ITRE

Carolina Transportation Program

Final Report

Incident Management Assistance Patrols: Assessment of Investment Benefits and Costs

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16. Abstract

Incident Management Assistance Patrols (IMAP's), classified as part of Intelligent Transportation Systems, help enable smooth traffic flow by aiding stranded motorists and assisting in incident clearance. Many major urban areas currently have patrols and most medium-sized urban areas are following suit. The success of IMAP's has resulted in frequent requests for service expansion. The decision of where to put the next patrol is becoming more difficult because an assessment of greatest need typically indicates that the high-priority areas already have the service and possible effects of the service are often indistinguishable on lower-priority facilities. In this report, we develop a new approach that helps determine the most beneficial locations in North Carolina for patrol deployment using expanded placement criteria. Analysis of three incident/crash indices was combined with spatial analysis, incident type distributions, average hourly freeway traffic volumes, and incident delay estimations to identify, evaluate, and compare IMAP expansion candidate facilities. Results of the research have been incorporated into a decision-support tool that allows easy planning and operational assessment of candidate sites by comparing performance values between sites, modeling the effect of IMAP's, and estimating their key potential benefits and costs. By using the tool, decision-makers can quickly assess the needs of different facilities to make an informed, cost-effective decision as to where to implement the next service patrol.

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Summary

Incident Management Assistance Patrols (IMAP) are often critical in dealing with traffic in urban areas and often offer substantial congestion relief benefits. IMAP's have been implemented in many urban areas and some rural areas of North Carolina. However, we do not know the extent of their benefits and costs and importantly, we do not have a procedure by which to identify high-impact locations where IMAP's will be most beneficial. This study uses North Carolina data on crashes/incidents, traffic and roadway characteristics to prioritize potential sites and quantify benefits and costs. A decision support tool is developed that ranks existing and potential IMAP sites and evaluates their benefits and costs. The results show that present IMAP's in NC are located in the areas of greatest need. That is, they ranked relatively highly in terms of Crashes per 100 million vehicle miles, crashes per mile per year, and average annual daily traffic per lane and their benefit cost ratios were greater than 1. The analysis identified sites near Asheville and the Raleigh beltway as having good IMAP deployment potential. Their benefits far exceed the costs. The decision support tool is flexible and it can be applied to other North Carolina sites. Ultimately the tool allows us to make more informed and educated IMAP implementation decisions while maximizing their impacts.

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1. Introduction

Incidents typically cause about 50%-60% of the congestion in urban areas. Incidents are defined as situations on the roadway that temporarily impact driver behavior and include, but are not limited to, stranded vehicles, debris, and crashes. Incident Management Assistance Patrols are one of the least expensive and most effective Intelligent Transportation Systems (ITS) strategies addressing incident-induced congestion (*1*). These patrols typically roam along urban corridors looking for incidents. Once located, the patrols supply gasoline, make minor repairs, remove debris, and assist with incident clearance (*2*). Their shortened response times, special equipment, and expertise in dealing with incidents result in a substantial decrease in incident duration (*3*). IMAP's can be vital for managing traffic and benefiting the public in terms of motorist assistance, reduction in incident-induced delay, higher throughput, improved safety (reduction in secondary incidents), lower energy use, and lower emissions.

In part due to their large benefit to cost ratios, IMAP's have expanded rapidly across the country since their inception in Chicago in the 1960's (*4*). As of 2002, over 50% of freeway miles in the largest 78 metropolitan areas in the United States were covered by a patrol along with almost 20% of the miles in the 30 medium-sized urban areas (*5*). Although the patrols continue to expand, expansion criteria have remained relatively unchanged. Areas experiencing heavy traffic volumes typically receive the service but these areas only cover a fraction of the incidents occurring nationwide. Thus, there is a need to assess good IMAP deployment opportunities and impacts using expanded criteria such as incident rates and congestion.

This report focuses on analyzing IMAP's in North Carolina. The state has a population of 8 million and a mix of urban and rural areas. The primary urban areas have relatively high traffic and congestion and many already have IMAP coverage, along with selected rural portions of Interstate 40 in the mountains and where Interstates 40 and 77 converge. With the popularity of these services, there is considerable political and public pressure to expand the service to other areas. However, decision-makers do not have a tool that allows them to compare the relative needs of IMAP candidate facilities.

To cost-effectively deploy IMAP's, there is a need for an accurate, systematic method to identify which of the potential sites should receive the highest deployment priority. This research addresses the need to place patrols on the facilities where they will have the most impact by performing statistical, spatial, delay, and benefit-cost analyses. The results are used to develop a decision-support tool that compares various freeway facilities to determine their viability for IMAP's.

The next section of this report provides a literature review and identifies gaps in the literature. Then the methodology is described. Next the data and results from planning and operational analysis are presented. A decisions support tool that was developed as part of this project is presented next. To demonstrate the application of the tool in North Carolina, the next section applies the tool to existing and potential sites. Finally, conclusions and drawn and recommendations are given. The Appendix summarizes the study in a presentation format.

2. Literature Review

In response to the growing adverse impacts of incidents, most large- and medium-sized cities have initiated incident management programs (*6*). The strategy has also been implemented in rural areas that have high incident rates and/or roadway configurations that increase the effect of incidents, such as in the mountains of North Carolina and on the floating bridges in the Puget Sound (*3*).

The goal of such programs is to detect and respond to incidents and to quickly restore the freeway to full capacity after the incident occurs. A variety of techniques are used to accomplish this goal including offering basic repairs and gasoline, calling for private tow trucks, providing short-range vehicle relocation, and helping to manage traffic around an incident (*2*). Customers are overwhelmingly supportive of this service because it is free, fast, and it increases their sense of safety on the highway (*2*). Police officers are also pleased because IMAP's create a safer environment around incidents (*7*) and free up officers from having to respond to some calls.

In a comprehensive study, Fenno and Ogden report that benefit to cost ratios for IMAP's range from 2.1 to 36.2 nationwide (*4*). In part, the benefit/cost ratio is so favorable because it has been shown that incident management is an effective way to increase roadway capacity by up to 20% without paying for expensive physical improvements such as increasing physical capacity (*8*).

Most IMAP's constantly patrol a stretch of freeway looking for incidents and requests for assistance. Thus, they are typically in close proximity to incidents to which they are dispatched and find many of the incidents themselves. For instance, the San Francisco/Oakland IMAP located 92% of all incidents themselves (*9*). For lane blocking incidents in the Puget Sound region of Washington the average response time without an IMAP was 7.5 minutes. With an IMAP, response time was reduced over 50% to roughly 3.5 minutes (*3*). Across the nation, IMAP's have been found to reduce incident response times by 19%-77% (*3, 10*). Any reduction in incident detection, response, and clearance times reduces the total duration, which in turn reduces queuing delay (e.g., one minute of response time reduction is associated with approximately 0.6 to 1 minute reduction of clearance time) (*11*). Average incident clearance times were reduced at IMAP sites by 8 minutes and in some cases by up to 1.5 hours (*12, 13, 14*).

An evaluation of the Coordinated Highways Action Response Team (CHART) in Maryland, which includes incident response along with traffic monitoring, traveler information, and traffic management, reported an annual savings of 40.1 million vehicle hours of delay, 398,000 gallons of fuel, and $30.5 million (*15*). The most significant finding, according to the authors, was that the incident response program (including, but not limited to, IMAP), supported by traffic surveillance technology, resulted in a 7.5:1 benefit/cost ratio using estimated delay, fuel consumption, and secondary incident reductions.

Georgia's Intelligent Transportation System, "NAVIGATOR", includes incident management patrols, electronic toll collection, signal control, and other ITS innovations (*16*). An evaluation of NAVIGATOR determined a 30% reduction in identification, response, and dispatch time, a 23-minute reduction in incident duration that saved $44.6 million, and a 3.2:1 benefit/cost ratio for the freeway and incident management components. Other benefits not fully quantified include air quality impact reductions, fuel consumption savings, crash reduction, more efficient use of emergency services, and more satisfied travelers.

Results from the evaluation of nine ITS implementation projects in San Antonio, Texas, indicate that the most effective stand-alone implementation is incident management (*10*). For a particular corridor modeled during this study, implementation of integrated surveillance and incident management resulted in a 5.7% decline in delay, a 2.8% decrease in crashes, and a 1.2% reduction in fuel consumption annually. The study reported that integrated use of incident management, surveillance and arterial traffic control could achieve even higher benefits.

A review of the literature did not reveal any studies dedicated to determining where IMAP's should be located. Of the reviewed articles, only two studies mention placement criteria. Tennessee's new HELP program used areas of high traffic volume and the assumption that a benefit/cost ratio for IMAP's in Nashville applies to other urban areas across the state (*17*). However, the report is dedicated to a discussion of planning and training techniques for a successful IMAP, not site selection. Maryland's CHART evaluation determined that the incident management program is located in the areas of greatest need by comparing vehicle miles traveled, incidents, non-recurring delay, and incidents per mile against the averages for non-CHART roadways (*15*). However, the results do not indicate whether CHART routes cover segments that have relatively low-levels of need and/or do not cover segments with high-levels of need that deserve patrols. Thus, there is a need for research that addresses the prioritization of placement of IMAP's.

3. Methodology

The goal of this project is to develop criteria for IMAP expansion in North Carolina and create a decision support tool that can prioritize and rank current and future IMAP projects. To achieve this goal, we used a combination of techniques including statistical and geographic analysis of statewide crash data, visualization of crash and inventory data to identify high-impact locations, and benefit-cost analysis of current and potential segments using incident simulations.

Exhibit 1 depicts our methodology and shows the relevant Chapters where the details are discussed. The study is broadly divided into IMAP planning and operational analysis. The planning analysis is meant to identify how a particular segment ranks relative to the rest of the state in terms of crashes and traffic. The input data consists of NCDOT GIS shapefiles, NCDOT crash and inventory data. The operational analysis performs a more detailed assessment of the benefits and costs involved in implementing IMAP's. Additional data included traffic counts from NCDOT automatic traffic recorders, incident data from Charlotte and Greensboro, and IMAP cost data. The planning and operational analysis were combined in an IMAP decision support tool that can be used to evaluate current and proposed IMAP sites. Finally, the decision support tool is applied to the existing and two promising IMAP sites in North Carolina.

To perform the planning analysis, index statistics indicating a facility's relative need were first created using 3 years of crash, traffic and inventory data. These index statistics consisted of AADT per lane, crashes per mile per year, and crashes per 100 million vehicle miles. Note that ideally, we would have preferred to have incidents instead of crashes. However, there is no central repository for statewide incident data.

Therefore, we relied on statewide crash statistics for planning analysis. GIS was then used to map the indices along roadway segments and to show existing IMAP coverage. In essence this allows us to spatially observe concentrations of traffic and crashes and see if the IMAP solutions are in the most needy locations (i.e. determine if locations that have high concentrations of traffic and crashes are the same locations with IMAP coverage). Statewide density maps of the index statistics were then created to visually determine traffic and crash/incident concentrations and possible IMAP expansion sites. (Note that density maps facilitate clearer presentation of crash and traffic concentrations and are more appropriate when simply mapping crash locations make it difficult to see which areas have higher concentrations.) The index statistics and results of the GIS analysis were then used as inputs for the operational analysis.

The operational analysis estimates incident delays with and without IMAP's as well as the costs in case IMAP's are implemented. Necessary data for the operational analysis included statewide crash, traffic and inventory data; incident data in selected locations (needed to obtain crash to non-crash incident ratios and incident type distributions), hourly traffic volumes at count stations, costs and fleet sizes. To analyze the effects of queuing and vehicle delay for different incident severities, facilities, and time periods, some of these data were used as inputs in an incident simulation software called FREEVAL. The results provide an indication of IMAP benefits.

To get an estimate of the costs, it is important to know the number of patrol vehicles needed at the selected site. This obviously depends on the length and amount of traffic (and incidents) on the segment. NCDOT data on existing IMAP programs was used to calibrate a regression model. Average annual daily traffic (AADT) and facility length were explanatory variables for number of IMAP vehicles. The model can be used to predict the number of vehicles needed at a potential IMAP site.

To determine the cost per vehicle, cost per driver, and cost per route mile, information for existing IMAP costs was analyzed. When combined with the regression model indicating the required number of vehicles for a potential IMAP site, the results give an estimate of IMAP implementation costs at new sites. The cost figures for potential sites can then be compared with the potential benefits, based on delay savings from implementing IMAP's.

Finally, a decision-support tool was developed to identify and rank potential IMAP expansion sites and compare their benefits and costs. The tool combines the planning and operational analyses to help with decision-making regarding potential IMAP sites. The tool requires user-entered facility and incident severity variables and has certain built-in assumptions. Based on North Carolina data, the literature and our judgment, it assumes that (1) the ratio of non-crash incidents to crash incidents is 7.2, (2) IMAP's reduce incident durations by 25%, on average, and (3) the value of time saved is $10 per hour. The outputs include hours of delay savings with the implementation of an IMAP, which is then converted to monetary savings using the value of time. The total costs are based on number of vehicles required and the costs of acquiring and operating the patrols. To demonstrate, the tool is applied to existing IMAP sites and two potential sites.

4. *Planning Analysis*

The planning analysis takes a broad look at roadway facilities across the state and allows the selected segments to be ranked in terms of traffic and crashes relative to the rest of the state. Specifically, archived data are used to calculate: Crashes per 100 million vehicle miles, crashes per mile per year, and average annual daily traffic (AADT) per lane. Using these index statistics, percentiles are calculated for each segment. These percentiles are attached to GIS roadway segment files and displayed visually to determine the highest-ranking facilities.

Data

A 1999 roadway segment file that contains inventory information such as AADT and number of lanes was obtained from the Highway Safety Information System (HSIS) database. NC HSIS is a relatively high-quality database of North Carolina crashes and roadway inventory that is federally maintained, although not federally mandated. In addition, the North Carolina Department of Transportation (NCDOT) also provided crash data with location information and traffic volume data from thirty permanent automatic traffic recorder sites spread across the state. To obtain a large sample (3 years), crash and traffic data were used from January 1, 1997 to December 31, 1999. NCDOT provided 49,000 crashes during this time period on the relevant roadways. NCDOT also provided the current locations of all IMAP's in the state along with Geographic Information System (GIS) shapefiles that allow spatial presentation of the data. Finally, two IMAP sites (Charlotte and Greensboro) collected incident data for this project between March and May of 2003.

Site Rankings

The HSIS database contains multiple files, of which we only used one—the roadway inventory file. Although HSIS also provided crash data, through the course of the project it became evident that NCDOT's crash database was more complete. As mentioned before, incident data were not available on a statewide basis. Using NCDOT defined route numbers and mileposts, matching crashes to inventory data went seamlessly.

To perform segment-level analysis, we calculated the total number of crashes occurring on each segment. The resulting file contains the total number of crashes on each segment along with facility and traffic information, such as number of lanes and AADT. Because we summarized crashes by segment, this method does not allow us to analyze individual crash characteristics.

To identify candidate expansion sites, it was first necessary to identify indicators of high traffic and high crash rates. We identified three different indicators, AADT per lane, crashes per mile per year, and crashes per 100 million vehicle miles. Throughout this report, these statistics are commonly referred to as index statistics.

The three index statistics were calculated for each roadway segment. Crashes per mile per year are obtained by dividing annual crashes by facility length. This index identifies sites where the total number of crashes is high, regardless of traffic considerations. AADT per lane is obtained by dividing AADT by the number of lanes. This index identifies locations with high volume to capacity ratio and therefore is a measure of congestion. Finally, crashes per 100 million vehicle miles is defined as the number of annual crashes divided by (the product of 100 million, segment length, and AADT) annual 100 million Vehicle Miles Traveled (VMT). This index identifies facilities with high crash rates. Facilities with high (percentile) values for one or more of the statistics are considered to be possible IMAP expansion sites.

Using GIS (see process steps in the GIS section), a field was created in the crash segment file indicating whether or not it is covered by IMAP's. The data were then analyzed to calculate the percentile distributions of the three index statistics for three categories of facilities: 1) all segments, 2) segments covered by IMAP, and 3) segments not covered by IMAP. The percentile index values for the three categories are shown in Exhibit 2. As shown in the exhibit, the 85^{th} percentile for AADT per lane for non-IMAP sites is 11,500 and for all sites it is 15,370. These are 40% and 19% lower than AADT per lane for IMAP sites (19,000), respectively. Similar differences are seen with the other two statistics. The results provide statistical evidence that, as a whole, IMAP's are located in the areas of greater need.

Visual Display

GIS is a vital component of this research because it allows spatial representation and analysis of the data. Specifically, GIS allows the three indices (and other data) to be displayed on a statewide map, making it relatively easy to identify high-impact locations. To provide a reference for the location of the roads and to identify NCDOT Division boundaries, we combined the North Carolina road shapefiles, which are available from the NCDOT GIS Division, with county boundaries available from the US Census Bureau. Then crash data were linked to the GIS roadway files by using the unique county route identifiers and mileposts present in both datasets.

Mapping Crash Data

The overall quality of data was very good. However, it is important to note a few limitations. Some NCDOT road shapefiles were miscoded, mainly on I-95. Therefore, we were unable to match these miscoded segments to the crash data. In addition, some of the crash data were miscoded and/or missing. We manually corrected the obvious miscoding errors, but were still unable to display crashes occurring in certain locations, such as on I-40 in Statesville. Exhibit 3 shows locations where data could not be matched. The inability to match a small subset of the data did not adversely affect the analysis. Additional data was obtained from NCDOT in order to include the data missing from the original GIS data, and the completed GIS files were used for analysis.

The map with the matched results can be manipulated to display any of the values contained within the crash-inventory file, such as AADT, shoulder width, speed limit, total number of incidents, and/or all of the index statistics.

Locating Expansion Candidates

Existing IMAP facilities were then manually located on a map using the beginning and ending mileposts of the patrols. The resulting IMAP location map can be viewed along with selected features of the incident segment file. By displaying current IMAP locations and the 85th percentile for any of the three index statistics along with IMAP locations, it is possible to obtain a general idea of where high-impact areas are located. Exhibit 4 shows that IMAP's are located at high-impact locations. However, the map that shows all three index statistics is disjointed because index values for contiguous facilities can vary substantially. In addition, for very short segments, the crashes per mile per year and crashes per 100 million vehicle miles values are inflated because the formulas divide by facility length.

To account for this inflation and the scattering of values, density maps were created using the three index statistics. Density maps spread values for the line segments over a wider area, showing concentrations more clearly and eliminating or reducing any disconnect between adjacent segments. Exhibits 5, 6 and 7 show the density maps for 85^{th} percentile or higher calculations for AADT per lane, crashes per mile per year and crashes per 100 million vehicle miles, respectively. The combination of the density maps in Exhibit 8, shows continuous segments where IMAP service may be needed by displaying the 85^{th} percentile and above for the three indices along with existing IMAP service. Two important observations can be made from the map. First, existing IMAP's are located in high-impact locations. Second, I-440 in Raleigh and the interstates around Asheville are prime candidates for IMAP expansion.

5. Operational Analysis

The operational analysis entails calculating Benefit/Cost ratios based on traveler delay savings with IMAP's versus cost of IMAP deployment. In the absence of a statewide incident system, the team relied on Charlotte and Greensboro IMAP data to create incident distribution trees and use these figures to estimate non-crash incidents. The ratio of non-crash incidents to crashes was found to be 7.2:1. This ratio is used to predict the frequency of incidents on roadway segments. However, in the long-term, incident rates can be predicted using models based on ADT, truck volume, length and weather.

Implementation of IMAP implies finding the number of patrol vehicles needed, the overall costs and the incident delay reductions. After gathering the data (crashes, incidents, inventory, hourly traffic distributions and costs), we used models to estimate delay savings from IMAP's and anticipated expansion site costs. Specifically, FREEVAL estimated the effects of incident duration and queuing on different facilities to estimate Vehicle Hours of Delay (VHD). Estimates of the number of vehicles necessary for an expansion site was developed based on current IMAP coverage. Finally, a cost model was developed using the existing IMAP costs and estimated number of vehicles. The steps for each analysis are discussed below.

Inputs

To create inputs, it was necessary to use the incident data to create incident ratios and an incident distribution tree. In addition, the traffic volume data was divided into rural and urban locations and aggregated by time periods. The results of these three processes were used in the modeling process discussed in the subsequent chapter.

Incident Ratios

Incident data collected from IMAP sites helped quantify the anticipated number of non-crash incidents compared to crash incidents. Roughly two months of IMAP logs from the Charlotte and Greensboro sites were entered into a database and provided to the project team. The incident type distribution is shown in Exhibit 9. Along with frequencies, this table shows average incident response, clearance, and duration times. The figure indicates a ratio of 7.2 non-crash incidents for every crash. This figure is similar to the 9:1 ratio reported by Cambridge Systematics (*18*). Because we know the number of crashes occurring on every road segment in the state and we know the normal ratio between crashes and non-crashes, it is possible to predict the number of non-crash incidents.

Incident Distribution Tree

The IMAP incident data also allows for the creation of an incident distribution tree that shows the frequencies and average durations of shoulder incidents, incidents blocking one lane, and incidents blocking two or more lanes. Exhibit 10 shows that 91% of all incidents occur on the shoulder, 8% block one lane, and 1% block two or more lanes. These results are quite reasonable. The third level of the tree divides the type of blockage into peak and off-peak frequencies.

Hourly Traffic Distributions

To determine the hourly traffic distributions for rural and urban freeways, we used data from permanent Automatic Traffic Recorder sites spread across the state. These recorders collect traffic volumes by hour. To remain consistent with the incident data, we selected traffic count records from January 1, 1997 to December 31, 1999. Data for the available 30 sites was divided into rural (6 sites) and urban (24 sites) and limited to weekdays. The data for each category were then averaged for each hour and plotted on graphs. The resulting graphs show an average weekday traffic profile for each site. The rural and urban profiles were then averaged respectively to create general urban and rural traffic volume profiles. The resulting urban graph is shown in Exhibit 11 and the rural graph is shown in Exhibit 12. For the urban areas, the distribution is bimodal; the average morning traffic peaks at 7% of the AADT at 8 am while average afternoon traffic peaks at 8% at 6 pm. Rural profile is uni-modal, where traffic volume steadily increases to an average afternoon peak of 7% of the AADT at 5 pm. The data reveal that rural and urban areas require different IMAP strategies.

To simplify the analysis process, we reduced the number of time slots to reflect general peak and off peak periods. Because of the two-peak structure of the urban profile, it was divided into 5 categories, as seen in Exhibit 13. Because of its one-peak nature, the rural profile was divided into 3 different hourly categories, as seen in Exhibit 14.

Models

Models allow us to estimate delay savings from IMAP, patrol fleet size needed and total costs. The section below discusses the relevant models.

Estimating IMAP Delay Reductions: The FREEVAL Model

To estimate potential benefits of IMAP implementation, the effects of queuing and vehicle delay for an incident were assessed using the FREEVAL model, which faithfully replicates the freeway facility methodology in Chapter 22 of the 2000 Highway

Capacity Manual (*19*). FREEVAL enables modeling of the effect of incidents on traffic operations in a macroscopic environment. In this study, an incident analysis was made for freeway facilities that are 10 miles in length, have constant ramp intervals (1 mile for urban, 2 miles for rural), and have constant ramp volume.

The software requires geometric variables, including area type (rural or urban), number of lanes in a single direction (2 to 5), and demand volume to capacity (v/c) ratios (from 0.5 to 0.9 using intervals of 0.1). An incident occurring on a facility with a v/c below 0.5 would most likely see little to no benefit in terms of delay savings even if an IMAP existed. Incident variables are then entered, including capacity reduction based on incident severity (shoulder, 1 lane, or 2 lanes blocked) and duration (15, 30, 45, and 60 minutes). Incidents with two or more lanes blocked and incidents lasting over an hour were not modeled partly because they represent only 1% of the total (see Exhibit 10) and often represent severe incidents which receive only limited benefit from IMAP.
A capacity reduction factor is determined for each of these severities based on Exhibit 22-6 from the Highway Capacity Manual (*19*). The resulting value is a percent of the capacity remaining with the existing incident. The reduction factor for shoulder crashes was used for shoulder non-crash incidents because the reductions for shoulder disablements caused no impact in the simulations.

To allow traffic to be restored to normal flow conditions after all incidents, the simulations were run for 1.5 hours. At the conclusion of the simulations, data points were obtained using all combinations of these variables. These data were used to develop regression delay models for various freeway incidents and served as an integral part of the decision-support tool resulting from this research. Delay is expressed in seconds per VMT of travel on the facility.

After running the FREEVAL application using every combination of variables, the resulting 440 data points were collected and FREEVAL generated results on total vehicle hours of delay, vehicle miles traveled, demand volume, and actual volume. The data were used to create curve-fitting models by analyzing the relationship of vehicle delay versus incident v/c ratios. A sample model for urban facilities is shown in Exhibit 15 and a sample model for rural facilities is shown in Exhibit 16. These graphs were divided into separate models by the number of lanes, area type, and incident duration. Within each model, distinct equations were created for each incident severity. Exhibit 17 contains the resulting equations for all possible combinations of FREEVAL runs. The estimated vehicle delay models serve as the basis for determining the estimated delay savings from installing an IMAP; this process is described later in this report.

Fleet Size Estimation

Because the focus of this study was to help determine possible IMAP expansion sites, it was necessary to estimate how many vehicles would be required at the expansion site to maintain patrol coverage similar to the existing IMAP sites. To accomplish this, we estimated a regression model using number of vehicles as the dependent variable and route length and AADT as independent variables. The non-linear regression is shown in Exhibit 18. The model fits the data reasonably well, explaining 81% of the variation. The results show that more traffic and longer facilities require more patrol vehicles, as expected. The model can be used for prediction, i.e., the length of the potential IMAP route and AADT can be entered into the regression equation to determine the number of patrol vehicles necessary for the selected site.

Cost Model

After identifying potential benefits from expanding IMAP service to different sites, it is necessary to determine potential costs. To accomplish this, we analyzed aggregate cost data provided by NCDOT.

IMAP cost data were divided by NCDOT Division and included number of patrol vehicles, number of drivers, length of route, service hours, and total annual costs. Exhibit 19 shows expenses for each NCDOT Division. They include the capital and operational costs, but do not include any overhead factor for driver salaries. A more comprehensive method of reporting costs is to determine how much it costs to add one more mile to the route. To calculate this statistic, we divided the total cost for the division by the total number of route miles. Exhibit 20 shows that, on average, IMAP's cost $10,200 per route mile (per year).

Another useful statistic, cost per service hour, indicates how much it will cost to add one hour to the patrol's existing operating hours (Exhibit 21). For instance, if Division 5 wants to extend their operating hours by two hours on Saturday, it would cost 2 (hours) times $6,200, or $12,400 a year. If the same division wanted to extend service by 2 hours for 7 days a week, it would cost 2 hours times 7 days times $6,200, or $86,800 per year. The average annual cost for extending service by 1 hour per week is $7,300 a year.

Finally, a cost per vehicle operating hour was calculated to use in the decision-support tool. To calculate this cost, total costs for each division were divided by the total annual operating hours and the total number of vehicles in the fleet to attain the total hourly cost.

$$\textit{Hourly Operating Cost} = \frac{\textit{NCDOT Division Expenses}}{\textit{Annual Op. Hrs.} * \textit{Number of Patrol Vehicles}}$$

The results of this calculation, shown in Exhibit 22, were then averaged for the entire state using a weighted average that multiplies the number of vehicles for each division by the hourly cost for each division then adds the results together and divides them by the total number of vehicles in the state. Accordingly, it costs $16.70 per hour, on average, to operate a patrol vehicle in North Carolina. Including an overhead factor of 1.4 to driver salaries raises this average to $18.90 per hour. Additionally, including cost data from all of the divisions may not represent an accurate average cost per vehicle per hour due to the inclusion of some outliers (i.e. cost per vehicle per hour data for Division 14 is significantly lower than other divisions). Therefore, the median value may better represent statewide costs of operating an IMAP vehicle for an hour. The median value for the hourly vehicle costs in Exhibit 22 is $19.00 per hour.

Benefits Model

To estimate the annual vehicle hours of delay savings for a new IMAP implementation, the estimated vehicle hours of delay savings for single incident types are determined. These delay savings are then multiplied by the total number of expected annual incidents (broken down by type) for the facility. Finally, the annual delay savings are converted into a monetary value. The results of this model indicate the amount of money that will be saved if an IMAP is implemented on the selected facility. Because wage costs of vehicle hours of delay is the only captured benefit, the predicted savings are conservative. Other factors that can be modeled in future research include fuel savings, emissions reductions, and economic impacts on businesses.

Single Incident Assessment

The single incident assessment model requires the user to enter the incident duration without an IMAP (in minutes) and select the time of the incident, incident severity, and the percentage that an IMAP may reduce the duration. The model then generates delay estimates, including estimated delay benefits with IMAP implementation. It also provides an option for the user to select the value of time to report monetary benefits. Once the model is run, the information entered for the site as well as the benefits that may be realized with the implementation of an IMAP are displayed. Exhibit 23 contains a flowchart displaying single incident assessment calculations.

Based on the area type of the facility, capacity and traffic volume estimates are determined. Capacity is calculated as a function of base capacity, percentage of trucks, PHF, and number of lanes. The values used by the program for base capacities are 2300 and 2400 vehicles per hour per lane for urban and rural area types respectively. For the percentage of trucks, 5 and 10 were used for urban and rural area types respectively. Values for the number of lanes and PHF are user defined and are entered by the user on the data entry screen. Once these values are calculated, the overall capacity (of a single direction) of the facility is calculated by dividing by one plus the percentage of trucks as a decimal and the multiplication of the base capacity, number of lanes, and the PHF.

The next value that relies on area type is the traffic volume of the segment during the incident in question. To determine the volume, hourly traffic distributions and the time of day of the incident, as entered by the user, are utilized. Depending on the area type, the time of day is input into the correct hourly traffic distribution and a percentage of the total AADT is estimated. The traffic volume of the facility is estimated by multiplying the total AADT by this percentage and then multiplying this value by the directional distribution of the facility as a fraction.

After volume and capacity values are established, traffic intensity ratios are determined. Normal demand to capacity ratio is found by dividing the volume by the capacity. As for incident demand to capacity ratio, a reduction factor must be applied to the capacity. Found in Exhibit 22-6 of the HCM 2000, the reduction factor is based on the number of lanes and severity of the incident (*19*). The incident demand to capacity ratio is then calculated as the normal capacity divided by the reduction factor as a decimal.

The next step of the single-incident analysis assessment involves the delay models created using FREEVAL. During this step, the delay for the incident is determined assuming no IMAP is present. To use these models, durations in 15-minute intervals are needed. Therefore, durations that are multiples of 15 minutes can be used in the models directly. However, durations entered by the user that are not a multiple of 15 minutes must be estimated using delays calculated from the nearest 15 minute intervals. To estimate this delay, the nearest 15-minute interval above the actual duration and the nearest 15 minute interval below that actual duration were used. These values were plugged into the delay models to find the delay for those durations. Linear interpolation using the above and below durations is then used to estimate the delay for the actual duration. Once the duration was determined, the correct delay model is chosen based on the duration, number of lanes, and area type. The incident demand to capacity ratio is input into the model and delay is output in the form of seconds per vehicle mile traveled (VMT) of delay. After the delay without the presence of an IMAP is determined, the delay estimation process is repeated with the duration assuming the presence of an IMAP. The duration with the presence of an IMAP is calculated by multiplying the duration without an IMAP present by one minus the IMAP reduction of duration as a decimal.

Savings per Incident

After delay with and without the presence of an IMAP has been estimated, the overall results are presented to the user. These results show the individual delays with and without IMAP present, as well as the delay savings for the individual incident. The delay saving is found by subtracting the estimated delay with an IMAP from the estimated delay without an IMAP. All delays are displayed as seconds per VMT.

Apply Total Annual Incidents

The final level of analysis within the tool is the operational level, which determines the annual benefits of implementing an IMAP based on the annual number of crashes entered by the user. The operational analysis first determines the total number of non-crash incidents by combining the user-entered total crashes with the previously reported non-crash to crash ratio of 7.2:1. These incidents are divided into categories using the percentages in Exhibit 10 to calculate the benefits for each incident type using the single incident analysis process. The only difference for these delay estimations is the use of peak and off-peak as the time of day versus a specific time of day as used by the single-incident analysis. For the operational level assessment, average values for the peak and off-peak timeframes of the hourly traffic distributions were used. For each of the categories, delay per incident is calculated using the single-incident analysis.

Total Savings per Year

The benefits for each incident are then combined to show the total annual benefits in terms of vehicle hours of delay that the site could experience with the deployment of an IMAP. The total vhd is then multiplied by a cost per hour factor to determine the total monetary benefits expected with the implementation of an IMAP.

6. Incident Management Decision-Support Tool

A key product of this research is the decision-support tool that synthesizes the knowledge previously discussed in this report, and allows easy access to the results of this research. It also allows easy comparison of potential IMAP expansion sites in terms of rankings and benefits/costs. The tool allows users to analyze existing or future IMAP facilities using 1) planning level analysis and 2) operational analysis. In addition, if desired, it can perform analysis of single incidents occurring on a facility (though this will not be typically done by NCDOT). Together, they encompass making decisions about IMAP implementation. The following section describes each screen in the tool.

Introduction Screen (See Exhibit 24)

Continue – Continue button must be pushed to begin. Pressing the continue button will proceed to the Facility Data Entry Screen.

Facility Data Entry Screen (see Exhibit 25)

Facility Name – Enter the name of the facility that is being considered for IMAP installation. This field is open and allows the user to enter in any text (up to 50 characters). This field must be filled (entry required) in order to continue to other sections of the tool.

County – Enter the name of the county where the facility is located. This field is open and allows the user to enter in any text (up to 20 characters). This field is not required (optional) in order to continue to other sections of the tool.

Area Type – Select the general area type of the facility. Urban areas are typically characterized by a free flow speed of 70 mph, short interchange spacing (average of one mile) and low truck percentages (~5%). Rural areas typically have higher free flow speeds of 75 mph, longer interchange spacing (2+ miles) and relatively higher truck percentage (~10%) trucks. This entry is required.

Facility Length – Enter the length of the facility that is considered for IMAP patrol, in center-line miles. This field is restricted to numbers with up to 15 decimal numbers allowed. This entry is required.

Number of Lanes per Direction – Select the average number of travel lanes per direction for the facility. This number can vary from 2 to 5 lanes only. This entry is required.

AADT – Enter the most recent (or as appropriate the projected) Average Annual Daily Traffic (AADT) for the facility. This field is restricted to integer values. This entry is required.

Directional Distribution – Select the closest directional distribution of ADT traffic volumes on the facility to the indicated values. This entry is required.

Annual Total Crashes – Using most recent data, enter the average number of total crashes that occurred on the facility in a year (or average of the last 2-3 years). This field is required.

Peak Hour Factor (PHF) – Select appropriate peak hour factor PHF for the facility. This entry is required.

Value of Time – Select the average value of time per hour for the users of the facility. This value will enter into the benefit calculations for the facility. This field is required.

Planning Level Assessment – When pressed, the tool will execute a Planning level analysis of the candidate site. This analysis will provide the ranking of the candidate facility with respect to statewide, IMAP only, and non-IMAP only sites in the state of North Carolina. This entry is optional.

Single Incident Assessment – Allows the user to produce detailed estimates of the benefits of an IMAP for a single incident with user-defined incident characteristics. This entry is optional.

Operational Benefits Assessment – When pressed, the tool will execute an Operational level analysis of the candidate site. This analysis will provide estimates of annual implementation costs, added user benefits and the cost benefit ratios should an IMAP program be implemented for the facility. This entry is optional.

Planning Level Assessment Screen (See Exhibit 26)

The three criteria for comparison shown on the leftmost column are described in the body of the research report. The information below is provided solely for the interpretation of the tool results. Three comparisons are made: facility against statewide data (top box); facility against non-IMAP sites only (middle box); and facility against IMAP-only sites (lower box).

Facility Average – These are the average values for each of the 3 comparison criterion for the facility as computed from the entries to the Data Entry Screen. These values are the same for all boxes.

Statewide Average – These are the average values for each of the 3 comparison criterion for the facility as computed from the entries to the Data Entry Screen. These value vary depending on whether all (top box), non-IMAP (middle) or IMAP-only (bottom) sites are compared with the candidate site.

Statewide Ranking – Percentile rankings for the respective 3 comparison criteria for each of the ranking categories (Overall Statewide, Non-IMAP Statewide, and IMAP Statewide rankings). This value represents the percentage of statewide (or IMAP-only, etc.) facilities that have a comparison criterion value that is less than the facility average for the given ranking category. For example, a 90^{th} percentile ranking for crashes per 100MVM in the middle box indicates that the candidate site is in the top 10 percent of all non-IMAP sites for that criterion. Statewide rankings compare the given facility to all freeway facilities in the state of North Carolina.

Single Incident Assessment Screen (See Exhibit 27)

Time Period – Select the time period from the list in which the single incident being examined occurs. The time period is used to pick the appropriate hourly volume factor from the urban or rural volume profiles. This entry is required

Severity – Select the severity of the incident (shoulder closure, single lane blockage, etc.) from the pull down menu. This entry is required.

Duration – Enter the duration of the incident assuming that no IMAP program has been implemented on the facility. This represents the total time starting from the occurrence (or first notification) of the incident until the incident is completely cleared and the normal roadway capacity resumes. This field is required.

Reduction of Incident Duration with IMAP – From the pull-down menu, select the percentage of reduction of the total incident duration that would be expected if an IMAP program were to be implemented on the facility. This field is required.

Single Incident Analysis Results Screen (See Exhibit 28)

The benefits of a single incident are summarized in this screen. The top portion of the screen gives the input echo data items which describe the facility and incident characteristics. The following items describe the tabulated output.

Measure – Describes the delay value type that is used for comparison of results. This includes facility delay, delay per VMT, delay per vehicle, and delay cost per hour (based on the value of time as entered by the user).

Units – Displays the units of the respective measure.

Without IMAP – Estimated delays (in the displayed units) that are incurred due to the facility and incident characteristics (shown on the upper half of the screen). This column assumed that no IMAP program has been implemented for the facility.

With IMAP – Estimated delays (in the displayed units) that are incurred due to the facility and incident characteristics (shown on the upper half of the screen). This column assumed that an IMAP program has been implemented for the facility.

Benefits – Displays the difference between the Without IMAP and With IMAP categories.

Cost Estimation Screen (See Exhibit 29)

IMAP Vehicle Operating Cost – Enter the estimated cost of operating a single IMAP vehicle for one hour on the proposed facility. This value is the total estimated annual capital and operational costs for the new IMAP program divided by the number of operational vehicle-hours (the product of the number of IMAP vehicles and the expected number of annual hours of operation per vehicle). This value must be in the range of 10 to 100 dollars and the entry is required.

Hours of Operation– Enter the number of hours the IMAP program operates on an average day. This value must be in the range of 4 to 24 hours and is required to continue.

Weekly Days of Operation – Enter the number of days the IMAP program operates per week. This value must be in the range of 1 to 7 days. This entry is required.

Fleet Size Estimation Screen (See Exhibit 30)

This screen allows the user to accept an estimated number of required IMAP vehicles in the fleet, based on current statewide IMAP sites. Optionally, the user can override this estimate with a preferred number of vehicles. This value represents the number of vehicles that may be used for IMAP patrol and does not include a supervisor's vehicle. This entry is required.

Operational Level Assessment Screen (See Exhibit 31)

The overall benefits and costs are summarized in this screen. The top and middle portions of that screen give the input echo data items which describe the facility and IMAP fleet characteristics. The following items describe the tabulated output.

Incident Category – Describes the category of incidents based on severity. It includes shoulder closure, 1 lane closure and 2+ lane closures (only for facilities with 3+ lanes per direction).

With IMAP - Estimated total annual delays in veh. hrs that are incurred due to the indicated incident category and for the indicated time period (peak or off peak—see definition below). This column assumed that an IMAP program has been implemented for the facility.

No IMAP - Estimated total annual delays in veh.hrs that are incurred due to the indicated incident category and for the indicated time period (peak or off peak—see definition below). This column assumed that no IMAP program has been implemented for the facility.

Peak – Refers to delays that are estimated to occur during peak hours only. This category represents delays that occur during all peak hours in a day.

Off-Peak – Refers to delays that are estimated to occur during off-peak hours only. This category represents delays that occur during all off-peak hours in a day.

Savings – Displays the difference in estimated annual delays (in veh.hrs) between the No IMAP and With IMAP categories. These values are reported in separate columns for the peak and off-peak hours, respectively.

Total – Displays the total delays savings expected for the facility for the given Incident Category. This value is the sum of peak and off-peak hour savings.

Annual Benefits – Displays the total annual savings in dollars resulting from the annual delays savings computed earlier. This value is computed assuming two levels of incident severities namely (a) those that exclude two lane closures, and (b) all incidents. The user should remember that no full roadway closures can be modeled with this tool.

Annual Costs – Displays the estimated total annual costs in dollars for operating an IMAP program at the indicated fleet size on the facility. These values are based on fleet data entered by the user in the cost estimation screen.

Benefit/Cost – Displays the estimated Benefit to Cost (B/C) ratio of the IMAP program for the candidate facility. This ratio represents the total annual benefits divided by the annual costs for the proposed IMAP program.

7. Evaluation: Application to North Carolina Conditions

The final step in this project is to apply the decision-support tool. Presented below are the evaluation results for existing IMAP facilities and for the two candidate sites (Asheville and Raleigh) identified by the analysis of crash and traffic indices.

Statewide Existing IMAP

Currently, North Carolina has deployed IMAP services in 5 divisions across the state. These services are found on different roadway segments, such as on I-85 and on I-40 in the Triangle. Since each roadway has different AADTs and incident rates, it is necessary to further divide the IMAP patrols into their unique roadway segments. Thus, the results presented below are not aggregated by division, but separated into 16 unique facilities.

Planning Results

Exhibit 32 shows the planning analysis results for each IMAP patrol compared against statewide values. (Also refer to Exhibit 33 for the data used to calculate these numbers.) The high values found in this table (Exhibit 32) show that, on average, the IMAP's are deployed in the areas of greatest need. Interstate 40 in the Triangle, for instance, ranks in the 70^{th} percentile for crashes per 100 MVM, indicating that only 30% of the roadway facilities in the state rank higher. Because the project uses data from the late 1990's, no data were available for I-485.

Operational Results

The characteristics of each facility, including operating hours, length, AADT, number of lanes, and the average number of annual crash incidents are shown in Exhibit 33. These data are the inputs for the (planning and) operational analysis.

Using the literature and the incident data, we assumed that IMAP's will reduce incident duration by 25%, which is a relatively conservative figure given a range of reductions from 19% to 77% (*3, 10, 13*). The user can enter a value of time into the tool in order to convert the vehicle delay savings into a monetary value. For this analysis, we used $10 as the hourly value of time.

Because these sites currently have patrols, the cost information is readily available (see Exhibit 19). However, the costs are broken down by division, not segments. Thus, we combined the benefits for the segments in each division to create the B-C ratios shown in Exhibit 32. Not including Division 14, the Benefit-Cost (B-C) ratios for the divisions range from 1.1:1 to 10.4:1. The results indicate that as a whole the current IMAP's are economically justified, i.e., their benefits exceed the costs. It is important to note that although Division 14 has no measurable benefits in terms of delay savings, there are other significant unquantified benefits such as motorist safety. In addition, the B-C ratios are conservative because they only include vehicle delay reductions and not fuel and emissions savings.

Candidate Site Evaluation

The GIS analysis determined that I-440 in Raleigh and sections of I-40 and I-26 in Asheville are the most viable candidates for future IMAP sites. This next section applies the evaluation tool to determine the benefits of implementing an IMAP at these sites.

Planning Results

The planning analysis for Raleigh determined that this facility, in terms of crashes per 100 million vehicle miles, is in the 85th percentile relative to all sites in the state; it is in the 90th percentile relative to non-IMAP sites and the 85th percentile relative to IMAP sites. It ranks similarly on other indices as well. The Asheville facility was found to be in the 65th percentile for all sites, the 70th percentile for non-IMAP sites, and the 55th percentile for IMAP sites for crashes per 100 million vehicle miles. Although these values are lower than Raleigh's facility, they both seem to be reasonable good candidates for IMAP deployment.

Operational Results

Exhibit 35 shows the characteristics of Raleigh and Asheville facilities. For the models, we assumed a 60/40 directional traffic volume ratio. The total crashes of 712 per year in Raleigh returned an estimated 5126 non-crash incidents per year, of which 4665 were on the shoulder, 410 blocked one lane, and 51 blocked 2 or more lanes. The tool estimated 60,000 VHD savings. Thus, implementing an IMAP on I-440 in Raleigh would result in a total monetary savings of $600,000 if the value of time is $10 per hour.

For Asheville's operational analysis, the total crashes of 303 per year returned 2182 estimated non-crash incidents per year, of which 1986 were on the shoulder, 175 blocked one lane, and 22 blocked 2 or more lanes. The total benefits of implementing an IMAP on this facility are estimated to be 65,000 VHD saved, which is higher than the estimated effects for implementation in Raleigh. Assuming a value of time of $10 per hour, the total monetary savings resulting from implementing an IMAP would be $650,000.

The results indicate that Asheville is the facility where relatively greater IMAP delay benefits are expected. Implementing an IMAP here should result in a savings of 5,000 VHD, or $50,000, more than would occur in Raleigh. However, these savings must be considered relative to the costs.

To estimate the costs of creating a new IMAP patrol, we can multiply the results of the vehicle regression to the existing IMAP hourly cost data and an assumption about the annual operating hours of the patrol. Using the regression model, the Raleigh facility needs 3 vehicles and the Asheville facility needs 4 vehicles. To calculate annual cost, the tool multiplies the number of vehicles times the operating hours per year and then multiplies the result by the cost per hour. For this model, we assumed that each facility would operate for 12 hours a day, 300 days a year (3600 total hours per year). We also used the average hourly cost for NC, which is $16.70 (see Exhibit 22).

The vehicle estimation results and the operating hours and costs determined that the total cost of deploying IMAP would be $139,500 for Raleigh and $186,000 for Asheville. When combined with the benefits, the B/C ratio for Raleigh is 4.3:1 and 3.5:1 for Asheville. Thus Exhibit 33 shows that deploying IMAP in Raleigh has relatively greater benefits, although both sites are valid candidates because their B/C ratios are much greater than one. Interestingly, the net worth (B-C) for Asheville is $464,000, which is slightly higher than Raleigh's $460,500. Note that the IMAP benefits will be higher if fuel and air quality savings were included in the calculations along with secondary incident reductions, consumer appreciation, and benefits to businesses.

8. Conclusions and Recommendations

This research develops a new method for determining the value of existing IMAP's in North Carolina and identifying high-impact IMAP's deployment sites. The method includes statistical analysis of crashes and incidents, spatial analysis, estimation of incident-induced delays, and estimation of IMAP benefits and costs. The results of the research were combined to create a decision-support tool that enables informed decisions regarding where to place IMAP's by comparing the rankings of freeway facilities along with potential benefits/costs resulting from patrol expansion. Key findings are that existing IMAP's are located in high-impact locations and I-440 in Raleigh and the interstates around Asheville are prime candidates for IMAP expansion.

As it is, the tool can be applied to any candidate site within North Carolina. However, the methods and results of this report can be applied to other states as well to help determine if existing patrols are in appropriate locations and where "high-impact" expansion candidates are located.

Further research is needed in several areas. Specifically, a more thorough analysis on the effects of IMAP's should be conducted for IMAP operating hours, patrol beat lengths, number of patrol vehicles, peak and non-peak incidents, and different roadway geometries (e.g. narrow shoulders). These factors should also be included in spatial analyses to determine specific locations where the patrols are most viable. The inclusion of such factors can help create a more comprehensive decision-support tool that can greatly improve incident management and restore freeway capacity. The tool can also benefit from including fuel and air quality savings.

Another study should also be undertaken to reveal the benefits of implementing IMAP's on short term, temporary bases, such as during holiday weekends along Interstate 95. The potential for benefits in this area is very high, but the research methodology used in this report does not adequately address this issue.

More broadly, the report provides a strong rational basis for evaluating IMAP's as a promising incident management strategy. To optimize the performance of IMAP's, it is desirable to have them as part of the broader ITS Architecture. The associated actions that can enhance IMAP performance include a surveillance system (e.g., cameras and/or loops), telecommunication links, stronger interagency coordination, Transportation Management Centers, and Traveler Information Systems.

Recommendations

The following is a compilation of suggestions for NCDOT's IMAP program. The ideas listed here were identified during the research project.

It would be beneficial for both NCDOT and for future research if IMAP data were standardized across the state. First, every NCDOT Division should collect the same information on their driver logs. Exhibit 34 presents a form that captures important incident variables. The incident information collected should be as complete and accurate as possible.

Next, the driver logs should be entered into a database such as MS Access upon receipt. IMAP drivers collect valuable information that can and should be analyzed. Entering this information into a database will ensure that it is readily available for future projects. The same database should be provided to all NCDOT Divisions to ensure compatibility.

One possibility for efficient data collection is to provide portable devices to IMAP drivers. These devices can range from PDA's to small personal computers. With this technology, the drivers can automatically enter digital data instead of having to fill out a form that is later transcribed into digital form, which can lead to coding errors. It would be even more beneficial if the devices were equipped with GPS receivers to automatically plot the location of the vehicle.

To conclude our recommendations, IMAP patrol boundaries clearly follow the NCDOT Division boundaries. The division boundaries may be the easiest to administer, but the fact is that traffic problems do not follow such lines. Thus, it is our recommendation that, where appropriate, patrol boundaries should extend across division boundaries. For instance, the Division 12 patrol ends at the Burke County border even though the GIS analysis reveals that there are two trouble spots just inside Burke County.

9. Implementation and Technology Transfer

A key product of this research is the IMAP Decision Support Tool. The Intelligent Transportation Systems Branch of NCDOT will be the most likely user of the tool. The tool is likely to be most useful when cities or counties request IMAP's. The tool can be applied to rank the candidate sites in terms of crashes and traffic relative to the rest of the State and also provide an estimate of the benefits and costs involved in deploying IMAP's. The tool can be used in the Microsoft Windows environment and the displays provided in this report illustrate the use of the tool. No specific training is needed for using the tool.

In terms of Technology Transfer, the work done under this project has been presented at the TRB Annual Meeting in January 2004, and will be published as a paper in an upcoming Transportation Research Record. The Appendix provides a copy of the final project presentation.

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List of Exhibits

Exhibit 33. Planning and Operational Analysis Data for Existing IMAP Sites
Exhibit 34. Benefit Cost Analysis for Existing IMAP Sites by NCDOT Division
Exhibit 35. Planning and Benefit Cost Analysis Results for Raleigh and Asheville
Exhibit 36. Proposed Incident Data Collection Form.