP Roving County. The higher average SMS severity values for the two locations indicate that comparatively more serious driver violations were identify by the roving inspection crews. This may imply that drivers with safety issues tried to avoid a fixed TWIS, but were flagged for inspection by roving traffic enforcement.

Summary of Findings and Discussions

This section briefly summarizes findings from the descriptive data analysis (previous chapter) as well as resource allocation model runs and discusses the implications of the findings.

Comparison with peer states and the national average indicated that the Maryland roadside inspection program is effective. Comparative analyses of MCMIS roadside inspection and violation data provide somewhat mixed implications for the Maryland roadside inspection program. Maryland conducted more inspections than many other states in terms of the absolute number of inspections (7th) and the number of inspections normalized by population (10th) and VMT (10th). Simultaneously, average violations per inspection (35th) were lower than many other states; that is, violations as a percentage of total inspections were lower. While these facts may call into question the effectiveness of the program, average time taken per inspection (3rd) and OOS violations as a percentage of total violations (20%; 10th) send a different message: higher effectiveness of Maryland roadside inspectors in finding safety defects.

The comparison of five-year trends in Maryland with the national average trends seems to support the higher effectiveness of the Maryland inspection programs. Nationally, the total number of violations and OOS violations marginally decreased between 2006 and 2010. However, the total number of violations and OOS violations significantly decreased in Maryland. For example, the total violations decreased at annual rates between 0.1% and 1.4% nationally, which was much lower than Maryland's 1.4% to 6.02% decrease. For OOS violations, Maryland's decrease rates were between 2.61% and 14.09%, compared to the national rates of 3.2% to 6.7%. Across all metrics, the reduction in violations was much higher in Maryland than in the U.S. This trend analysis suggests that the population of safe trucks in Maryland has been increasing gradually, at rates higher than the national averages. This population of safe trucks may be the result of the effectiveness of prior inspection programs in the state and adjoining regions.

Maryland roadside inspection programs generated large social benefits. The calculation of the benefits, "without resource reallocation," indicated that MSP and MdTAP roadside inspection programs brought considerable benefits to Marylanders. For example, the MSP roadside inspection's return on $1 in budget spending was $4.19 at the 40% crash reduction coefficient, and $2.18 for MdTAP.

Reallocating resources would yield additional benefits over the current level benefits. For each crash reduction coefficient of 30%, 40%, and 50%, the reallocation of the given resources would create additional benefits of 28.18%, 19.06%, and 14.58%, respectively, for MSP. Similarly, MdTAP would reap increased benefits of 22.62%, 10.49%, and 9.01%.

A budget increase would generate increased benefits for MSP and MdTAP roadside inspections. Even without relaxing the capacity constraint assumption (upper bound on total inspections), a budget increase of 10% would increase benefits by 2.22% and 7.23% to MSP and MdTAP respectively.

Inspection crews did their jobs effectively and efficiently utilizing their expert domain knowledge. All resource reallocation scenarios generated increases in benefits over the status quo. However, no scenarios, except for the budget increase scenario, suggested a dramatic increase or decrease in the total number of inspections at the agency level. This implies the current inspection activities are appropriate and effective.

In most cases additional inspections for levels I and II were suggested, while decreasing level III inspections. This result is contradictory to the recent trends in Maryland and the nation. During the study period, the share of level III inspections increased in Maryland as well as in the U.S. The resource allocation models gave more priority to the inspection level with higher SMS severity: the average SMS severity of level III (2.53) is much lower than levels I (11.94) and II (6.68).

An increase in level III inspections at random locations (i.e. roving) was suggested. Scenarios 2, 3, and 4 suggested additional level III inspections at MSP Roving County. For MdTAP, additional level III inspections were suggested for MdTAP Roving County, only if additional resources can be expended (i.e., scenario 4). This is because the average SMS severities for level III inspections at these locations were higher than for other locations. This finding implies that drivers with safety issues may be avoiding fixed inspection locations but, none-the-less, were flagged for inspection by roving traffic enforcement crews.

CONCLUSIONS

An integer programming resource allocation model was successfully developed and run in order to accomplish the study goal of allocating resources to maximize benefits of the roadside inspection programs of MSP and MdTAP. As expected, the resource allocation model behaved consistently; it reallocated more resources to high-return inspection levels and locations based on the trade-offs among SMS severity values, costs, benefits, and total number of inspections.

The modeling findings suggest that the current level of inspections are quite effective and generate significant benefits to Marylanders, which suggest the high effectiveness of roadside inspections in Maryland. The effectiveness of the programs is also supported by the comparative analysis of MCMIS data. Furthermore, the findings indicate that the roadside inspections programs of MSP and MdTAP can further improve their effectiveness and bring about more benefits by reallocating resources with the given resources. Depending on crash reduction coefficients (30%, 40%, and 50%), the percentage increase of additional benefits from resource reallocation ranges between 14.58% and 28.18% for the MSP roadside inspection program, and between 9.01% and 22.62% for the MdTAP roadside inspection program. At the disaggregated level, the model recommends conducting more levels I and II inspections at TWIS, and fewer level III inspections. On the other hand, for MdTAP and MSP Roving County, an increase in level III inspections is recommended, which would have significant impact on capturing potentially dangerous drivers who avoid fixed inspection locations on purpose.

Implications for implementation

The findings of the study are based on the mathematical formulation with the given data to the team. However, there are several points that need to be recognized prior to implementing the findings.

First, the definition of the benefits generated by the inspection program should be understood clearly. As shown in the model formulation, the benefits are monetized values from preventing crashes. The costs include monetary loss of the victims and their family. Thus, the generated benefits from the model need to be understood as social benefits, not hard currency inflow to the program. However, the findings showed that the roadside inspection generated significant benefits to Marylanders, which fulfills one of the important goals of a public organization. In this sense, the reallocation of the resources based on the recommendations of the model would benefit Marylanders.

Second, the developed model is flexible. That is, crash reduction coefficients and upper/lower boundaries of the number of roadside inspections can be changed for rerunning the model. Based on the domain expertise of the MSP and MdTAP roadside inspection personnel, various scenarios can be evaluated to find out better resource reallocation options.

Third, decision making should be based on expertise. The model behaves by giving priorities to high severity violations. Due to this reason, for some TWIS, reduction or removal of level IV, V and VI inspections is suggested. This is because, in general, violations from these levels had lower SMS severities. However, eliminating these levels is neither reasonable nor recommended.

For example, no serious violations related to level VI inspections (enhanced NAS inspection for radioactive shipments) were identified in Maryland during the study period. This does not mean that level VI inspections have a low safety impact. In the case of level VI, a potential negative impact of noncompliance is too serious to afford no-action. This is why the model's findings need to be interpreted and implemented carefully based on expertise.

Suggestions for Future Work

Comparative study to identify the differences in violation and OOS statistics between Maryland and other selective states to find out factors making differences. The analysis of Maryland inspections in comparison with peer states led to several questions about the reasons behind different violation rates and OOS rates. While the study team suspects that differences in productivity, expertise of state roadside inspectors, and use of different technologies would probably contribute to different violation rates, an in-depth comparative study can reveal clear associations and identify the best operational practices.

Impacts of new inspection technology on optimal resource allocation, including the analysis of benefit costs analysis. The resource allocation model used in this study does not include different technical systems such as mobile weigh-in-motion. Data on the safety characteristics of truckers who are flagged for inspection by new technologies can be used in the existing resource allocation model to evaluate the effectiveness of roadside inspection program due to such new technologies, in a manner that is not amenable by using other methodologies. This will also enable the team to conduct cost-benefits analysis of new inspection technologies.

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APPENDIX A. DATA QUESTIONS TO SHA

1. **Data and Forms**

1.1. Data Needs

1.1.1. What data can be obtained and how soon?

1.1.1.1. See the attached data wish list

1.1.2. Any additional contacts for some data in the wish list?

1.2. Samples of Forms

1.2.1. A few sample copies of roadside inspection forms

1.2.2. A few sample copies of traffic enforcement forms for commercial vehicles

1.2.3. A few samples of Preventive Maintenance Audits, Compliance Reviews, New Entrant Safety Audits Forms

2. **Questions about Inspection Programs**

2.1. Which agency is responsible for the following activities: PM Audits, Compliance Reviews, and New Entrant Safety Audits?

2.1.1. What are main goals of each activity?

2.1.2. Where are the original and copies of vehicle inspections kept?

2.1.3. Who can do the inspection?

2.1.4. Do carriers receive any education on safety regulations and carrier's responsibilities?

2.2. Facility operation hours and inspector assignment

2.2.1. How are inspectors assigned to each facility?

2.2.2. Is the inspector assignment to each TWIS same across the year?

2.2.3. How do you assign inspection hours to each TWIS?

2.2.4. What criteria were used in determining facility hours?

2.2.5. Are hours of operation for each facility same throughout the year?

2.2.6. If the number of inspectors and operation hours in each facility vary throughout the year, what are the criteria for such change?

2.3. TWIS Roadside Inspection

2.3.1. Is ASPEN being used for all inspections? If not, what percentage of inspections is manual using MSP-24-32?

2.3.2. ASPEN software tabs?: Vehicle, Driver, State.

2.3.3. ASPEN software: Is ISS-2 value and/or SafeStat value available?

2.3.4. ASPEN software: Past Inspection Query retrieves history for how many days?

2.3.5. How frequently are inspection reports updated to SAFER

2.3.6. IFTA decals are checked, how about IRP?

2.3.7. Is the list of Maryland Truck Weigh and Inspection Stations dated 9-16-2009 current?

2.4. Roving Inspection

   2.4.1. What criteria do rovers use to identify vehicles that are trying to bypass weigh stations?

   2.4.2. Are rovers called in to inspect a vehicle for a traffic enforcement activity?

   2.4.3. Does MSP have portable scales at Park and Ride, College Park and Vienna, route US 50?

2.5. Traffic Enforcement

   2.5.1. What's the process for traffic enforcement? Can all MSP officers inspect a commercial vehicle (other than a driver's credentials) ?

3. Program Evaluation

   3.1. Does MD have unique features to improve TWIS operation and commercial vehicle safety in addition to federally mandated activities included in the MCSAP?

   3.2. How do you measure success of Maryland Inspection program (i.e., what are the performance measures)?

   3.3. Are there any interstate collaborative features?

      3.3.1. Are your operations hours dependent upon operation hours of neighboring states?

   3.4. Do you compare MD's performance with other states?

Can you provide contacts responsible for inspection programs in other states?

APPENDIX B. FORM 24-1, MSP SUMMARY FOR YEAR 2009

MARYLAND MOTOR CARRIER PROGRAM ACTIVITIES SUMMARY

11/16/2011

Agency: MSP From: 01/01/2009 To: 12/31/2009

I. PERSONNEL

INSP	SA	CT	TR	CR	PC	TE	CRM	PM	Total hours
60134.0	3983.0	3601.0	4768.0	3630.0	551.0	1434.0	1081.0	796.0	79978.0
WT/MS	CT	TR	OPD	SHD	TE				
30275.5	1408.0	6349.0	17915.0	49925.5	1733.0				107606.0
							Total Personnel Hours		187584.0

II. INSPECTIONS

Level	I	II	III	IV	V	VI	Total	HMCargo Tank	Other H/M	BUS
Primary	12776	41056	18327	1262	49	10	73480	1866	896	263
OOS V	3591	6287		241	3	0	10122	77	47	5
OOS D	574	2649	877	29		0	4129	6	3	9
Secondary	8780	20938	0	704	18	10	30450			

Post Crash INV	50	Diesel Test: Initial Test	270	Fail	67	Retest	74	SERO	60

INSPECTION ENFORCEMENT:

CDL Viol	611	25-111	13840	Reg Viol	960	Brakes	1216	DOT#	581	395	3404	Ld Sec	386	392.5	104
Fuel TAX	308	Other Cit.	1496	SERO: CMV	2516	NCMV	117	TotalSERO's	2693	CMVWarnings	52670				
SEATBELTCitations: CMV	1699	NCMV	954	SBWarnings: CMV	220	NCMV	137								

III. SIZE & WEIGHT

Vehicles Weighed:	Fixed	792710	Portable	2262	Total Weighed	794972	WIM	1397960			
Over Weight Violations:	Axle	10587	Reg	898	Gross	1695	Ext Bridge	96	Int Bridge	263	
Rest Bridge	9	MD Reg	1957	O/Wght Permit	115	Total Overweight	13663				
O/Weights That Were:	Fixed Over Weight	10470	Portable Over Weight	1317	Port off Load	539					
Fixed off Load	485	Fixed By-Pass	31	SWWarnings	230						
O/Length	1526	O/Height	7	O/Width	30	Permit	174	TotalSize	1737	Refused	2

IV. TRAFFIC ENFORCEMENT

	CMV Citations	CMV Warnings	NCMV Citations	NCMV Warnings
21.201	883	196	58	70
21.310	27	40	59	67
SPEED	1081	633	2088	1498
Other	189	210	1275	1244

ARRESTS	Sus/Rev		21.902		CDS		Warrants		Criminal		Guns		Other	
Adults	Sus/Rev	74	21.902	20	CDS	52	Warrants	120	Criminal	20	Guns	8	Other	6
Juvenile.	Sus/Rev	0	21.902	0	CDS	2	Warrants	0	Criminal	2	Guns	0	Other	0

V. TOTAL FINES

	Size & Weight	Inspection	Traffic	Total
Fines	$2,928,421	$3,929,332	$799,716	$7,657,469
Citations	15400	24605	6614	46619
Warnings	230	52670	3958	57215

VI. IN TERMINAL

PM Audits	Initials	737	In Compl	172	Citations	39	Warnings	526	Susp	1	Fines	$3,615
PM Audits	Compliance	460	In Compl	352	Citations	72	Warnings	38	Susp	3	Fines	$12,850
C/R's	State	139	Citations	88	Lead	126	Assist	0			Fines	$74,480
C/R's	Federal	137	Citations	75	Lead	120	Assist	3			Fines	$39,965
IRAP Delinquent Letters		30	Citations	18	Warnings	3	Complied	9			Fines	$4,540
New Entrant Program (S/A)		592	Incident reports	48							Total PM/CR Fines	$135,450

APPENDIX C. LOCATION NAME CONVERSION

MCMIS Location Names	New Location Names	Agency In Charge
Northbound on 895}Toll Facilit	I 895 NB BHT Toll Plaza	MdTAP
Southbound on 895}Toll Facilit	I 895 SB BHT Toll Plaza	MdTAP
I-95 N/B Ft. Mchenry Toll Plaz	I 95 NB FMT Toll Plaza	MdTAP
I-95 Northbound Scale Facility	I 95 NB JFK	MdTAP
I-95 Southbound Scale Facility	I 95 SB JFK	MdTAP
RT 50 E/B Bay Bridge Toll Fac	Rt 50 EB Bay Bridge	MdTAP
I-95 NSA S/B Cecil County	MdTAP P Roving County	MdTAP
I-95 @ RT 210	MdTAP Roving	MdTAP
RT 50 W/B Bay Bridge Toll Fac	MdTAP Roving	MdTAP
Baltimore City	MdTAP Roving	MdTAP
Baltimore City	MdTAP Roving	MdTAP
N/B RT. 301	MdTAP Roving	MdTAP
RT 40 E/B Hatem Scale House	MdTAP Roving	MdTAP
RT 40 W/B Hatem Scale House	MdTAP Roving	MdTAP
I-95 S/B Ft. Mchenry Toll Plaz	MdTAP Roving	MdTAP
I-695 E/B FSK Bridge Toll Faci	MdTAP Roving	MdTAP
I-695 W/B FSK Bridge Toll Faci	MdTAP Roving	MdTAP
I-95 N/B Harford County	MdTAP Roving County	MdTAP
I-95 S/B Harford County	MdTAP Roving County	MdTAP
I-70 W Friendship TWIS	West Friendship	MSP
I-70 New Market TWIS	New Market	MSP
I-95 @ I-495 (Park and Ride)	Park and Ride	MSP
I-83	I-83/Parkton	MSP
I-81	MSP Roving	MSP
US301 Upper Marlboro TWIS N/B	Upper Marlboro	MSP
US301 Upper Marlboro TWIS S/B	Upper Marlboro	MSP
US301 Upper Marlboro S.H. S/B	Upper Marlboro	MSP
US13 Delmar TWIS N/B	Delmar	MSP
US13 Delmar TWIS S/B	Delmar	MSP
Finzel TWIS	Finzel	MSP
I-270 N/B Hyattstown TWIS	Hyattstown	MSP

MCMIS Location Names	New Location Names	Agency In Charge
I-270 S/B Hyattstown TWIS	Hyattstown	MSP
RT 1 N/B Darlington	Conowingo	MSP
RT 1 S/B Darlington	Conowingo	MSP
US301 Cecilton TWIS	Cecilton	MSP
RT 40 E/B Foy Hill TWIS	Foy Hill	MSP Roving
Anne Arundel County	MSP Roving County	MSP
Baltimore County P.D.	MSP Roving County	MSP
Montgomery County P.D.	MSP Roving County	MSP
Prince Georges County	MSP Roving County	MSP
Allegany County	MSP Roving County	MSP
Anne Arundel County	MSP Roving County	MSP
Calvert County	MSP Roving County	MSP
Caroline County	MSP Roving County	MSP
Carroll County	MSP Roving County	MSP
Cecil County	MSP Roving County	MSP
Charles County	MSP Roving County	MSP
Dorchester County	MSP Roving County	MSP
Frederick County	MSP Roving County	MSP
Garrett County	MSP Roving County	MSP
Harford County	MSP Roving County	MSP
Howard County	MSP Roving County	MSP
Kent County	MSP Roving County	MSP
Montgomery County	MSP Roving County	MSP
Prince Georges County	MSP Roving County	MSP
Queen Annes County	MSP Roving County	MSP
St. Mary's county	MSP Roving County	MSP
Somerset County	MSP Roving County	MSP
Talbot County	MSP Roving County	MSP
Washington County	MSP Roving County	MSP
Wicomico County	MSP Roving County	MSP
Worchester County	MSP Roving County	MSP

MCMIS Location Names	New Location Names	Agency In Charge
US50 Vienna Pull-off Site	MSP Roving	MSP
IS695 N/B MM004	MSP Roving	MSP
Montgomery County	MSP Roving County	MSP
Gaithersburg City P.D.	MSP Roving	MSP
Baltimore County	MSP Roving	MSP
RT 15 @ Biggs Ford Rd	MSP Roving	MSP Roving
PSC Terminal	PSC Terminal	PSC

APPENDIX D. TOTAL AND AVERAGE SMS SEVERITY BY INSPECTION LOCATION AND LEVEL

(A) MSP

Location	Inspection Level	Number of Inspections	Total SMS Severity	Average SMS Severity
Cecilton	1	420	4006	9.54
Cecilton	2	2080	14109	6.78
Cecilton	3	262	539	2.06
Conowingo	1	1073	13469	12.55
Conowingo	2	917	5850	6.38
Conowingo	3	303	647	2.14
Conowingo	4	64	450	7.03
Delmar	1	1131	13002	11.50
Delmar	2	3019	22913	7.59
Delmar	3	303	378	1.25
Delmar	4	109	659	6.05
Finzel	1	1931	33052	17.12
Finzel	2	2152	10937	5.08
Finzel	3	5797	5044	0.87
Finzel	4	112	639	5.71
Hyattstown	1	1824	23617	12.95
Hyattstown	2	4021	20018	4.98
Hyattstown	3	2143	2669	1.25
Hyattstown	4	165	1144	6.93
Hyattstown	5	1	0	0.00
I-83/Parkton	1	1513	22544	14.90
I-83/Parkton	2	1711	8489	4.96
I-83/Parkton	3	2211	8728	3.95
I-83/Parkton	4	94	752	8.00
MSP Roving	1	249	1726	6.93
MSP Roving	2	1129	5944	5.26
MSP Roving	3	205	319	1.56
MSP Roving	4	13	139	10.69
New Market	1	1683	17514	10.41
New Market	2	2011	9779	4.86
New Market	3	4029	5861	1.45
New Market	4	65	267	4.11
New Market	5	1	13	13.00
Park and Ride	1	461	3088	6.70
Park and Ride	2	5396	28567	5.29
Park and Ride	3	2003	712	0.36
Park and Ride	4	139	902	6.49

Location	Inspection Level	Number of Inspections	Total SMS Severity	Average SMS Severity
Park and Ride	5	7	1	0.14
Upper Marlboro	1	723	3678	5.09
Upper Marlboro	2	4028	15429	3.83
Upper Marlboro	3	427	328	0.77
Upper Marlboro	4	179	575	3.21
West Friendship	1	1307	18122	13.87
West Friendship	2	2836	13721	4.84
West Friendship	3	1416	2462	1.74
West Friendship	4	306	1779	5.81
MSP Roving County	1	5422	45041	8.31
MSP Roving County	2	14164	122074	8.62
MSP Roving County	3	1325	3991	3.01
MSP Roving County	4	100	724	7.24
MSP Roving County	5	1885	986	0.52
MSP Roving County	6	3	0	0.00

(B) MdTAP

Location	Inspection Level	Number of Inspections	Total SMS Severity	Average SMS Severity
I 895 NB BHT Toll Plaza	1	683	6041	8.84
I 895 NB BHT Toll Plaza	2	1780	12013	6.75
I 895 NB BHT Toll Plaza	3	562	1790	3.19
I 895 NB BHT Toll Plaza	4	3	4	1.33
I 895 NB BHT Toll Plaza	5	1		0.00
I 895 SB BHT Toll Plaza	1	329	2902	8.82
I 895 SB BHT Toll Plaza	2	1195	6266	5.24
I 895 SB BHT Toll Plaza	3	386	928	2.40
I 895 SB BHT Toll Plaza	4	3		0.00
I 895 SB BHT Toll Plaza	5	309	25	0.08
I 95 NB FMT Toll Plaza	1	500	3373	6.75
I 95 NB FMT Toll Plaza	2	1144	8243	7.21
I 95 NB FMT Toll Plaza	3	317	702	2.21
I 95 NB JFK	1	1874	22810	12.17
I 95 NB JFK	2	926	7375	7.96
I 95 NB JFK	3	383	1408	3.68
I 95 NB JFK	4	67	323	4.82
I 95 SB JFK	1	2774	41949	15.12
I 95 SB JFK	2	2361	20313	8.60
I 95 SB JFK	3	1014	3974	3.92
I 95 SB JFK	4	170	1463	8.61
MDTAP Roving	1	744	6268	8.42
MDTAP Roving	2	2880	26473	9.19
MDTAP Roving	3	632	2384	3.77
MDTAP Roving	4	35	135	3.86
MDTAP Roving	5	360	20	0.06
MDTAP Roving	6	11		0.00
Rt 50 EB Bay Bridge	1	374	4201	11.23
Rt 50 EB Bay Bridge	2	1860	19682	10.58
Rt 50 EB Bay Bridge	3	312	1416	4.54
Rt 50 EB Bay Bridge	4	27	89	3.30
MDTAP Roving County	1	3	113	37.67
MDTAP Roving County	2	20	190	9.50
MDTAP Roving County	3	31	202	6.52

APPENDIX E. RESOURCE ALLOCATION MODEL OUTPUT

(a) MSP – Scenario 1 (30% Crash reduction coefficient)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
Cecilton	1	420	504	244666
Cecilton	2	2080	2496	765221
Cecilton	3	262	314	13257
Conowingo	1	1073	1287	863913
Conowingo	2	917	1100	298547
Conowingo	3	303	0	0
Conowingo	4	64	76	22776
Delmar	1	1131	1357	928257
Delmar	2	3019	3622	1470088
Delmar	3	303	363	2776
Delmar	4	109	130	30717
Finzel	1	1931	2317	2461445
Finzel	2	2152	2582	479580
Finzel	3	5797	0	0
Finzel	4	112	134	40647
Hyattstown	1	1824	2188	1596643
Hyattstown	2	4021	4825	987715
Hyattstown	3	2143	0	0
Hyattstown	4	165	198	69699
Hyattstown	5	1	0	0
I-83/Parkton	1	1513	1815	1610303
I-83/Parkton	2	1711	2053	401522
I-83/Parkton	3	2211	2653	202590
I-83/Parkton	4	94	112	50723
MSP Roving	1	249	298	91523
MSP Roving	2	1129	1354	231986
MSP Roving	3	205	0	0
MSP Roving	4	13	15	8838
MSP Roving County	1	5422	6506	1988513
MSP Roving County	2	14164	16996	6734519
MSP Roving County	3	1325	0	0
MSP Roving County	4	100	120	39699
MSP Roving County	5	1885	0	0
MSP Roving County	6	3	0	0
New Market	1	1683	2019	1044209
New Market	2	2011	2413	383470

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
New Market	3	4029	0	0
New Market	4	65	78	8118
New Market	5	1	1	613
Park and Ride	1	461	553	152257
Park and Ride	2	5396	6475	1305553
Park and Ride	3	2003	0	0
Park and Ride	4	139	166	41165
Park and Ride	5	7	0	0
Upper Marlboro	1	723	867	146757
Upper Marlboro	2	4028	4833	412408
Upper Marlboro	3	427	0	0
Upper Marlboro	4	179	214	7723
West Friendship	1	1307	1568	1214417
West Friendship	2	2836	3403	590291
West Friendship	3	1416	0	0
West Friendship	4	306	367	81281
Total		84868	78372	27024425.52

(b) MSP – Scenario 2 (40% Crash reduction coefficient)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
Cecilton	1	420	504	536,727
Cecilton	2	2080	2246	1,614,178
Cecilton	3	262	210	35,114
Conowingo	1	1073	1287	1,845,425
Conowingo	2	917	1100	724,891
Conowingo	3	303	242	25,382
Conowingo	4	64	76	55,242
Delmar	1	1131	1357	1,876,040
Delmar	2	3019	3622	3,140,212
Delmar	3	303	242	20,193
Delmar	4	109	130	78,469
Finzel	1	1931	2317	4,870,924
Finzel	2	2152	2582	1,276,828
Finzel	3	5797	0	-
Finzel	4	112	134	87,096
Hyattstown	1	1824	2188	3,317,833
Hyattstown	2	4021	4825	2,447,085
Hyattstown	3	2143	1714	81,457
Hyattstown	4	165	198	153,104
Hyattstown	5	1	0	-
I-83/Parkton	1	1513	1815	3,253,351
I-83/Parkton	2	1711	2053	1,020,360
I-83/Parkton	3	2211	1768	559,033
I-83/Parkton	4	94	112	105,160
MSP Roving	1	249	298	217,022
MSP Roving	2	1129	1004	493,163
MSP Roving	3	205	164	3,587
MSP Roving	4	13	15	18,582
MSP Roving County	1	5422	6506	5,272,066
MSP Roving County	2	14164	16996	15,634,016
MSP Roving County	3	1325	1590	278,952
MSP Roving County	4	100	120	92,483
MSP Roving County	5	1885	0	-
MSP Roving County	6	3	0	-

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
New Market	1	1683	2019	2,320,703
New Market	2	2011	2413	1,096,358
New Market	3	4029	3223	179,270
New Market	4	65	52	18,389
New Market	5	1	1	1,402
Park and Ride	1	461	553	377,310
Park and Ride	2	5396	6475	3,388,192
Park and Ride	3	2003	0	-
Park and Ride	4	139	166	106,611
Park and Ride	5	7	0	-
Upper Marlboro	1	723	867	414,720
Upper Marlboro	2	4028	3222	1,024,756
Upper Marlboro	3	427	0	-
Upper Marlboro	4	179	143	33,069
West Friendship	1	1307	1568	2,535,280
West Friendship	2	2836	3403	1,590,574
West Friendship	3	1416	1132	95,451
West Friendship	4	306	367	210,910
Total		84868	83019	2,526,966

(c) MSP – Scenario 3 (50% Crash reduction)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
Cecilton	1	420	371	671506
Cecilton	2	2080	2496	3116374
Cecilton	3	262	209	68533
Conowingo	1	1073	1287	3107369
Conowingo	2	917	1100	1273049
Conowingo	3	303	242	65746
Conowingo	4	64	76	96984
Delmar	1	1131	1357	3094618
Delmar	2	3019	3622	5287515
Delmar	3	303	243	43956
Delmar	4	109	130	139863
Finzel	1	1931	2317	7968824
Finzel	2	2152	1721	1534277
Finzel	3	5797	4637	266398
Finzel	4	112	134	146815
Hyattstown	1	1824	2188	5530791
Hyattstown	2	4021	4825	4323418
Hyattstown	3	2143	1714	248206
Hyattstown	4	165	198	260338
Hyattstown	5	1	0	0
I-83/Parkton	1	1513	1815	5365841
I-83/Parkton	2	1711	2053	1816008
I-83/Parkton	3	2211	1768	1104205
I-83/Parkton	4	94	112	175150
MSP Roving	1	249	298	378378
MSP Roving	2	1129	903	814915
MSP Roving	3	205	164	23521
MSP Roving	4	13	15	31110
MSP Roving County	1	5422	6506	9493778
MSP Roving County	2	14164	16996	27076227
MSP Roving County	3	1325	1590	653053
MSP Roving County	4	100	120	160348
MSP Roving County	5	1885	0	0
MSP Roving County	6	3	0	0
New Market	1	1683	2019	3961911
New Market	2	2011	1608	1341396

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
New Market	3	4029	3223	545506
New Market	4	65	52	35074
New Market	5	1	1	2418
Park and Ride	1	461	553	666662
Park and Ride	2	5396	6468	6059312
Park and Ride	3	2003	0	0
Park and Ride	4	139	166	190755
Park and Ride	5	7	0	0
Upper Marlboro	1	723	578	506162
Upper Marlboro	2	4028	3222	1988806
Upper Marlboro	3	427	341	3676
Upper Marlboro	4	179	143	68951
West Friendship	1	1307	1568	4233534
West Friendship	2	2836	2268	1917205
West Friendship	3	1416	1132	249195
West Friendship	4	306	367	377576
Total		84868	84916	10648525 0

(d) MSP – Scenario 4 (10% budget increase, scenario 2 as a base)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits (after adding 10% additional budget)	Benefits (40%)	Additional Benefits
Cecilton	1	420	504	536,727	536,727	-
Cecilton	2	2080	2496	1,793,850	1,614,178	179,672
Cecilton	3	262	314	52,504	35,114	17,390
Conowingo	1	1073	1287	1,845,425	1,845,425	-
Conowingo	2	917	1100	724,891	724,891	-
Conowingo	3	303	363	38,072	25,382	12,691
Conowingo	4	64	76	55,242	55,242	-
Delmar	1	1131	1357	1,876,040	1,876,040	-
Delmar	2	3019	3622	3,140,212	3,140,212	-
Delmar	3	303	363	30,289	20,193	10,096
Delmar	4	109	130	78,469	78,469	-
Finzel	1	1931	2317	4,870,924	4,870,924	-
Finzel	2	2152	2582	1,276,828	1,276,828	-
Finzel	3	5797	0	-	-	-
Finzel	4	112	134	87,096	87,096	-
Hyattstown	1	1824	2188	3,317,833	3,317,833	-
Hyattstown	2	4021	4825	2,447,085	2,447,085	-
Hyattstown	3	2143	2571	122,185	81,457	40,728
Hyattstown	4	165	198	153,104	153,104	-
Hyattstown	5	1	0	-	-	-
I-83/Parkton	1	1513	1815	3,253,351	3,253,351	-
I-83/Parkton	2	1711	2053	1,020,360	1,020,360	-
I-83/Parkton	3	2211	2653	838,865	559,033	279,832
I-83/Parkton	4	94	112	105,160	105,160	-
MSP Roving	1	249	298	217,022	217,022	-
MSP Roving	2	1129	1354	665,083	493,163	171,919
MSP Roving	3	205	246	5,380	3,587	1,793
MSP Roving	4	13	15	18,582	18,582	-
MSP Roving County	1	5422	6506	5,272,066	5,272,066	-
MSP Roving County	2	14164	16996	15,634,016	15,634,016	-
MSP Roving County	3	1325	1590	278,952	278,952	-
MSP Roving County	4	100	120	92,483	92,483	-
MSP Roving County	5	1885	0	-	-	-
MSP Roving County	6	3	0	-	-	-
New Market	1	1683	2019	2,320,703	2,320,703	-
New Market	2	2011	2413	1,096,358	1,096,358	-

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits (after adding 10% additional budget)	Benefits (40%)	Additional Benefits
New Market	3	4029	4834	268,877	179,270	89,607
New Market	4	65	78	27,584	18,389	9,195
New Market	5	1	1	1,402	1,402	-
Park and Ride	1	461	553	377,310	377,310	-
Park and Ride	2	5396	6475	3,388,192	3,388,192	-
Park and Ride	3	2003	0	-	-	-
Park and Ride	4	139	166	106,611	106,611	-
Park and Ride	5	7	0	-	-	-
Upper Marlboro	1	723	867	414,720	414,720	-
Upper Marlboro	2	4028	4833	1,537,134	1,024,756	512,378
Upper Marlboro	3	427	0	-	-	-
Upper Marlboro	4	179	214	49,488	33,069	16,419
West Friendship	1	1307	1568	2,535,280	2,535,280	-
West Friendship	2	2836	3403	1,590,574	1,590,574	-
West Friendship	3	1416	1699	143,261	95,451	47,810
West Friendship	4	306	367	210,910	210,910	-
Total		84868	89675	63,916,497	62,526,966	1,389,531

(e) MdTAP – Scenario 1 (30% Crash reduction)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
I 895 NB BHT Toll Plaza	1	683	819	231266
I 895 NB BHT Toll Plaza	2	1780	2136	432181
I 895 NB BHT Toll Plaza	3	562	449	19812
I 895 NB BHT Toll Plaza	4	3	0	0
I 895 NB BHT Toll Plaza	5	1	0	0
I 895 SB BHT Toll Plaza	1	329	263	46228
I 895 SB BHT Toll Plaza	2	1195	956	29090
I 895 SB BHT Toll Plaza	3	386	0	0
I 895 SB BHT Toll Plaza	4	3	0	0
I 895 SB BHT Toll Plaza	5	309	0	0
I 95 NB FMT Toll Plaza	1	500	400	46680
I 95 NB FMT Toll Plaza	2	1144	1120	233696
I 95 NB FMT Toll Plaza	3	317	0	0
I 95 NB JFK	1	1874	2248	971910
I 95 NB JFK	2	926	740	108904
I 95 NB JFK	3	383	0	0
I 95 NB JFK	4	67	53	351
I 95 SB JFK	1	2774	3328	2253687
I 95 SB JFK	2	2361	2833	736986
I 95 SB JFK	3	1014	0	0
I 95 SB JFK	4	170	204	70887
MDTAP Roving	1	744	892	323067
MDTAP Roving	2	2880	3454	1721340
MDTAP Roving	3	632	507	48463
MDTAP Roving	4	35	42	6246
MDTAP Roving	5	360	0	0
MDTAP Roving	6	11	0	0
MDTAP Roving County	1	3	3	7512
MDTAP Roving County	2	20	24	9162
MDTAP Roving County	3	31	31	7838
Rt 50 EB Bay Bridge	1	374	448	207820
Rt 50 EB Bay Bridge	2	1860	2232	1001931
Rt 50 EB Bay Bridge	3	312	373	49070
Rt 50 EB Bay Bridge	4	27	0	0
Total		24070	23555	8564127

(f) MdTAP – Scenario 2 (40% Crash reduction)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits
I 895 NB BHT Toll Plaza	1	683	819	671,369
I 895 NB BHT Toll Plaza	2	1780	1424	872,000
I 895 NB BHT Toll Plaza	3	562	449	106,697
I 895 NB BHT Toll Plaza	4	3	0	-
I 895 NB BHT Toll Plaza	5	1	0	-
I 895 SB BHT Toll Plaza	1	329	263	187,170
I 895 SB BHT Toll Plaza	2	1195	956	333,643
I 895 SB BHT Toll Plaza	3	386	308	27,032
I 895 SB BHT Toll Plaza	4	3	0	-
I 895 SB BHT Toll Plaza	5	309	0	-
I 95 NB FMT Toll Plaza	1	500	400	210,621
I 95 NB FMT Toll Plaza	2	1144	915	591,476
I 95 NB FMT Toll Plaza	3	317	253	16,776
I 95 NB JFK	1	1874	2248	2,634,302
I 95 NB JFK	2	926	740	466,971
I 95 NB JFK	3	383	306	41,000
I 95 NB JFK	4	67	53	15,874
I 95 SB JFK	1	2774	3328	5,311,282
I 95 SB JFK	2	2361	2310	1,808,388
I 95 SB JFK	3	1014	811	155,015
I 95 SB JFK	4	170	204	177,548
MDTAP Roving	1	744	892	779,632
MDTAP Roving	2	2880	3456	3,652,375
MDTAP Roving	3	632	505	164,006
MDTAP Roving	4	35	42	16,088
MDTAP Roving	5	360	0	-
MDTAP Roving	6	11	0	-
MDTAP Roving County	1	3	3	14,377
MDTAP Roving County	2	20	24	23,014
MDTAP Roving County	3	31	31	20,111
Rt 50 EB Bay Bridge	1	374	448	513,552
Rt 50 EB Bay Bridge	2	1860	2232	2,436,865
Rt 50 EB Bay Bridge	3	312	249	101,415
Rt 50 EB Bay Bridge	4	27	21	1,096
Total		24070	23690	21,349,693

(g) MdTAP – Scenario 3 (50% Crash reduction)

Location	Inspection Level	Current number of inspections	Optimal number of inspections	Benefits
I 895 NB BHT Toll Plaza	1	683	819	1237214
I 895 NB BHT Toll Plaza	2	1780	1424	1622701
I 895 NB BHT Toll Plaza	3	562	449	218406
I 895 NB BHT Toll Plaza	4	3	2	177
I 895 NB BHT Toll Plaza	5	1	0	0
I 895 SB BHT Toll Plaza	1	329	263	368380
I 895 SB BHT Toll Plaza	2	1195	956	725210
I 895 SB BHT Toll Plaza	3	386	308	84873
I 895 SB BHT Toll Plaza	4	3	0	0
I 895 SB BHT Toll Plaza	5	309	0	0
I 95 NB FMT Toll Plaza	1	500	400	421402
I 95 NB FMT Toll Plaza	2	1144	915	1106475
I 95 NB FMT Toll Plaza	3	317	253	60541
I 95 NB JFK	1	1874	2248	4771663
I 95 NB JFK	2	926	740	927343
I 95 NB JFK	3	383	306	128872
I 95 NB JFK	4	67	53	35833
I 95 SB JFK	1	2774	3328	9242475
I 95 SB JFK	2	2361	2309	3359377
I 95 SB JFK	3	1014	811	403292
I 95 SB JFK	4	170	204	314684
MDTAP Roving	1	744	892	1366644
MDTAP Roving	2	2880	3456	6133852
MDTAP Roving	3	632	505	312807
MDTAP Roving	4	35	42	28742
MDTAP Roving	5	360	0	0
MDTAP Roving	6	11	0	0
MDTAP Roving County	1	3	3	23204
MDTAP Roving County	2	20	24	40824
MDTAP Roving County	3	31	31	35890
Rt 50 EB Bay Bridge	1	374	448	906636
Rt 50 EB Bay Bridge	2	1860	2232	4281781
Rt 50 EB Bay Bridge	3	312	249	189689
Rt 50 EB Bay Bridge	4	27	21	6503
Total		24070	23691	38355492

(h) MdTAP – Scenario 4 (10% budget increase, scenario 2 as a base)

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits (after adding 10% additional budget)	Benefits (40%)	Additional Benefits
I 895 NB BHT Toll Plaza	1	683	819	671,369	671369	-
I 895 NB BHT Toll Plaza	2	1780	2136	1,307,999	872000	436,000
I 895 NB BHT Toll Plaza	3	562	450	106,934	106697	238
I 895 NB BHT Toll Plaza	4	3	0	-	0	-
I 895 NB BHT Toll Plaza	5	1	0	-	0	-
I 895 SB BHT Toll Plaza	1	329	393	279,687	187170	92,517
I 895 SB BHT Toll Plaza	2	1195	956	333,643	333643	-
I 895 SB BHT Toll Plaza	3	386	308	27,032	27032	-
I 895 SB BHT Toll Plaza	4	3	0	-	0	-
I 895 SB BHT Toll Plaza	5	309	0	-	0	-
I 95 NB FMT Toll Plaza	1	500	400	210,621	210621	-
I 95 NB FMT Toll Plaza	2	1144	1372	886,891	591476	295,415
I 95 NB FMT Toll Plaza	3	317	253	16,776	16776	-
I 95 NB JFK	1	1874	2248	2,634,302	2634302	-
I 95 NB JFK	2	926	1020	643,663	466971	176,692
I 95 NB JFK	3	383	306	41,000	41000	-
I 95 NB JFK	4	67	53	15,874	15874	-
I 95 SB JFK	1	2774	3328	5,311,282	5311282	-
I 95 SB JFK	2	2361	2833	2,217,820	1808388	409,432
I 95 SB JFK	3	1014	811	155,015	155015	-
I 95 SB JFK	4	170	204	177,548	177548	-
MDTAP Roving	1	744	892	779,632	779632	-
MDTAP Roving	2	2880	3456	3,652,375	3652375	-
MDTAP Roving	3	632	758	246,171	164006	82,165
MDTAP Roving	4	35	42	16,088	16088	-
MDTAP Roving	5	360	0	-	0	-
MDTAP Roving	6	11	0	-	0	-
MDTAP Roving County	1	3	3	14,377	14377	-
MDTAP Roving County	2	20	21	20,137	23014	-2,877

Location	Inspection Level	Current number of inspections	Optimal Number of Inspections	Benefits (after adding 10% additional budget)	Benefits (40%)	Additional Benefits
MDTAP Roving County	3	31	36	23,354	20111	3,244
Rt 50 EB Bay Bridge	1	374	448	513,552	513552	-
Rt 50 EB Bay Bridge	2	1860	2232	2,436,865	2436865	-
Rt 50 EB Bay Bridge	3	312	374	152,326	101415	50,911
Rt 50 EB Bay Bridge	4	27	21	1,096	1096	-
Total		24070	26,173	22,893,429	21349693	1543737