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Identification of Core Functions and Development of a Planning Tool for Safety Service Patrols in Virginia

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Supplementary Notes

Abstract

The purpose of this study was to identify and document the core functions of the Virginia Department of Transportation's (VDOT) Safety Service Patrol (SSP) programs and to develop a deployment planning tool that would help VDOT decision-makers when considering expanding SSP coverage and/or altering existing route coverage. The study involved a literature review of the functions, mission statements, objectives, and deployment criteria of other SSP programs across the United States that are commonly accepted as successful; documentation of the functions currently provided by VDOT's SSP programs and the benefit each provides; and the development of an SSP deployment planning tool.

VDOT's SSP programs share core functions, but the urban and rural programs differ in the type of benefits they emphasize. Urban regions place greater emphasis on the benefits associated with reduced travel delays and number of secondary crashes, and rural regions place greater emphasis on the benefits associated with improved safety for motorists in distress and creation of goodwill for VDOT. The study recommends that VDOT's regional operations directors prioritize the core functions of their programs in relation to the direct, indirect, and incidental benefits each provides. Emphasis should be placed on those core functions that provide the most direct benefits. Indirect and incidental benefits are also of importance and should not be overlooked in the prioritization process.

The planning tool developed in this study is a segment-based ranking scheme that can be applied to rural and urban freeway segments. Within the tool an incident prediction model was developed to predict incidents statistically using freeway segment average annual daily traffic (AADT), length, average daily percent of ADT served, and truck percentage. The study recommends that the SSP deployment planning tool be used by VDOT's regional operations directors as they consider deploying new patrols or altering existing ones. To do this, existing and potential SSP routes should be included in the evaluation. Each route must be divided into its constituent segments (traffic links), and each segment scored using the predicted number of incidents, level of service, planned projects, air quality, maximum access distance, maximum structure length, AADT, and daily truck volume. Routes should then be ranked based on their scores.

Hypothetically, if three routes (X, Y, and Z) are under consideration for SSP deployment in an urban region and funding is made available for only one deployment, the planning tool will indicate the route that will provide the greatest return on investment. For example, if the annual costs of operating an SSP on a route are $275,000 and if routes X, Y, and Z have benefit/cost ratios of 4.8, 4.3, and 3.1, respectively, the benefits to VDOT of choosing route X over route Y or Z are $137,500 and $467,500, respectively.

FINAL REPORT

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(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

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DISCLAIMER

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INTRODUCTION

In response to the growing impacts of congestion on our nation's freeways, freeway incident management (IM) has become a priority for many departments of transportation (DOTs). Freeway incidents include anything that disrupts the normal flow of traffic such as stalled vehicles, accidents, and objects that have fallen on the roadway. Improving the overall traffic IM process will improve the safety of responding agency personnel, reduce the chance of secondary crashes occurring in the unexpected traffic backup, and reduce the overall delay experienced by motorists.[1]

Five measurable objectives of IM are as follows:[2]

1. reducing the time for incident detection and verification
2. reducing response time (the time for response personnel and equipment to arrive at the scene)
3. exercising proper and safe on-scene management of personnel and equipment while keeping as many lanes open to traffic as possible
4. reducing clearance time (the time required for the incident to be removed from the roadway)
5. providing timely, accurate information to the public that enables them to make informed choices.

Many transportation agencies take part in the IM process by deploying safety service patrols (SSPs), typically on highly congested, urban roadways. SSPs are a countermeasure to freeway operations problems, and their implementation can improve safety and mitigate congestion. They respond to minor incidents such as vehicle breakdowns, spilled loads, or debris in the roadway. Clearing such minor incidents restores freeway capacity quickly, thus reducing congestion, or the duration of congested conditions.[3] For major incidents, such as vehicle crashes, SSPs assist with traffic control and can push disabled vehicles from the roadway. In part, because of their large benefit to cost ratios, SSPs have expanded rapidly across the United States since their inception in Chicago in the 1960s. As of 2002, more than 50 percent of freeway miles in the largest 78 U.S. metropolitan areas and almost 20 percent of the miles in 30 medium-sized areas were covered by an SSP.[4]

In Virginia, SSPs have long been regarded as a tremendous asset to the Virginia Department of Transportation's (VDOT) traffic and IM programs. The customer service provided by these programs is often cited by the media, and the delay reduction benefits can be used as a justification for their deployment. The particular functions provided by an SSP vary from program to program across the United States, and the same is true in Virginia. Some SSPs are committed to providing customer service functions such as gas, water, and minor mechanical repairs, whereas others are more singularly focused on IM. The definition of *incident management* itself can vary; some programs consider the customer service functions a key element in IM by getting the vehicles off the roadway, thereby preventing potential incidents. Although program variation is often necessary because of regional differences in geography and traffic characteristics (e.g., urban vs. rural), identifying and documenting a core set of SSP functions will help form a basis for performance reporting of existing programs and can help serve as a criterion for decisions regarding new coverage areas. In addition, a methodology for determining where deployment of SSPs would provide the greatest benefit is needed to guide investment decisions.

PURPOSE AND SCOPE

The purpose of this project was two-fold: (1) identify and document a core set of functions for Virginia's SSP programs and map them to the benefits that each serve; and (2) develop a planning tool that would help VDOT decision-makers when considering expanding SSP coverage and/or altering existing route coverage. The scope was limited in three ways:

1. The geographic domain of the study was limited to data from SSP programs currently operating in Virginia, which include the Northern Virginia (NOVA), Fredericksburg, Hampton Roads, Salem, and Staunton regions.

2. The deployment methodology incorporated incident data collected by Virginia's SSP programs for a 1-year period and focused on incidents such as accidents, vehicle disablements/breakdowns, and debris. Incident data from the Staunton region were not used in the study because the program was only recently established and thus has limited incident data. Incorporating incident data from the Virginia State Police (VSP) Computer-Aided Dispatch (CAD) System was beyond the scope of the study.

3. Traffic data such as roadway segment annual average daily traffic (AADT), average daily traffic (ADT), and truck percentages were limited to data in VDOT's Traffic Management System database.

METHODOLOGY

To achieve the study objectives, three tasks were undertaken:

1. Perform a literature review of the functions, mission statements, goals, and objectives of other SSP programs across the United States that are commonly accepted as successful. Further, investigate the methodologies of those programs that have developed criteria for deployment.

2. Identify the functions currently provided by SSP programs in Virginia and relate the functions to the benefit each provides.

3. Develop an SSP deployment planning tool that can be used by Virginia's SSP programs.

Literature Review

The objective of the literature review was to identify the functions, mission statements, objectives, goals, and deployment criteria of various SSP programs throughout the United States. Specifically, the goal was to compare and contrast functionality and incident priority differences, if any, to the programs operating in Virginia; relate how the functions support the goals of IM; and investigate the criteria some programs have employed to determine where to deploy SSPs. Because Virginia currently deploys SSPs in both rural and urban regions, particular focus was given to agencies that operate SSPs in both. To obtain information on SSP programs, the following data sources and methods were used:

- VDOT Research Library

- Transportation Research Board's Transportation Research Information Services (TRIS) database

- Ovid Technologies WebSPIRS database

- Google search engine

- On-site interviews

- Telephone interviews

- Email correspondence.

Identification of the Core Functions of Virginia SSPs

To identify the core functions of the programs in Virginia, the investigators conducted in-person, telephone, and email interviews with SSP supervisors and program managers in all Virginia locations that operate SSPs, including NOVA, Fredericksburg, Hampton Roads, Salem, and Staunton. Two programs operate in urban regions (NOVA and Hampton Roads), two in rural regions (Salem and Staunton), and one in a region with both urban and rural characteristics (Fredericksburg). Information was obtained from all programs on SSP functions for shoulder disablements, shoulder and travel-lane crash scenes, personal assistance to motorists, traffic control, and incident clearance activities. Of particular interest to the investigators was how (and if) the core functions in rural and urban programs vary, and to what extent. In addition, to help SSP management prioritize core functions (in terms of an IM and motorist assistance perspectives), the investigators mapped the core functions to "IM" benefits (reductions in travel delays, secondary crashes, and emissions) and "motorist assistance" benefits (improved safety to motorists and customer service).

Development of an SSP Deployment Planning Tool

To perform this task, the investigators identified the data requirements from the literature and determined the feasibility of collecting such data from VDOT resources. These data included SSP incident statistics, traffic characteristics, and freeway geometrics. (The term *incident* in this report refers to all SSP-assisted incidents.) To collect recent incident statistics, 1 year of data from June 1, 2005, to May 30, 2006, were analyzed for SSP programs in Hampton Roads, Fredericksburg, and Salem. For the NOVA SSP, incident statistics from 2004 were analyzed. The Staunton SSP, which is a new program, had yet to capture 1 year's worth of incident data, and therefore, incident statistics from this region were not incorporated into the planning tool.

The next step was to identify each SSP's route coverage, shift configurations (days and durations), and number of patrol trucks operating per shift and route. Each patrol route was then divided into segments (traffic links), and incident data for each segment were collected using VDOT's Archived Data Management System (ADMS) and SSP databases. Segment traffic data (AADT, hourly flow profiles, truck percentages) and geometric characteristics (segment length, number of lanes, presence of high-occupancy vehicle [HOV] lanes) were then obtained from VDOT's traffic management system (TMS) database.

The data collected were used to create a segment-based incident prediction model (IPM) using regression analysis. The IPM was then integrated with criteria used in the Maintenance Planning and Leadership Group (MPLG) methodology discussed later in this report (level of service [LOS], planned projects, air quality, maximum access distance, maximum structure length, AADT, and daily truck volume). The evaluation scales and criteria weights were adopted from the MPLG methodology (with few modifications), which allowed for the development of a segment-based scoring scheme. This scoring scheme was then incorporated into a user-friendly spreadsheet-based program.

RESULTS AND DISCUSSION

Literature Review

Core Functions

A review of many large scale and some smaller scale SSP programs (e.g., urban and rural) operating throughout the United States, revealed that the goals of IM drive the mission statements, objectives, and core functions of the programs. Therefore, many of the functions provided by SSPs are consistently similar. The elements of IM include:[5]

1. detection/verification
2. response
3. scene management
4. traffic management
5. incident clearance
6. motorist information.

Detection/verification and response are included in many of the programs' mission statements and objectives. For example, Georgia's HERO program objectives are as follows:[6]

- Minimize major disruption of freeway traffic flow at incident locations.
- Focus on the factors that cause disruption in the flow of traffic at incident locations.
- Relieve congestion and maintain consistent flow of traffic at incident locations.
- Reduce response-time to traffic-related incidents.

The stated objective of the Colorado DOT's Mile High Courtesy Patrol is to maximize the efficiency of the urban transportation facilities for vehicular traffic and to minimize the total delay to the traveling public.[7] The mission and objective of the Florida DOT's Road Ranger program are to provide highway assistance services during incidents to reduce delay and improve safety for the motoring public.[8] The mission of the Illinois DOT's Emergency Traffic Patrol is to promptly detect and respond to any disruptive incident on the Chicagoland expressways and to initiate quick and safe clearance procedures that will restore traffic flow.[9] The primary objective of the Minnesota DOT's Freeway Incident Response Safety Team (FIRST) program is to alleviate congestion and to prevent secondary crashes with the objective of promoting efficiency and safety.[1] Each of the aforementioned objectives and/or mission statements reflects the programs' purpose of reducing non-recurring congestion-related delay and improving safety by quick detection, verification, and response to freeway incidents.

Scene management, traffic management, incident clearance, and motorist information are typically reflected in an SSP program's stated core functions. The majority of the core functions reviewed that relate to scene management include:

- containing minor spills

- clearing crash debris

- providing road and traveler information to motorists in need
- notifying and communicating with traffic management centers, the state police, and other emergency responders
- providing basic first aid
- providing cell phone use
- reporting abandoned vehicles to the state police.

Some programs include other scene management objectives in their core functions such as:

- tagging abandoned vehicles, which helps the state police with clearing such vehicles (Oregon's Incident Response,[10] Missouri's Motorist Assist[11])
- transporting motorists in need (Florida Road Rangers,[8] Missouri's Motorist Assist[11]).

The core functions relating to traffic management are common across most SSPs reviewed and include:

- maintaining a presence at the point of lane or shoulder closures
- creating a buffer zone at incident scene with the patrol vehicle and cones
- utilizing a patrol vehicles' arrow boards for visibility
- operating and coordinating the use of portable message signs that inform motorists of impending lane closures.

Some programs, such as Minnesota's FIRST program,[1] also include the management of HOV and/or ramp-metering gates during peak-hour periods and when incident-related conditions warrant.

By far, the most pervasive commonalities among SSPs are their functions during the incident clearance element of IM. It is during this phase that the SSPs interact most with motorists because the majority of reported incidents comprise tending to minor shoulder incidents. A recent study of the NOVA SSP found that approximately 85 percent of incidents occur in the shoulder.[12] Typical core functions within incident clearance include:

- Assisting with mechanical failures and performing minor repairs (changing flat tires, jump starting vehicles, providing gas/water/coolant).

- Pushing disabled vehicles out of the roadway or moving disabled vehicles in the shoulder to a safer location. The extent of the authority the SSP has to move vehicles varies. Legislation in Maryland allows operators to push a vehicle or spilled cargo out of the roadway without approval by law enforcement and without being held liable for damages to the property.[12,13] California's Freeway Service Patrol (FSP) vehicles are tow trucks and, therefore, have the ability to remove vehicles without risking property damage.[14]

- Clearing incidental debris from the roadway (dead animals, tire rubber, spilled loads).

The last IM element involves motorist information dissemination. It is the core function of most SSPs to coordinate with traffic management centers to provide accurate and timely roadway information for motorists via portable message signs, fixed changeable message signs, highway advisory radio, the Internet, and other incident dissemination conduits.

Deployment Criteria

Although patrols continue to expand throughout the nation, deployment criteria have remained relatively unchanged[4] (e.g., deployment is often driven by congestion patterns in major metropolitan areas).[15] In addition to congestion patterns, deployment decisions are driven by funding, resource availability, and political factors. In lieu of the relatively limited factors used for deployment decisions (funding, congestion patterns, politics), a few SSP programs have deemed it necessary to develop empirically driven deployment criteria to help guide decision-makers in making sound, data-driven investment decisions. The principal factors influencing deployment criteria for some of the programs reviewed include crash or incident history, AADT (or ADT), and roadway geometry. Examples of these types of programs follow.

Oregon Department of Transportation

In 2001, the Oregon DOT's Incident Response (IR) program initiated a research project to identify the benefits of implementing incident response in both small urban and rural settings.[10] One product of the study was a planning tool to enable the DOT to perform analyses to consider expanding or introducing an IR program. The tool was derived from a study of the Highway 18 and Interstate 5 corridors. Because the majority of the delay-causing incidents in these corridors are crashes (75 and 70 percent for Highway 18 and Interstate 5, respectively), the planning tool emphasized the modeling of crash rates. Based on duration-delay diagrams for two-lane highways, accident statistics, and ADT, total delay were computed for these corridors. By modeling the roadway length, ADT, and the accident rate, the study attempted to estimate the delay on similar facilities under different scenarios. The purpose of the planning tool was not to provide a definitive answer as to whether an IR program would provide immediate returns but whether the roadway under consideration should be given additional review when future IR programs were considered.

Ohio Department of Transportation

The Oregon Department of Transportation developed a warrant process for the deployment of SSPs.[3] The principle behind the warrant process is the relationship between traffic volumes and crash frequency. When ADT nears 75,000, crashes and incidents reach acute levels and the impacts of the incidents to motorists (in terms of delay) can be mitigated by an SSP. There are seven warrants in the process (and premises upon which they are based):

1. *Construction, Holiday, and Special Event*. Short-term incidents such as construction, holidays, or special events can reduce capacity or cause severe peaks in traffic volume.

2. *Air Quality Conformity/Transportation System Management*. In urbanized counties, metropolitan planning organizations might identify SSPs as a method to achieve air-quality attainment goals as part of a transportation system management plan.

3. *Critical Infrastructure (includes bottleneck locations)*. Certain segments of a freeway network, especially bridges, tunnels, or interchanges, might be critical to the efficient flow of traffic in the region.

4. *ADT > 75,000*. There is a direct correlation between freeway volume and incident frequency, regardless of the total number of lanes. A critical threshold is reached at approximately 75,000 ADT.

5. *Volume to Capacity Ratio > 1*. The presence of recurrent congestion can warrant the use of SSPs.

6. *Crash Frequency > 200*. The critical threshold is reached when the 3-year crash history on a 2-mile segment of freeway reaches 200 crashes.

7. *Shoulder Width < 6 Feet*. Insufficient shoulder widths offer no space for vehicular breakdowns or debris, thus reducing capacity in incident conditions and creating a safety hazard.

If a single warrant is met, it is deemed “permissive” to deploy SSPs. However, the decision to implement is at the discretion of management. If warrants 4 and 5 or warrants 6 and 7 are met, SSP deployment is recommended because of the certainty that the freeway has acute operational deficiencies.

North Carolina Department of Transportation (NCDOT)

In 2005, researchers at the University of North Carolina at Chapel Hill developed criteria for the expansion of Incident Management Assistance Patrols (IMAP) in North Carolina and created a planning-level decision support tool that can prioritize and rank current and future IMAP projects.[4] A combination of statistical and geographic analyses of statewide crash data and benefit-cost analyses of current and potential deployment segments were performed using incident simulations. To perform the planning-level analysis, index statistics indicating a facility's relative need were created using 3 years of crash, traffic, and inventory data. The index statistics consisted of AADT per lane, crashes per mile year, and crashes per 100 million vehicle miles.[4] Ideally, the researchers would have preferred to use incident statistics rather than crashes, but there was no central repository of incident data in North Carolina.

California

Researchers at the University of California–Berkeley created a Freeway Service Patrol Evaluation (FSPE) model for the California Department of Transportation.[16] This model calculates a benefit/cost ratio for FSP "beats" (or routes) based on the cost of FSP service on a beat and reductions in motorist delay, fuel consumption, and emissions attributable to FSP operations. Imbedded in the FSPE model is a Freeway Service Patrol Prediction model, developed to predict the cost-effectiveness of providing FSP service on freeway sections that do not have FSP service. The model forecasts the total number of FSP assists based on the beat's geometric and traffic characteristics and on the FSP hours of operation; it then calls on the FSPE model to evaluate the beat as if the FSP assists were "known."

Virginia Department of Transportation

With respect to decisions regarding the deployment of SSPs in new areas or expanding the coverage area in an existing region, a methodology was developed in 1996 by VDOT's MPLG and the Statewide Incident Management Committee (SIM), two groups charged with maintenance of traffic issues resulting from incidents on Virginia's interstate roadways.[17] This methodology, referred to as the MPLG methodology throughout this report, is based on the following criteria:

1. *LOS:* measure of the traffic performance on the freeway segment.

2. *Incident history*: number of incidents in prior 3 years.

3. *Planned projects:* surrogate for the safety implications of work zones, based on the dollar value of projects in VDOT's Six-Year Improvement Program.

4. *Air quality*: Boolean variable (yes/no) to specify attainment and non-attainment areas.

5. *Access distance*: maximum distance an emergency vehicle has to travel from the interchange to assist an incident occurring on the segment. This distance is equal to half the distance between interchanges. Another context of this distance is when there is a breakdown and the motorist walks to the nearest exit—the greater the distance, the more dangerous.

6. *Structure length*: length of a bridge or tunnel within the segment. Long structures quite often form bottlenecks on freeways, hence making it difficult for incident response teams to assist incidents. Longer structures usually indicate significant barrier crossings where alternative routes might be limited. Structures that are long

usually have reduced shoulder widths, hence making it unsafe for the motorist involved with breakdown vehicles to walk for assistance.

7. *AADT*: surrogate for the number of customers served by an SSP patrol

8. *Daily truck volume*: number of trucks traveling the segment in 1 day.

Each criterion was assigned a weight and an evaluation scale for which scores were calculated on all interstate segments in Virginia. A threshold score was identified from a plot of the benefit/cost ratios versus the scores for SSP-deployed freeway segments. The developed methodology was intended to provide a “yes” or “no” answer to decision-makers when considering new routes for SSP deployments. Scores were computed for the segments and compared with the threshold score. Interstate segments with a score higher than the threshold were considered candidates for SSPs, and those with a score below the threshold were not.

Identification of the Core Functions of Virginia SSPs

The SSP program is a vital element of VDOT’s comprehensive traffic management program. The local SSP programs have developed primarily in response to local needs and, therefore, at times, differ in their operating philosophy. In urban areas, such as NOVA, Hampton Roads, and sections of Fredericksburg, where congestion is ubiquitous, emphasis is placed on the expeditious removal of any capacity-reducing obstruction. Research has shown that in urban areas, vehicle disablements on a shoulder can reduce capacity by 5 percent,[18] and such reductions in capacity have the potential to create large delays. In rural areas that operate SSPs, such as Salem, Staunton, and sections of Fredericksburg, capacity reductions attributable to minor incidents (shoulder disablements) occur infrequently. Emphasis, therefore, is placed on the customer service aspect of helping motorists in distress. However, the purpose, mission, and core functions of rural and urban SSPs remain consistent with the goals of IM.

The thrust of VDOT’s SSP program coincides with the first two IM elements of incident detection/verification and response. Its purpose is “to promote the efficient and effective flow of traffic through effective incident detection, verification, and notification to appropriate agencies to initiate rapid clearance of an incident.”[19,20] Its mission is:

> to provide initial response and promote and enhance the goals of incident management by patrolling the Commonwealth’s interstate system and providing customer service related assistance for the safe and efficient transportation of motorists, goods, and services in support of the economic, environmental, and public demands placed on the system.[19,20]

When responding to incidents, priority is placed in the following order: (1) incidents on the travel portion of the highway, (2) incidents on the shoulder area, and (3) incidents in rest areas. However, these priorities may vary due to the nature of the incident, i.e., HAZMAT spills and personal injury.[12,21]

As with the majority of other U.S. SSP programs, the core functions of Virginia’s SSP address the scene management, traffic management, incident clearance, and motorist information goals of IM. Based on interviews with VDOT SSP staff and documentation of SSP activity, the following constitutes the core set of functions for VDOT's rural and urban SSP programs:[19,20]

Scene Management:

- Notify the state police of abandoned vehicles.
- Provide cellular service to disabled motorists.
- Upon request, provide directions and a Virginia State Map.
- Provide the service of remaining with disabled vehicles. When conditions warrant, patrollers are encouraged to stay with occupied disabled vehicles when possible.[21]
- Provide basic first aid and CPR.
- Initiate maintenance action reports for state property damage.
- Communicate activities with STCs/provide information to other responders.

Traffic Management:

- Assist with traffic control at incident scenes/manage lane closures.
- Manage/verify operation of ramp-metering gates/HOV gates (urban only).

Incident Clearance:

- Perform minor mechanical repairs (tightening battery terminals, taping leaking hoses, reconnecting spark plugs, wires, etc.). A patroller should perform such tasks only if they are trained and have the equipment assigned to the patrol vehicle to complete such repairs. The patroller should complete only such tasks that can be done on site. Minor mechanical repairs should be completed while a patroller is standing. The patroller should not need to crawl under a vehicle to make repairs.[20]
- Jump start vehicles.
- Provide gas/water.
- Change tires/provide air.
- Remove debris.
- Push vehicles to shoulder. In Virginia, the VSP and local law enforcement have jurisdiction over moving a vehicle, cargo, or personal property. VDOT's SSP does not have the authority to push a vehicle out of the roadway unless waiver forms are

signed by the motorist relinquishing VDOT from liability for damages to property.[12,19]

Information to Motorists:

- Communicate activities with STCs/provide information to other responders.

To help VDOT decision-makers gain a better understanding of how the core functions relate to the benefits each provides, a diagram was developed that qualitatively maps each VDOT SSP core function to benefits. The diagram, which was adapted from research conducted by Tennessee's HELP program,[22] is shown in Figure 1 and denotes the direct, indirect, or incidental benefits of each core function as applied to each benefit category. The figure also shows the relationship between the core functions and the IM goals of scene management, traffic management, incident clearance, and motorist information.

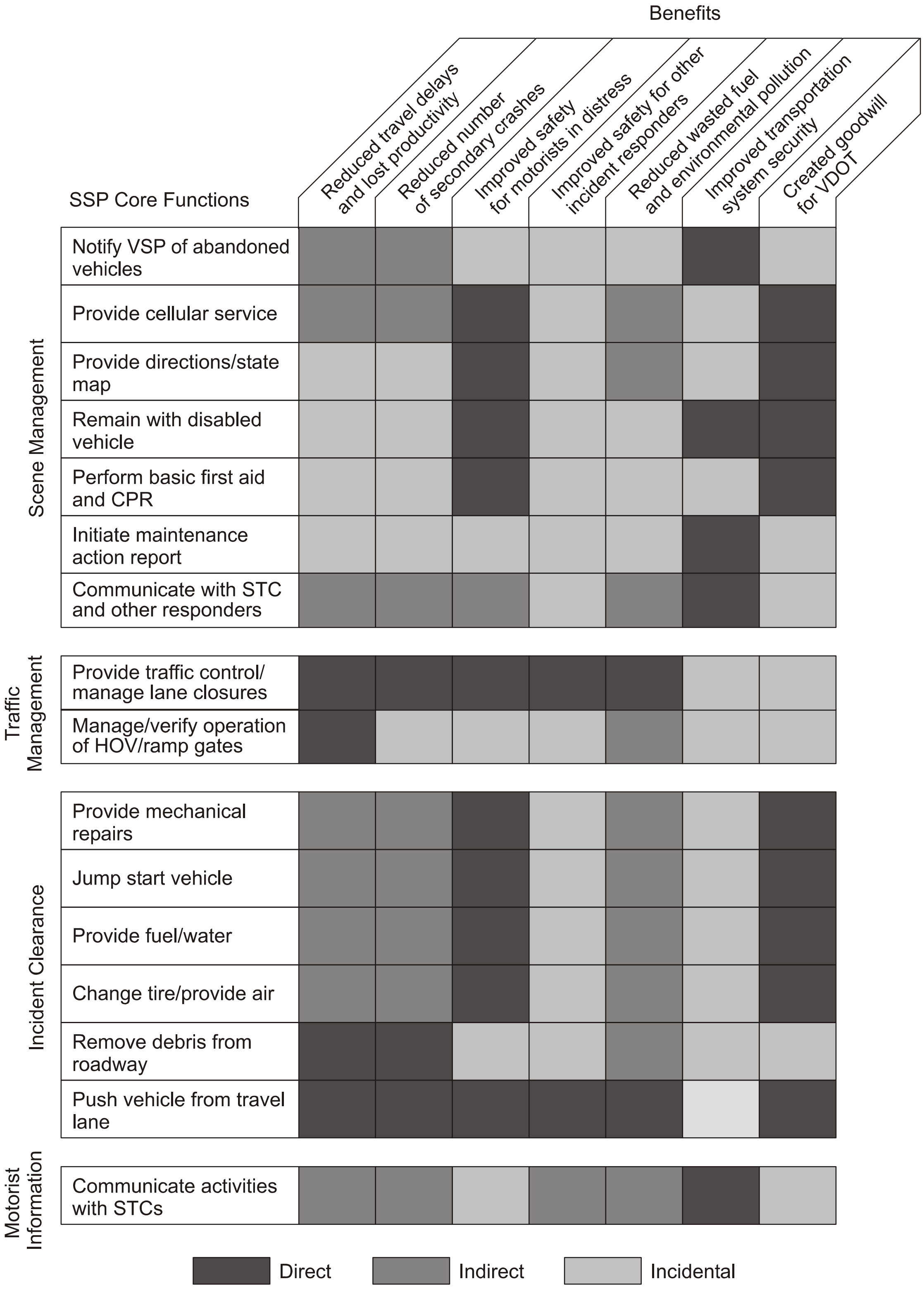
The benefits include:

- reduced travel delays
- reduced number of secondary crashes
- improved safety for motorists in distress
- improved safety for incident responders
- reduced wasted fuel and environmental pollution
- improved transportation system security
- creation of goodwill for VDOT.

Development of an SSP Deployment Planning Tool

To assist in the development of a planning level methodology to rank freeway segments competing for SSP deployments, the investigators reviewed the current deployment practices in other state agencies and VDOT's MPLG study. The critical criteria used across the agencies were relatively consistent (e.g., AADT, incident history/crash history, geometric characteristics). The MPLG study[17] used many of the same criteria; however, the study has not been updated since its development in 1996 and some limitations prevented its applicability to statewide SSP deployment decisions. Those limitations include:

- *Limited data and inadequate model specification for incident history*. Incident history, defined as the number of incidents in the past 3 years, is calculated using a regression equation. The equation was developed using incident and crash data from 1993 to 1995 on 28 road segments served by SSPs. These included 6 segments on I-77 in Salem, 16 on I-81 in Salem, and 6 on I-95 in Fredericksburg. Segments in Hampton Roads and NOVA were not used. Further, the regression equation was estimated assuming that the number of incidents is only a function of the number of crashes and no traffic or geometric variables were considered.



Benefits

	SSP Core Functions	Reduced travel delays and lost productivity	Reduced number of secondary crashes	Improved safety for motorists in distress	Improved safety for other incident responders	Reduced wasted fuel and environmental pollution	Improved transportation system security	Created goodwill for VDOT
Scene Management	Notify VSP of abandoned vehicles	▨	▨	□	□	□	■	□
	Provide cellular service	▨	▨	■	□	▨	□	■
	Provide directions/state map	□	□	■	□	▨	□	■
	Remain with disabled vehicle	□	□	■	□	□	■	■
	Perform basic first aid and CPR	□	□	■	□	□	□	■
	Initiate maintenance action report	□	□	□	□	□	■	□
	Communicate with STC and other responders	▨	▨	▨	□	▨	■	□
Traffic Management	Provide traffic control/ manage lane closures	■	■	■	■	■	□	□
	Manage/verify operation of HOV/ramp gates	■	□	□	□	▨	□	□
Incident Clearance	Provide mechanical repairs	▨	▨	■	□	▨	□	■
	Jump start vehicle	▨	▨	■	□	▨	□	■
	Provide fuel/water	▨	▨	■	□	▨	□	■
	Change tire/provide air	▨	▨	■	□	▨	□	■
	Remove debris from roadway	■	■	□	□	▨	□	□
	Push vehicle from travel lane	■	■	■	■	■	□	■
Motorist Information	Communicate activities with STCs	▨	▨	□	▨	▨	■	□

■ Direct ▨ Indirect □ Incidental

Figure 1. Direct, Indirect, and Incidental Benefits as Mapped to VDOT's Core Functions. SSP = Safety Service Patrol , VSP = Virginia State Police , CPR = cardiopulmonary resuscitation , STC = Smart Traffic Center, HOV = High-Occupancy Vehicle.

- *Limited data for deriving the threshold score*. The threshold score was set based on a plot of the B/C ratios versus the scores for freeway segments where SSPs were deployed. The dataset consisted of 24 segments: 7 segments on I-77, 9 on I-81, 1 on I-581, and 7 on I-95. These segments are predominantly rural (77, 81, and 581 in Salem and 95 in Fredericksburg). Though this dataset covers more than 100 miles in various terrains, the size of the dataset (24) is actually very small to derive a threshold score. This shortcoming is even more important when nearly 50 percent of the observations have a B/C ratio less than 1.0. From the plot, a threshold score of 35 was chosen. Of the 15 segments that had scores greater than the threshold, only 10 had B/C ratios greater than 1.0.

- *Outdated threshold score*. For the calculation of benefits in determining the B/C ratios, the MPLG methodology considers the following items: (1) reduction in traffic backups, (2) reduction in number of secondary accidents, and (3) reduction in state expenses to respond to disabled vehicles and other non-accidents such as debris. Based on empirical observations from the SSP deployments in the NOVA, Fredericksburg, and Salem districts, values of 16 and 52 were used as percentage reductions for incident response and service times, respectively. These values are not consistent with national research. The Texas Transportation Institute’s 2003 Urban Mobility Report documented a 15 percent reduction in incident duration (response time plus service time) for regions with combined CCTV coverage and SSP operations.[23]

- *Other limitations*. The MPLG methodology provides only a “yes” or “no” answer for patrol deployment on a freeway section with no distinction given to time of day. Therefore no guidance is given on the number of hours in a day or days in a week that a patrol should be deployed. The criteria also appear to be more suited to urban than rural areas with greater point values possible for LOS and incident history, both of which will obtain higher scores in urban areas.

To serve VDOT in the deployment decision-making process better, this study developed a new methodology that incorporates many of the principles of the MPLG study and addresses most of its limitations. A more robust IPM was developed using recent data that covered SSP-served freeway segments in four locations: Hampton Roads, NOVA, Fredericksburg, and Salem. Several traffic and geometric characteristics as well as operational hours were also incorporated in the model specification. A threshold score was not derived because of insufficient data to introduce such a threshold. Further, the intent of this study was to develop a ranking methodology, not a threshold-based “yes” or “no” deployment decision. The new methodology consists of an IPM and a revised set of decision variables taken from the MPLG study. The framework of the ranking methodology is shown in Figure 2. In the first step, segments that are being considered for new SSP deployments are identified. Next, the IPM is used, for each segment, to predict incidents that will be assisted by SSPs if they are to be deployed on the segment. Based on a defined evaluation scale and criteria weights, scores are computed for all segments. In the final step, the segments are ranked based on the computed scores.

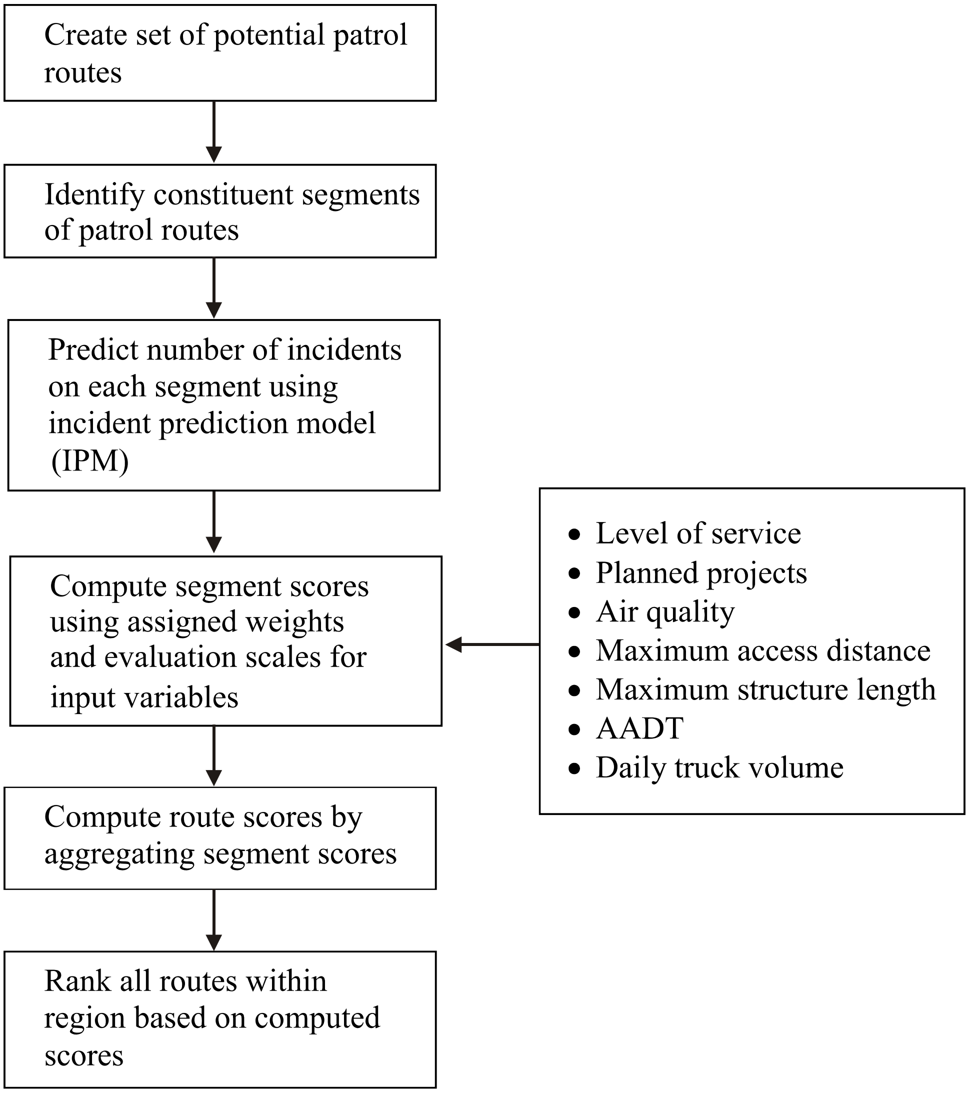


Figure 2. Deployment Planning Tool Framework. AADT = average annual daily traffic.

Incident Prediction Model

Data Extraction

At the time this study was conducted, SSPs were serving five geographic regions in Virginia specified previously and covered 25 routes (see Table 1). Data related to all the routes were obtained from several sources. Route characteristics, operating hours, and number of SSP vehicles deployed were obtained from VDOT SSP program managers in each region. Incident data were extracted from the ADMS database for Salem and Hampton Roads. For NOVA routes, incident data were obtained from the NOVA SSP Incident Management database. For Fredericksburg routes, incident location data were manually extracted from the SSP logs.

Table 1. Virginia SSP Routes Reviewed in This Study

SSP Route Name	Route Number	Begin	End
Hampton Roads			
Reversible Roadway (RR)	I-64 and I-564 (reversible lanes)	Indian River Rd.	Naval Base Gate 3 on I-564
2 Inner (2I)	I-264	Lynnhaven Pkwy. via inside lanes	Campostella Rd.
2 Outer (2O)	I-264	Lynnhaven Pkwy. via outside lanes	Military Hwy.
Bridge Tunnel (HRBT)	I-64	4th View St.	Armistead Ave.
Coliseum A (Col A)	I-64 and I-664	J. Clyde Morris Blvd.	Mallory St. on I-64 and to Terminal Ave. on I-664
Coliseum B (Col B)	I-64 and I-664	J. Clyde Morris Blvd.	Mallory St. on I-64 and to Terminal Ave. on I-664
Naval Base (NB)	I-64 and I-564	Indian River Rd.	Naval Base Gate 3 on I-564
Highrise (HI)	I-64	Route 17	Indian River Rd.
Downtown Tunnel (DT)	I-264 and I-464	Military Hwy. via Berkeley Br.	I-464 /I-64 Interchange
Monitor-Merrimack Memorial Bridge-Tunnel (MMMBT)	I-664	Aberdeen Rd. through MMMBT	Dock Landing Rd.
Northern Virginia			
P-1	I-395	DC line	Beltway
P-2	I-95	Beltway	Rt. 123
P-3	I-95	Rt. 123	Exit 148
P-9	I-66	DC line	Rt. 243
P-10	I-66	Rt. 243	Rt. 234
B-2	Woodrow Wilson Bridge		
Dulles Toll Road (DTR)	DTR		
P-7	I-495	American Legion Bridge	Rt. 236
P-8	I-495	Woodrow Wilson Bridge	Rt. 650
Fredericksburg			
Caroline County	I-95	Exit 98	Exit 118
Spotsylvania County	I-95	Exit 118	Exit 133
Stafford County	I-95	Exit 133	Exit 148
Salem			
Route No. 1	I-81	Exit 114	Exit 141
Route No. 2	I-81 and I-581	Exit 140	Exit 156 on I-81 and all I-581
Staunton			
Route No. 1	I-81	Exit 180	Exit 195

Traffic-related data such as AADTs, section lengths, traffic flow profiles, and truck percentages were extracted from VDOT's TMS database. The database is designed in such a way that the freeway sections are divided into smaller segments (or links) with uniform characteristics. Data pertaining to the geometric variables, i.e., number of lanes, availability of right/left shoulders, and presence of HOV lanes, were obtained using VDOT's GIS Integrator, which is an online GIS server. Desired data to build the regression model could be obtained only for the 15 routes listed in Table 2. For the remaining 10 routes, data on crucial variables were missing, and in some cases, the level of detail of the available data was not sufficient to be used in estimating the model.

Table 2. Routes Used In Building Regression Model

SSP Route Name	Location
Bridge Tunnel (HRBT)	Hampton Roads
Coliseum A (Col A)	Hampton Roads
Coliseum B (Col B)	Hampton Roads
Highrise (HI)	Hampton Roads
Downtown Tunnel (DT)	Hampton Roads
Monitor-Merrimack Memorial Bridge-Tunnel (MMMBT)	Hampton Roads
Dulles Toll Road (DTR)	Northern Virginia
P-2	Northern Virginia
P-10	Northern Virginia
B-2	Northern Virginia
Route No. 1	Salem
Route No. 2	Salem
Caroline County	Fredericksburg
Spotsylvania County	Fredericksburg
Stafford County	Fredericksburg

To obtain a reasonably sized dataset for estimating the regression model, the segments defined by the TMS website for each SSP route were used as independent observations. There were a total of 92 segments for the 15 routes. Incidents on a complete SSP route are obtained by applying the model to the route's constituent segments and adding all the predicted values. Definitions and notations of possible explanatory variables (for a freeway segment) are as follows:

- AADT
- ADT
- N_L—Number of lanes
- PR_{HOV}—Presence of HOV lanes
- S_L—Segment length
- P_T—Percent of trucks
- PR_R—Presence of right shoulder
- PR_L—Presence of left shoulder
- P^{W}_{AM} —Percent of ADT served by SSP during A.M. (12 A.M. to 12 P.M.) on weekdays
- P^{W}_{PM} —Percent of ADT served by SSP during P.M. (12 P.M. to 12 A.M.) on weekdays)
- P^{S}_{AM} —Percent of ADT served by SSP during A.M. on Saturday
- P^{S}_{PM} —Percent of ADT served by SSP during P.M. on Saturday
- P^{N}_{AM} —Percent of ADT served by SSP during A.M. on Sunday
- P^{N}_{PM} —Percent of ADT served by SSP during P.M. on Sunday
- P_{AVE}—Average daily percent of ADT served

$$P_{AVE} = \frac{5}{7} \cdot (P^{W}_{AM} + P^{W}_{PM}) + \frac{1}{7} \cdot (P^{S}_{AM} + P^{S}_{PM}) + \frac{1}{7} \cdot (P^{N}_{AM} + P^{N}_{PM})$$

- DSVMT—Daily served vehicle miles of travel

$$DSVMT = AADT \cdot S_L \cdot \frac{P_{AVE}}{100}$$

- DTMT—Daily truck miles of travel

$$DTMT = AADT \cdot S_L \cdot \frac{P_T}{100}$$

- N_I—Number of annual SSP assists or incidents (assuming 7-days-a-week coverage).

Descriptive statistics of selected input variables for the combined dataset consisting of all 15 routes are shown in Table 3. Statistics by region are shown in Appendix A.

Table 3. Descriptive Statistics of Combined Dataset

Variable	Mean	Standard Deviation	Minimum	Maximum	Sum	Count
S_L	2.18	1.71	0.22	9.99	200.49	92
AADT	93005	43378	37019	239029	8556448	92
N_L	5.73	1.45	4	8	527	92
PR_{HOV}	0.17	0.38	0	1	16	92
P_{AVE}	88.36	15.16	51.1	100	8129	92
P_T	9.87	8.23	1	35	908	92
DSVMT	162782	119919	11118	525236	14975943	92
DTMT	19843	24949	269.206	127965	1825547	92
Log_e(AADT)	11.33	0.46	10.52	12.38	1043	92
Log_e(DSVMT)	11.72	0.79	9.32	13.17	1078	92
Log_e(DTMT)	9.20	1.23	5.60	11.76	846.81	92
N_I	320	319.90	2	1444	29406	92

Model Estimation

Linear regression (LR) is typically used when the dependent variable (in this case N_I) can take continuous values (real numbers). LR also assumes that the residual errors are normally distributed with a constant variance. These assumptions are not true for count data such as the incidents where the residual errors have a skew distribution with a non-constant variance.[24] In addition, the incident counts are always non-negative integer values. Statisticians have recommended the use of count data models for modeling count data. Poisson and negative binomial (NB) regression are two such methods that have been extensively used in traffic safety research.[25] For a detailed explanation of the count data models, readers are encouraged to refer to Cameron and Trivedi.[26]

As a first step, the correlations between the explanatory variables, as defined earlier, were calculated to identify if there were any variables that were highly correlated with one another. When two variables are highly correlated, both should not be in the estimated model as they are conveying the same information relating to the dependent variable. Therefore, it may be sufficient to include only one of the two variables in the model.

There is an additional benefit of calculating the correlation matrix. If consideration is given to estimating the dependent variable through regression and the estimated model performs well in terms of goodness-of-fit measures but the *p*-values (probability of the coefficient being equal to zero) of the coefficients of explanatory variables are very high, it can be assumed that there is high correlation between two or more explanatory variables (e.g., there is multicollinearity in the model because two or more explanatory variables are collinear). In general, high *p*-values mean that the variables do not have a statistically significant relationship with the dependent variable. However, when both the correlated variables are dropped from the model, the fit will become much worse. In such situations, one of the variables should be removed from the model or if possible; the use of a variable that is a combination of the collinear variables is recommended to circumvent the multicollinearity bias in the model estimation.

The correlation matrix from all segments estimated in this study is shown in Appendix B. From the values shown in the table it can be inferred that most of the variables (except between the variable and its logarithm form) are not highly correlated with one another. Only a few pairs of independent variables have reasonably high correlations (greater than 0.6), such as (S_L, DSVMT), (S_L, DTMT), [S_L, Log_e(DSVMT)], [S_L, Log_e(DTMT)]; (AADT, N_L); (N_L, PR_{HOV}); (P_{AVE}, DTMT), and [P_{AVE}, Log_e(DTMT)] and thus should not pose significant concerns with regard to the model development.

All variables shown in the table were tried in the regression model in a step-by-step procedure. Starting with an intercept-only model, input variables were added one by one to the regression model. The improvement in the goodness-of-fit (log likelihood ratio) attributable to the addition of new variables and the significance of each variable's estimated coefficient (at the 95 percent confidence level) are noted. Initially, a Poisson model was fitted and the deviance and Pearson chi-square values were much greater than 1.0, meaning that the data were overdispersed. Overdispersion indicates that the variance is greater than the mean and hence the assumption of a Poisson distribution is invalid (in Poisson distributions, the mean is equal to the variance). To account for overdispersion, the use of the NB distribution is recommended;[25] thus, the step-by-step fitting procedure was repeated using the NB model. The goodness-of-fit measures for the NB model are shown in Table 4. The log likelihood values were found to be higher than the Poisson model's values, and the deviance and Pearson chi-square values were close to 1.0, therefore confirming that the NB model was the right model for fitting the study data. All variables except $\log_e$ (DSVMT), $\log_e$ (DTMT), and P_T were not significant at the 95 percent confidence level. The coefficients of the estimated model along with their *p*-values for hypothesis testing are shown in Table 5.

Table 4. Goodness-of-Fit Measures

Criterion	DF	Value	Value/DF
Deviance	88.00	101.31	1.15
Scaled Deviance	88.00	101.31	1.15
Pearson Chi-Square		70.96	0.81
Scaled Pearson X2		70.96	0.81
Log Likelihood		154250.19	
R^2_α		0.56	
R^2_P		0.51	

Table 5. Estimation of Coefficients in Negative Binomial Distribution Model

Coefficient	Parameter Estimate	Standard Error	Chi-Square	*p* -value
Intercept	-3.8502	1.36	7.99	0.0047
Log_e(DSVMT)	0.6095	0.19	10.48	0.0012
Log_e(DTMT)	0.3421	0.14	5.69	0.0171
P_T	-0.099	0.02	36.15	<.0001
Dispersion	0.4762	0.07		

The final estimated regression equation using the NB model can be written as follows:

$$N_I = e^{[-3.8502 + 0.6095 \cdot \text{Log}_e(\text{DSVMT}) + 0.3421 \cdot \text{Log}_e(\text{DTMT}) - 0.1039 \cdot P_T]} \qquad \text{(Eq. 1)}$$

Substituting for DSVMT and DTMT gives

$$N_I = e^{[-3.8502 + 0.6095 \cdot \text{Log}_e(\text{AADT} \cdot S_L \cdot \frac{P_{AVE}}{100}) + 0.3421 \cdot \text{Log}_e(\text{AADT} \cdot S_L \cdot \frac{P_T}{100}) - 0.1039 \cdot P_T]} \qquad \text{(Eq. 2)}$$

The coefficient of the percentage of trucks (P_T) variable is negative, which indicates that as truck percentage increases, the number of incidents decreases. This deduction, however, should be made with caution. In the study data, the rural segments typically had lower incidents, higher truck percentages, lower AADTs, and lower P_{AVE} values as compared to most segments in urban areas. Even though the negative coefficient of P_T might not be intuitive when considered independently, it does become plausible when considering regional differences in SSP incident data.

For explanatory purposes, Eq. 2 can be further reduced into the following easy-to-use form:

$$\boxed{N_I = (0.02128) \cdot (\text{AADT})^{0.9516} \cdot (S_L)^{0.9516} \cdot (\frac{P_{AVE}}{100})^{0.6095} \cdot (\frac{P_T}{100})^{0.3421} \cdot (0.90132)^{P_T}}$$

where S_L is in miles, P_{AVE} and P_T are in percentages, and N_I is the number of incidents per year. For example, if AADT = 74,000 vehicles, S_L = 4 miles, P_{AVE} = 85%, P_T = 9%,

$$N_I = (0.02128) \cdot (74000)^{0.9516} \cdot (4)^{0.9516} \cdot (\frac{85}{100})^{0.6095} \cdot (\frac{9}{100})^{0.3421} \cdot (0.90132)^{9}$$
$$\approx 533 \text{ incidents per year.}$$

In cases where routes are not covered 7 days a week, the predicted incidents should be adjusted proportionally to the number of days per week a route is covered.

To explain the proportion of variation in the NB model, two types of pseudo-R^2 can be computed:

1. *Dispersion parameter-based R^2_α,* which is estimated as

$$R^2_\alpha = 1 - \frac{\hat{\alpha}}{\hat{\alpha}_{max}}$$

where $\hat{\alpha}$ is the estimated dispersion parameter for the candidate model, and $\hat{\alpha}_{max}$ is the estimated value when the model is run without any covariates (intercept only model). For the estimated incident model, $\hat{\alpha} = 0.4702$, $\hat{\alpha}_{max} = 1.0668$, hence $R^2_\alpha = 0.56$.

2. *Pearson product moment correlation coefficient,* which gives the correlation between the predicted number of incidents dataset and the observed number of incidents dataset. This measure is squared to get the Pearson R^2 measure.

$$R^2_P = \left[\frac{\Sigma (N_i^{obs} - \overline{N}^{obs}) \cdot (N_i^{pred} - \overline{N}^{pred})}{\sqrt{\Sigma (N_i^{obs} - \overline{N}^{obs})^2 \cdot \Sigma (N_i^{pred} - \overline{N}^{pred})^2}} \right]^2$$

where

N_i^{obs} = Observed number of incidents for section i

N_i^{pred} = Predicted number of incidents for section i

$\overline{N}^{obs}$ = Mean of the observed number of incidents

$\overline{N}^{pred}$ = Mean of the predicted number of incidents

For the IPM, the computed R^2_P value was 0.51. A plot of model predictions versus the observed incidents is shown in Figure 3 and reveals that the model slightly overpredicts incidents when observed incidents are low (the estimated NB model predicts the mean value of the incidents for any given segment). A 95 percent confidence interval for the predictions was computed, and the ratio of each predicted value to its upper limit and lower limit was calculated and is plotted in Figure 4. Based on the interval bounds, it can be postulated that the actual number of incidents will place within approximately 3/4 and 4/3 of the model prediction.

Other Segment-Based Decision Variables of the Planning Tool

Additional segment-based decision variables were derived from the MPLG study with some modifications. The incident history criterion was replaced by annual incidents per mile and was calculated by dividing the predicted number of incidents (N_I) by segment length (S_L). Further, to enable separate incident comparisons between urban and rural segments, two distinct incident evaluation scales were introduced and are shown in Table 6 (the MPLG methodology used the same evaluation scales for urban and rural segments). The remaining criteria, i.e., LOS, air quality, maximum access distance, maximum structure length, AADT, and daily truck

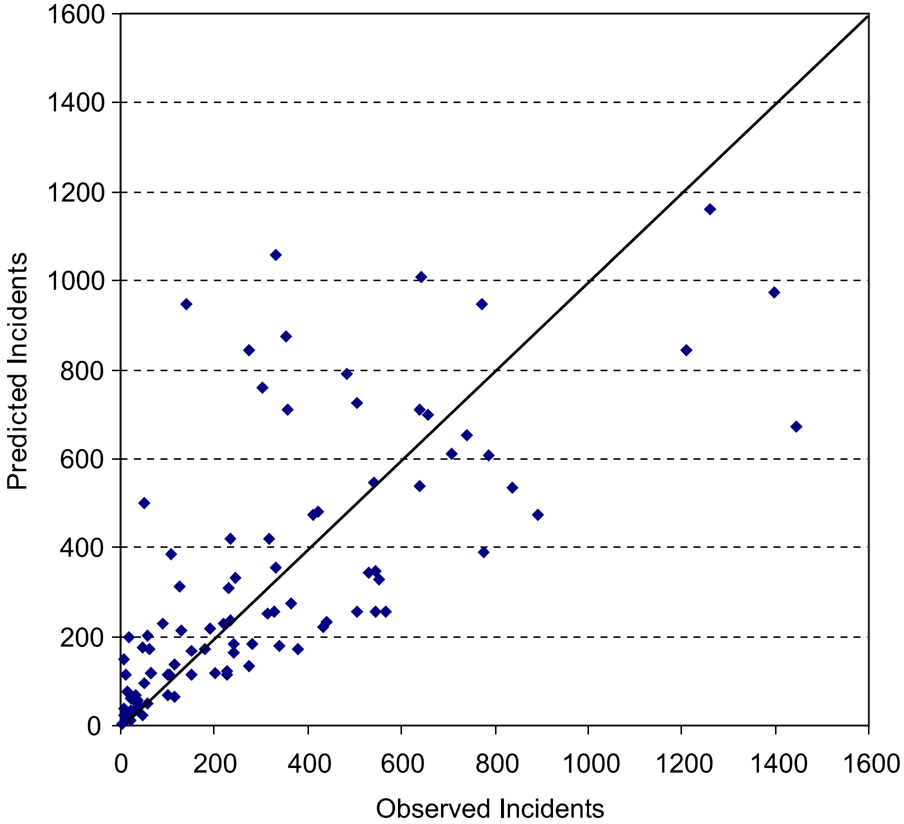


Figure 3. Model Predictions vs. Observed Incidents

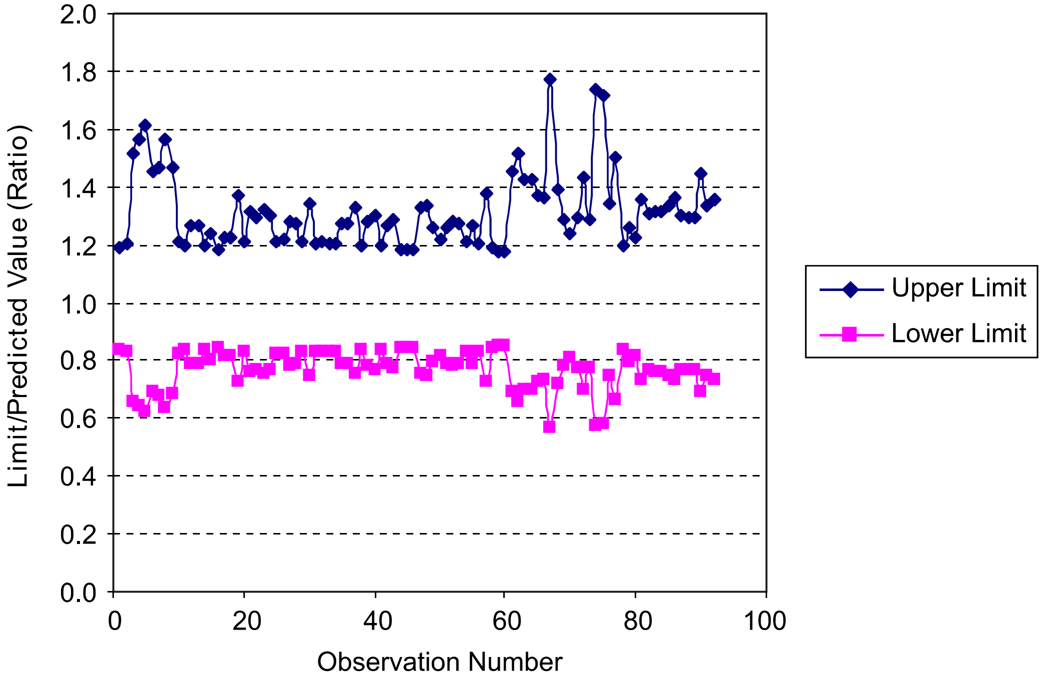


Figure 4. Confidence Intervals for Lower and Upper Bounds of Model Predictions

Table 6. Criteria Weights and Evaluation Scale for Incidents

Criterion	Evaluation Scale	Value	Weight
Urban			
Annual incidents per mile			4
	100 or less	0	
	101 through 150	1	
	151 through 200	2	
	201 through 250	3	
	251 through 300	4	
	Greater than 300	5	
Rural			
Annual incidents per mile			4
	20 or less	1	
	21 through 40	2	
	41 through 60	3	
	61 through 80	4	
	Greater than 81	5	

volume, are the same as those of the MPLG methodology. The evaluation scales and weights for the remaining criteria are shown in Table 7.

The complete planning tool was programmed into MS Excel using a Visual Basic macro. This program was developed with the intention of providing VDOT SSP staff with an easy-to-use mechanism for ranking potential SSP routes. The program can be found at http://www.virginiadot.org/vtrc/main/online_reports/pdf/append/07-r17.htm.

Limitations of the Planning Tool

- Most freeway segments had both left and right shoulders; therefore, Boolean descriptors for the presence of shoulders were not included in the IPM. Further, shoulder widths, which can impact incident occurrence, were not specified in the model because of inconsistencies found in data sources.

- Because of the short timeline of the project, only 1 year's worth of incident data were analyzed. It is recommended that incident data in the prior 3 to 4 years be used to build the regression model. A preliminary analysis of the data across years showed that the incidents are not as random as crashes. This is understandable as the incidents include breakdown, debris, and crashes; and vehicle breakdown and debris on heavily traveled corridors are recurring occurrences and are more common than the crash occurrence.

- The evaluation scale and weights for the segment-based variables were adopted from the MPLG study. The weights applied to the variables were based on the MPLG committee's recommendations and are subjective in nature. The investigators deemed these values appropriate; thus, no changes were made to the weighting scheme.

- All available incident data captured by VDOT's SSPs were required for the development of the IPM. Thus, it was not possible to test the validity of the model in this study. However,

Table 7. Criteria Weights and Evaluation Scale for MPLG Methodology

Criterion	Evaluation Scale	Value	Weight
Level of service			4
	A	0	
	B	1	
	C	2	
	D	3	
	E	4	
	F	5	
Planned projects			1
	less than $5 million	0	
	$5 million to $10 million	1	
	$10 million to $15 million	2	
	$15 million to $20 million	3	
	$20 million to $25 million	4	
	$25 million to $30 million	5	
Air quality			1
	attainment areas	0	
	non-attainment areas	5	
Maximum access distance			1
	1 mile or less	0	
	1 mile < MAD <=2 miles	1	
	2 miles < MAD <=3 miles	2	
	3 miles < MAD <=4 miles	3	
	4 miles < MAD <=5 miles	4	
	more than 5 miles	5	
Maximum structure length			1
	500 ft or less	0	
	501 ft < MSL <=750 ft	1	
	751 ft < MSL <=1000 ft	2	
	1001 ft < MSL <=1250 ft	3	
	1251 ft < MSL <=1500 ft	4	
	greater than 1501 ft	5	
Average annual daily traffic			1
	25,000 vpd or less	0	
	25,001 to 35,000	1	
	35,001 to 45,000	2	
	45,001 to 55,000	3	
	55,001 to 65,000	4	
	65,001 or greater	5	
Daily truck volume			1
	2,000 trucks or less	0	
	2,001 to 4,000	1	
	4,001 to 6,000	2	
	6,001 to 8,000	3	
	8,001 to 10,000	4	
	greater than 10,001	5	

as more data become available (e.g., SSP deployments on new routes) model validation can be accomplished.

CONCLUSIONS

Core Functions

- *VDOT's urban and rural SSP programs may have region-specific differences in core functions. However, a core set of functions can be identified that are applicable to all SSP programs in Virginia.* These functions are consistent with those of other programs throughout the nation and address the elements of IM: detection/verification and response, scene management, traffic management, incident clearance, and motorist information.

- *There are differences in operating philosophies (in terms of benefit emphases) of VDOT's urban and rural SSP programs.* Urban regions place greater emphasis on the benefits associated with reduced travel delays and lost productivity, reduced number of secondary crashes, and reduced wasted fuel and environmental pollution. Rural regions place greater emphasis on the benefits associated with improved safety for motorists in distress and creation of goodwill for VDOT. Both place equal emphasis on the benefits related to improved safety for incident responders and improved transportation system security.

- *The direct benefits that coincide with the majority of the core functions of VDOT's SSP programs are improved safety for motorists in distress, improved transportation system security, and creation of goodwill for the state agency.* The core functions of VDOT's SSP programs that provide the greatest number of direct benefits are (1) provide traffic control/manage lane closures as part of the traffic management goal of IM and (2) push vehicle from travel lane as part of the incident clearance goal of IM.

SSP Deployment Planning Tool

- *A limited number of SSP programs throughout the United States have developed criteria or planning tools for deployment. Those that have such tools typically use qualitative and quantitative techniques to derive them.* The data that drive such criteria include traffic and geometric characteristics as well as incident and/or crash statistics.

- *The planning tool developed in this study can assist VDOT decision-makers when considering expanding SSP coverage and/or altering existing route coverage.* The developed tool is a segment-based ranking scheme and can be applied to all rural and urban freeway segments in Virginia. An important criterion that drives the ranking scheme is the predicted number of incidents for a segment under consideration. An incident prediction model was developed that can be used in all locations in Virginia to predict the number of incidents on a given segment. Based on the model's goodness-of-fit measures, it was found that incidents can be statistically predicted with the knowledge of freeway segment's AADT, length, average daily percent of ADT served, and the truck percentage. This model can produce reasonable estimates of incidents as long as the input variables for the segment lie within the range of the values used in the model development process.

RECOMMENDATIONS

Core Functions

1. *VDOT's SSP decision-makers should prioritize the core functions of their programs in relation to the direct, indirect, and incidental benefits each provides.* Emphasis should be placed on those core functions that provide the most direct benefits. Indirect and incidental benefits are also of importance and should not be overlooked in the prioritization process.

2. *To maintain statewide consistency with SSP core functions, each regional SSP manager should communicate and keep abreast of changes in core function priorities in other operations regions.*

Deployment Criteria

3. *The SSP deployment planning tool should be used by VDOT's regional operations directors as they consider the deployment of new patrols or altering existing ones.* To do this, all existing and potential patrol routes should be included in the evaluation. Each route must be divided into its constituent segments (traffic links), and each segment scored using the predicted number of incidents, LOS, planned projects, air quality, maximum access distance, maximum structure length, AADT, and daily truck volume. For each patrol route, the segment scores should be summed to obtain individual route scores. All routes should then be ranked based on their scores. When ranking the routes, only routes within a regional boundary should be compared because of inherent differences in regional incident histories, traffic characteristics, and freeway geometries. For example, all routes considered in the Hampton Roads region should be compared with each other, not with routes in the NOVA or Salem regions.

4. *As a means of improving the SSP deployment planning tool, VDOT regional operations directors should consider additional research that expands upon the current dataset.* This can be accomplished by incorporating incident data over multiple years from established (existing) deployments and newly established deployments. To be consistent with the data requirements of the deployment planning tool, all SSPs should maintain adequate record-keeping procedures. At a minimum, drivers should record the dates and locations of all assisted incidents. For other evaluations (e.g., benefit-to-cost and performance measure evaluations), additional data such as incident duration, type, and lateral location should be recorded.

COSTS AND BENEFITS ASSESSMENT

The SSP deployment planning tool will provide a clear indication of which routes would benefit the most from the deployment of SSP and thereby will allow for better informed investment decisions. The costs involved in using this tool, in terms of person-hours, are minimal when compared to the benefits of prudent funding allocations.

In urban regions, the operating cost of SSPs are typically outweighed by the benefits the service provides to the traveling public (e.g., savings in delay and associated savings in fuel consumption and emissions). In rural areas, quantifying the benefits of SSP programs can be complex because of the difficulty in putting a dollar figure on customer satisfaction. This can be addressed with customer satisfaction survey cards, which are given to motorists requesting an estimate of the value associated with the services rendered. By compiling these surveys, an overall estimate of customer satisfaction can be quantified.

Hypothetically, if three routes (X, Y, and Z) are under consideration for SSP deployment in an urban region and funding is made available for only one deployment, the planning tool will indicate the route that will provide the greatest return on investment. For example, if the annual costs of operating an SSP on a route are $275,000 and if routes X, Y, and Z have B/C ratios of 4.8, 4.3, and 3.1, respectively, then the benefits to VDOT of choosing route X over Y or Z are $137,500 and $467,500, respectively.

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APPENDIX A
DESCRIPTIVE STATISTICS OF SEGMENT DATA

Table A1. Descriptive Statistics of Segment Data: Northern Virginia

Statistic	**S_L**	**AADT**	**N_L**	**PR_{HOV}**	**P_{AVE}**	**P_T**	**N_I**
Mean	1.81	134252	7	n/a	92.72	5.33	379
Median	1.80	131411	8	0	92	4	333.5
Standard Deviation	1.07	43484.82	1.31	n/a	1.70	3.87	220.25
Sample Variance	1.14	1.89E+09	1.71	n/a	2.88	15.01	48508.43
Minimum	0.41	61203	4	0	91	1	50
Maximum	4.78	239029	8	1	94.8	10	838
Sum	43.50	3222047	172	11	2225.2	128	9084
Count	24.00	24	24	24	24	24	24

Table A2. Descriptive Statistics of Segment Data: Hampton Roads

Statistic	**S_L**	**AADT**	**N_L**	**PR_{HOV}**	**P_{AVE}**	**P_T**	**N_I**
Mean	1.70	82548	5	n/a	100	5.44	385
Median	1.20	76261	6	0	100	5	237.5
Standard Deviation	1.19	33487.44	1.04	n/a	0	1.50	364.74
Sample Variance	1.41	1.12E+09	1.08	n/a	0	2.25	133032.88
Minimum	0.55	40385	4	0	100	3	19
Maximum	5.89	145961	8	1	100	8	1444
Sum	61.22	2971732	205	5	3600	196	13876
Count	36.00	36	36	36	36	36	36

Table A3. Descriptive Statistics of Segment Data: Salem

Statistic	**S_L**	**AADT**	**N_L**	**PR_{HOV}**	**P_{AVE}**	**P_T**	**N_I**
Mean	2.32	55428.24	4	0	82.63	20.14	33
Median	2.06	50783	4	0	82.5	22	23
Standard Deviation	2.06	10905.31	0	0	0.87	9.93	29.28
Sample Variance	4.26	1.19E+08	0	0	0.77	98.63	857.39
Minimum	0.22	37019	4	0	81.8	6	2
Maximum	9.99	75429	4	0	83.9	35	117
Sum	48.77	1163993	84	0	1735.3	423	695
Count	21.00	21	21	21	21	21	21

Table A4. Descriptive Statistics of Segment Data: Fredericksburg

Statistic	**S_L**	**AADT**	**N_L**	**PR_{HOV}**	**P_{AVE}**	**P_T**	**N_I**
Mean	4.27	108970.5	6	0	51.68	14.64	523
Median	4.00	118266	6	0	51.6	16	421
Standard Deviation	2.15	29805.45	0	0	0.46	3.11	332.55
Sample Variance	4.62	8.88E+08	0	0	0.21	9.65	110590.76
Minimum	2.00	75883	6	0	51.1	10	150
Maximum	8.00	160450	6	0	52.2	17	1261
Sum	47.00	1198676	66	0	568.5	161	5751
Count	11.00	11	11	11	11	11	11

APPENDIX B
CORRELATION MATRIX OF COMBINED DESCRIPTIVE STATISTICS

Table B1. Correlation Matrix of Combined Descriptive Statistics

Statistic	S_L	AADT	N_L	PR_{HOV}	P_{AVE}	P_T	DSVMT	DTMT	Log_e(AADT)	Log_e(DSVMT)	Log_e(DTMT)	N_I
S_L	1.00	-0.06	-0.10	0.04	-0.47	0.32	0.71	0.85	-0.04	0.67	0.71	0.39
p-value	-	0.56	0.34	0.73	<.0001	0.00	<.0001	<.0001	0.73	<.0001	<.0001	0.00
AADT	-0.06	1.00	0.63	0.33	-0.05	-0.35	0.48	0.03	0.98	0.52	0.15	0.44
p-value	0.56	-	<.0001	0.00	0.62	0.00	<.0001	0.77	<.0001	<.0001	0.15	<.0001
N_L	-0.10	0.63	1.00	0.61	0.12	-0.52	0.33	-0.14	0.63	0.35	-0.16	0.36
p-value	0.34	<.0001	-	<.0001	0.25	<.0001	0.00	0.18	<.0001	0.00	0.12	0.00
PR_{HOV}	0.04	0.33	0.61	1.00	0.21	-0.35	0.44	-0.17	0.36	0.39	-0.10	0.31
p-value	0.73	0.00	<.0001	-	0.04	0.00	<.0001	0.11	0.00	0.00	0.35	0.00
P_{AVE}	-0.47	-0.05	0.12	0.21	1.00	-0.51	-0.15	-0.71	-0.07	-0.16	-0.6427	0.04
p-value	<.0001	0.62	0.25	0.04	-	<.0001	0.16	<.0001	0.49	0.12	<.0001	0.74
P_T	0.32	-0.35	-0.52	-0.35	-0.51	1.00	-0.12	0.57	-0.41	-0.10	-0.65	0.32
p-value	0.00	0.00	<.0001	0.00	<.0001	-	0.24	<.0001	<.0001	0.36	<.0001	0.00
DSVMT	0.71	0.48	0.33	0.44	-0.15	-0.12	1.00	0.50	0.51	0.92	0.53	0.67
p-value	<.0001	<.0001	0.00	<.0001	0.16	0.24	-	<.0001	<.0001	<.0001	<.0001	<.0001
DTMT	0.85	0.03	-0.14	-0.17	-0.71	0.57	0.50	1.00	0.03	0.48	0.84	0.24
p-value	<.0001	0.77	0.18	0.11	<.0001	<.0001	<.0001	-	0.80	<.0001	<.0001	0.02
Log_e(AADT)	-0.04	0.98	0.63	0.36	-0.07	-0.41	0.51	0.03	1.00	0.55	0.13	0.48
p-value	0.73	<.0001	<.0001	0.00	0.49	<.0001	<.0001	0.80	-	<.0001	0.21	<.0001
Log_e(DSVMT)	0.67	0.52	0.35	0.39	-0.16	-0.10	0.92	0.48	0.55	1.00	0.60	0.63
p-value	<.0001	<.0001	0.00	0.00	0.12	0.36	<.0001	<.0001	<.0001	-	<.0001	<.0001
Log_e(DTMT)	0.71	0.15	-0.16	-0.10	-0.64	0.65	0.53	0.84	0.13	0.60	1.00	0.23
p-value	<.0001	0.15	0.12	0.35	<.0001	<.0001	<.0001	<.0001	0.21	<.0001	-	0.03
N_I	0.39	0.44	0.36	0.31	-0.04	-0.32	0.67	0.24	0.48	0.63	0.23	1.00
p-value	0.00	<.0001	0.00	0.00	0.74	0.00	<.0001	0.02	<.0001	<.0001	0.03	-