EXPLORING SPATIAL AND TEMPORAL PERFORMANCE MEASUREMENT IN METROPOLITAN TRANSPORTATION SAFETY IMPROVEMENT PROGRAMS

Christopher M. MONSERE
Research Assistant Professor
Department of Civil & Environmental Engineering
Portland State University, P.O. Box 751
Portland, Oregon 97207-0751 USA
Tel: +1 503 725 9746, Fax: +1 503 725 5950
E-mail: monsere@pdx.edu

Robert L. BERTINI
Associate Professor
Department of Civil & Environmental Engineering
Portland State University, P.O. Box 751
Portland, Oregon 97207-0751 USA
Tel: +1 503 725 4249, Fax: +1 503 725 5950
E-mail: bertini@pdx.edu

Ahmed M. EL-GENEIDY
Ph D Candidate
Center for Urban Studies
Portland State University, P.O. Box 751-CUS
Portland, Oregon 97207-0751 USA
Tel: +1 503 725 4249, Fax: +1 503 725 5950
E-mail: elgeneid@pdx.edu

Tom MOES
Graduate Research Assistant
Intelligent Transportations Systems Laboratory
Portland State University, P.O. Box 751
Portland, Oregon 97207-0751 USA
Tel: +1 503 725 4249, Fax: +1 503 725 5950
E-mail: moest@pdx.edu

Abstract: Traffic safety strongly impacts the overall health, livability and mobility in our urban areas. In the U.S., there were approximately 42,000 highway-related fatalities in 2003, nearly forty percent occurring in cities. Performance measurements of safety-related investments (particularly non-infrastructure ones) are challenging, encumbered by temporal and spatial variations not easily captured by traditional crash-based performance measures. In this paper, we summarize the results of our study examining the spatiotemporal effects of the Community and School Traffic Safety Partnership (CSTSP) using a geographic information system for display and analysis. The study used enforcement, crash, and other network data to develop spatial and temporal based performance measures, concentrating on a subset of CSTSP investments to reduce driver error (mobile photo radar and automated enforcement red-light running).

Keywords: performance measurement, transportation safety, automated enforcement, decision support, geographic information systems (GIS).

EXPLORING SPATIAL AND TEMPORAL PERFORMANCE MEASUREMENT IN METROPOLITAN TRANSPORTATION SAFETY IMPROVEMENT PROGRAMS

1 INTRODUCTION

Traffic safety strongly impacts the overall health, livability and mobility in our urban areas. In the United States, there were approximately 42,000 highway-related fatalities in 2003 - nearly forty percent occurring in cities (NHTSA, 2003). As a consequence, many transportation agencies have developed strategic highway safety improvement plans, with the goal of reducing the number of highway-related fatalities and injures. These plans have been mainly at the state level. In early 2003, however, the City of Portland Office of Transportation (PDOT) in the state of Oregon (USA) launched the Community and School Traffic Safety Partnership (CSTSP) to programmatically address transportation safety for all users.

The Portland metropolitan area is located in the Pacific Northwest with a population of 1.5 million and is known for its innovative long-range planning and bicycle/pedestrian friendly environment. The CSTSP program calls for targeted traffic safety investments in three major areas – reducing crashes associated with driver error, improving pedestrian and bicycle safety, and improving safety around school zones. Efforts in each of these major areas have a balanced approach, employing engineering, education, and enforcement strategies. The CSTSP is financed primarily by an incremental increase in traffic citations which generates annual revenues of approximately $2.5 million US dollars. As part of the program, PDOT envisions a comprehensive annual evaluation of the CSTSP, including development of performance measures to both track effectiveness and guide future investments.

Performance measurements of safety-related investments (particularly non-infrastructure ones) are challenging and are encumbered by temporal and spatial variations not easily captured by traditional performance measures. For the sake of brevity in this paper, performance measurement is only discussed and explored for one of the major traffic safety effort areas – reducing driver error. The program for reducing driver error includes several strategies aimed at modifying driver behavior as it relates to speeding, red light running, driving while impaired, and seat belt use. These driver errors are the top four causal factors of traffic injuries and fatalities in Portland.

In this paper, a brief general discussion of performance measurement is presented. The remainder of the paper is focused on the methodology for developing and exploring performance measures for the CSTSP. Measures are explored for photo radar enforcement and automated red light running using non-spatial measures and additional spatial techniques using a geographic information system. Finally, some brief conclusions are presented.

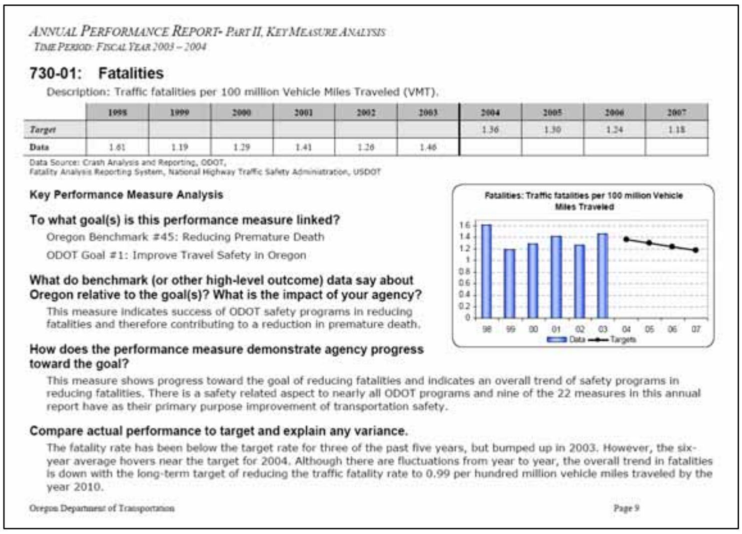
2 PERFORMANCE MEASUREMENT

Performance measurement for government transportation agencies is becoming far more common. Two recent reports by the National Cooperative

Research Program (NCHRP) and the Transportation Research Board (TRB) have summarized the state-of-the practice in transportation agency performance measurement in the USA (NCHRP, 2000 and Pickrell, 2001). These agencies included state departments of transportation, metropolitan planning organizations, as well as regional and local transit authorities. Two key findings from these recent research efforts were: 1) the development and use of system performance measures is widespread and increasing; and 2) the specific use of performance measure information varies widely from agency to agency and program to program.

Performance measures, whether they are for operations, construction project delivery, safety, environmental quality, or economic benefits can be used to communicate with both internal decision makers and external public stakeholders. There are many reasons to adopt performance measures; however, the primary reasons for doing so are 1) to increase accountability; 2) to document efficiency; 3) to measure effectiveness; and 4) to improve communications. The measures can be either quantitative (i.e., number of crashes) or qualitative (i.e., surveys such as customer orientation). It is essential that performance measures clearly relate to the identified agency or program goals so that decision makers and public constituents can follow investment decisions (Meyer, 2002). There should also be a limited number of performance measures - as few as necessary to meet the information needs of the decision makers and stakeholders.

Measuring the outcomes of transportation safety programs is a developing area. The literature includes examples of safety performance measurement but they are generally very broad (i.e. the number of motor vehicle fatalities) as shown in Figure 1. This is a sample page from the Oregon Department of Transportation's annual report (Oregon DOT, 2004). These broad measures of safety are typically not robust enough to capture temporal or spatial variations of the programs being measured. For example, a frequency count of fatalities does not address changes in traffic volume, driver aging, population shifts or other influencing variables which may have significant influences on the trends. The major impediment to more rigorous measurement is primarily the availability of data and resources required for analysis and ease of interpretation. In the following section, performance measures for a subset of strategies in the CSTSP are explored.



ANNUAL PERFORMANCE REPORT- PART II, KEY MEASURE ANALYSIS
TIME PERIOD: FISCAL YEAR 2003 – 2004

730-01: Fatalities

Description: Traffic fatalities per 100 million Vehicle Miles Traveled (VMT).

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Target							1.36	1.30	1.24	1.18
Data	1.61	1.19	1.29	1.41	1.26	1.46				

Data Source: Crash Analysis and Reporting, ODOT, Fatality Analysis Reporting System, National Highway Traffic Safety Administration, USDOT

Key Performance Measure Analysis

To what goal(s) is this performance measure linked?

Oregon Benchmark #45: Reducing Premature Death

ODOT Goal #1: Improve Travel Safety in Oregon

What do benchmark (or other high-level outcome) data say about Oregon relative to the goal(s)? What is the impact of your agency?

This measure indicates success of ODOT safety programs in reducing fatalities and therefore contributing to a reduction in premature death.

How does the performance measure demonstrate agency progress toward the goal?

This measure shows progress toward the goal of reducing fatalities and indicates an overall trend of safety programs in reducing fatalities. There is a safety related aspect to nearly all ODOT programs and nine of the 22 measures in this annual report have as their primary purpose improvement of transportation safety.

Compare actual performance to target and explain any variance.

The fatality rate has been below the target rate for three of the past five years, but bumped up in 2003. However, the six-year average hovers near the target for 2004. Although there are fluctuations from year to year, the overall trend in fatalities is down with the long-term target of reducing the traffic fatality rate to 0.99 per hundred million vehicle miles traveled by the year 2010.

Oregon Department of Transportation Page 9

Figure 1: Sample Page from Annual Performance Report, Oregon DOT (2004)

3 EXPLORING SAFETY PERFORMANCE MEASURES FOR THE CSTSP

For each of the CSTSP traffic safety elements, a systematic process was developed to identify suitable performance measures. The performance measurement plan for the CSTSP included measures for both the outcomes and the resources directed at those programs. In this way, the measures could be used to direct resource allocation. First, sample performance measures were obtained from the literature, researching available data, and brainstorming with city staff and researchers. The list included both qualitative and quantitative measures. The performance measures were then rated based on their ability to measure the defined objectives, likely access to current, future, and historical data, ability to capture temporal issues, and to include a spatial element.

In this context, performance measurement is not used to track the effectiveness of a single traffic safety strategy, rather the measures should be related to the high-level goals of the program. This is important for two reasons. First, the assumption was made that the effectiveness of the individual strategy is generally accepted and proven. More importantly, the “menu” of strategies is likely to change from year to year. For example, in programs designed to reduce speeding and related crashes, the intensity of enforcement, types of enforcement, and expenditures on engineering projects, and length of education activities are likely to change over time. In order to track the effectiveness of the CSTSP, the performance measure would need to capture the influence of many strategies over time. Second, many safety improvement efforts in the CSTSP program address the same problem and it can be difficult to separate and attribute the effect of any one strategy. For example, speed-related crashes are likely affected by automated enforcement efforts, regular enforcement, and education campaigns. Finally, it may be difficult to measure incremental effect of a single strategy unless it is measured in aggregate with other strategies. For these reasons, the final performance measures will be at the program level rather than the strategy level.

Safety performance measurement presents unique challenges, not all of which are addressed in the performance measurement framework. Even with rigorous studies of safety treatments their effectiveness can remain in doubt. Some recognized challenges with crash-based measurements of safety include dealing with regression-to-the-mean (RTM). Regression to the mean occurs in crash data and other time series events when safety improvements are implemented during a period of unusually high crash performance and are followed by lower crash performance. In these cases, it is likely that some effect, typically up to 10-20% of the change, can be attributed to RTM rather than the treatment. In many cases, the effect is as strong as or stronger than the treatment effect. Crash migration may also be a problem when a treatment or strategy forces crashes from one location to another. For example, heavy traffic enforcement in one area may reduce crashes in the targeted area but move the problem to another nearby zone. Other factors such as changes in weather patterns, traffic flow, or crash reporting practices may also influence how safety-based performance measures should be interpreted.

In the following subsections, non-spatial performance measures are compared to spatial measures for two safety strategies from the reducing driver error program – mobile photo radar and automated red light enforcement. The deployments of the photo radar and red light cameras are shown in Figure 2. A GIS tool is used to demonstrate more robust spatial and temporal analysis. It is hypothesized that by linking the location, duration, and other data to the performance measurement method, transportation planners and engineers can better understand the impact of a specific safety and mobility strategy. Further, by measuring both the investment of resources and at the level of deployment (in Portland's case, 48 neighborhood areas) CSTSP program managers can direct resources or more detailed investigations where the particular safety problem is most pronounced.

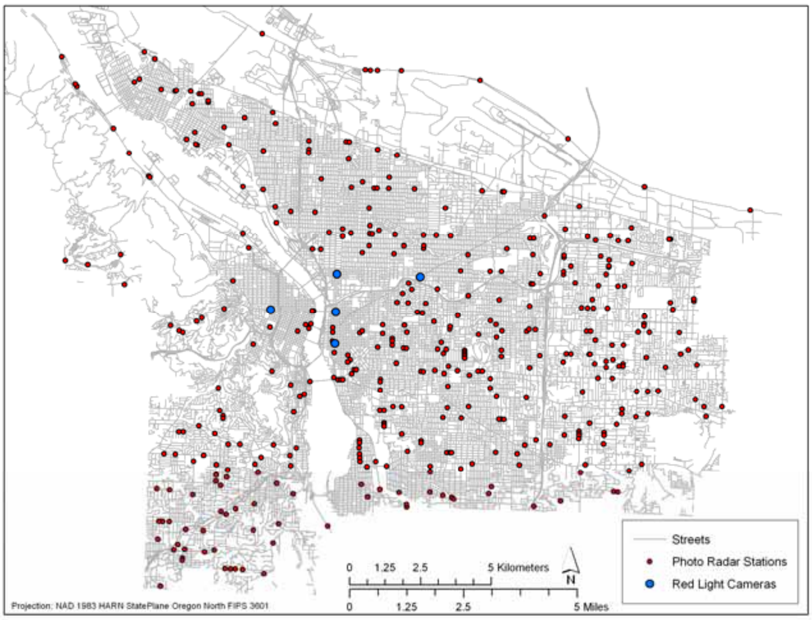


Figure 2: Deployment Locations of Photo Radar and Automated Red Light Enforcement

3.1 Photo Radar Performance Measurement

One of the important tools available to reduce speeding is the use of automated enforcement of speed by mobile photo radar. The photo radar equipment includes a radar device to measure vehicle speed and photo device to capture the driver's image and license plate. The equipment is installed in standard vans and is operated on the same side of the street as traffic. A speed reader board is placed in the back window to inform the driver of his or her vehicle's measured speed. While a police officer is present in the van to operate the equipment, the citations are issued automatically to every vehicle that passes the van above a certain threshold speed. This threshold depends on the posted speed limit but is typically between 5-10 mph. In Oregon, the citation is issued to the registered owner of the vehicle. The photo radar program in Portland has been administered by a private vendor

(ACS) since 1996 who processes the citations by matching the license plate images to motor vehicle records. If the owner was not operating the vehicle at the time of the citation, he or she can return the citation with a copy of their driver's license and a certificate of innocence. Deployment locations of the photo radar equipment are shown in Figure 2 for the 1996-2004.

Although a formal evaluation of the photo radar program in Portland has not been completed, the majority of the literature supports the claim that automated enforcement practices have positive influences on safety. A thorough study by Chen et al. in British Columbia evaluated the effect of the photo radar program on traffic speed and collisions at photo radar locations and found both speed and crash reductions (Chen et al., 2002). Other studies summarized in a meta-analysis in Zaidel have found reductions in crashes from photo radar programs (Zaidel, 2002).

The Portland photo radar program has been operating since 1996 and records are available for every time and location that the photo radar vans have been deployed. The records contain the hours of deployment, number of vehicles passing the van, number of violators (above posted speed limit) and finally the number of citation issued. Crash data were also available for Portland from the Oregon DOT. The data contains reported crashes meeting the property damage threshold at the time of the crash or injury to one of the participants. The database also contains information about the driver, the crash type, severity levels, and numerous other variables. Mapping the location of crashes is challenging as there are separate location protocols for state, city, and county streets and highways. However, PDOT staff has been able to develop an algorithm to map the majority of crashes to their centerline road network.

As performance measures of outcomes were explored, the following metrics rose to the top for further investigation:

- Speed-related crashes on all streets. This could be further separated by street functional classification, or streets that were subject to enforcement actions. Also, the crashes could be normalized by volume (rate) or by exposure to photo radar.
- Percent of violations and citations issued per total vehicle exposed to the photo radar vans.
- Average or 85th percentile vehicle speeds at spot locations.

Measures of investment (or deployment) were more straightforward:

- Total hours of photo radar enforcement. This could also be measured by street classification, or neighborhood zone.
- Total number of vehicles exposed to enforcement action by the photo radar vans.

A series of simple time-series graphs were created showing the trends represented by the crash and violation-based measures. Data representing vehicle speed observations are not explored in this paper. In Figure 3, the number of speed-related crashes over the time is shown on the left axis as well as the number of persons injured. Total crashes over the same time period are shown on the right axis. The photo radar program was initiated in 1996. The figure shows a significant decline in the number of speed-related crashes in the years following the deployment of the photo radar vans. However, not all of the decline can be attributed to enforcement. On the data side, there was a change in the minimum value for reported crashes from $400 to $1000 in 1998 which would reduce the number of property damage crashes reported. A closer look at injury crashes, usually more stable with reporting changes, still shows a slight decline in speed-related crashes. However, over the same time period there was also a slight decline in total crashes so a decline in speed-related crashes might also be expected. This simple analysis illuminates the challenge of measuring aggregate crash counts - while it might be plausible that the photo radar vans contributed to a reduction in speed crashes, there are clearly other contributing factors.

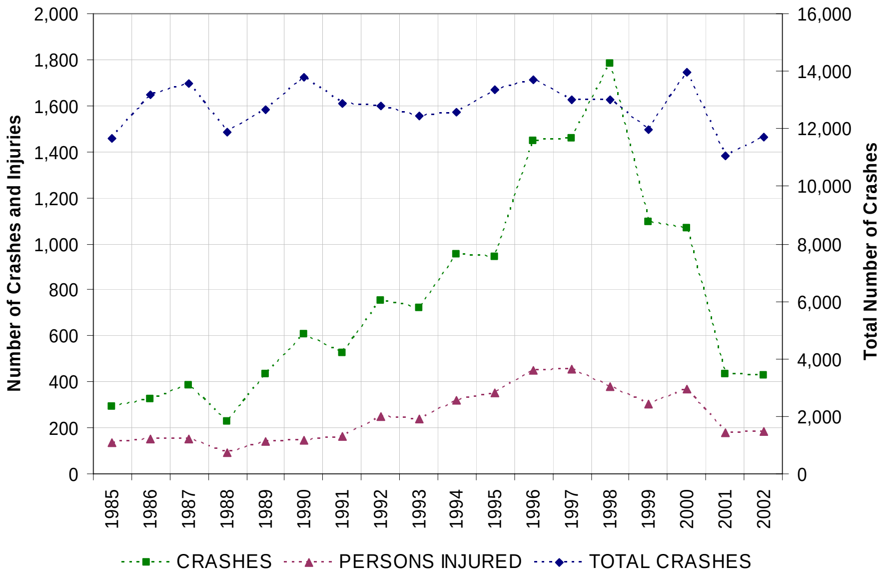


Figure 3: Crashes with Speed-Related Causal Factors (1985-2002)

As a more direct measure - the percentage of violations (exceeding posted limit) and the percent of citations of vehicles passing the photo radar vans is shown in Figure 4. Also shown on the figure, displayed on the secondary axis is the total number of vehicles exposed to the photo radar vans. The trend is clearly visible that with increasing exposure to the photo radar vans, the percent of vehicles that were exceeding the posted speed limit has been decreasing. One possible interpretation of this trend is that photo radar vans are decreasing vehicle speeds; in turn, this could be assumed to be decreasing speed-related crashes. There are other interpretations of course – people are now more familiar with the vans and deployments and learn to slow down but may not change their behavior elsewhere.

However, both of these measures could be improved by adding a spatial component to amplify the analysis. Some of the questions raised by the interpretation of these trends could be clarified with GIS by assigning a spatial component to the same metrics. A subset of crashes that one might expect to be influenced by photo radar can easily be accomplished in a GIS. For example the photo radar deployment that had the highest level of vehicle exposures during the 1999 is identified and shown in Figure 5. Research has shown there is a spatial and temporal decay for speed enforcement activities

(TRB, 1998). A one mile buffer measured along network is generated around the radar location. A time element could also be added to the buffer but was not. The crashes that occurred in the pre-period are separated in the figure from the ones that occurred in the post-one. The figure shows that the study in the pre time period had around 70 speed related crashes in 1998 while in 2000 only 20 speed related crashes are present. The decline in speed related could be partially related to the high levels of exposures to photo radar in the area during the year 2000. With a GIS tool, these specific measures would require no more effort than the previous simple time series analysis and would be a more directly related to the deployments. This could be confirmed through other performance measures and more in-depth analysis.

A more robust method or alternative is shown in Figure 6. Figure 6A of the figure is a thematic display of the number of vehicles exposed to photo radar vehicles during the year 2000. The spatial aggregations are measured at the neighborhood level (appropriate since CSTSP program elements have neighborhood boundaries). Figure 6B shows the number of crashes that occurred in these neighborhoods during the year 2000. Figure 6C combines information from Part A and Part B to form a 3D map. The color shades are the exposure of vehicles at the neighborhood level, while the height represents the number of crashes that occurred in these neighborhoods during the same time period. It is clear from the figure some neighborhoods have experienced high levels of speed-related crashes even though the amount of exposure was high relative to another neighborhood. Further, some neighborhoods with low exposure to photo radar have revealed a high involvement of speed in crashes. These figures essentially combine performance metrics and would allow a program manager to easily reallocate resources based on data. In addition, this type of analysis could be conducted for each year and analyzed over time. While this display isn't necessarily performance measurement, it clearly shows how a spatial analysis and visualizations could be useful to metropolitan planners and engineers.

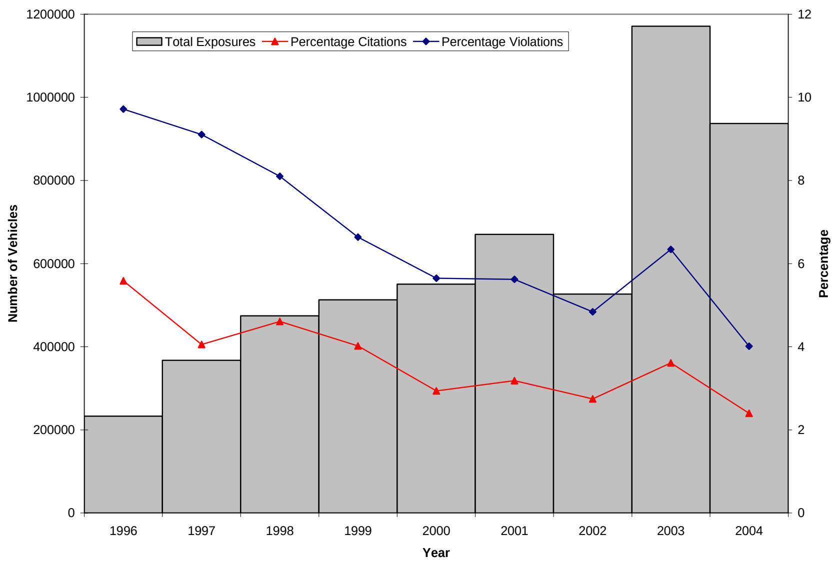


Figure 4: Percentage of Violations and Citations with Exposure by Year (1996-2004)

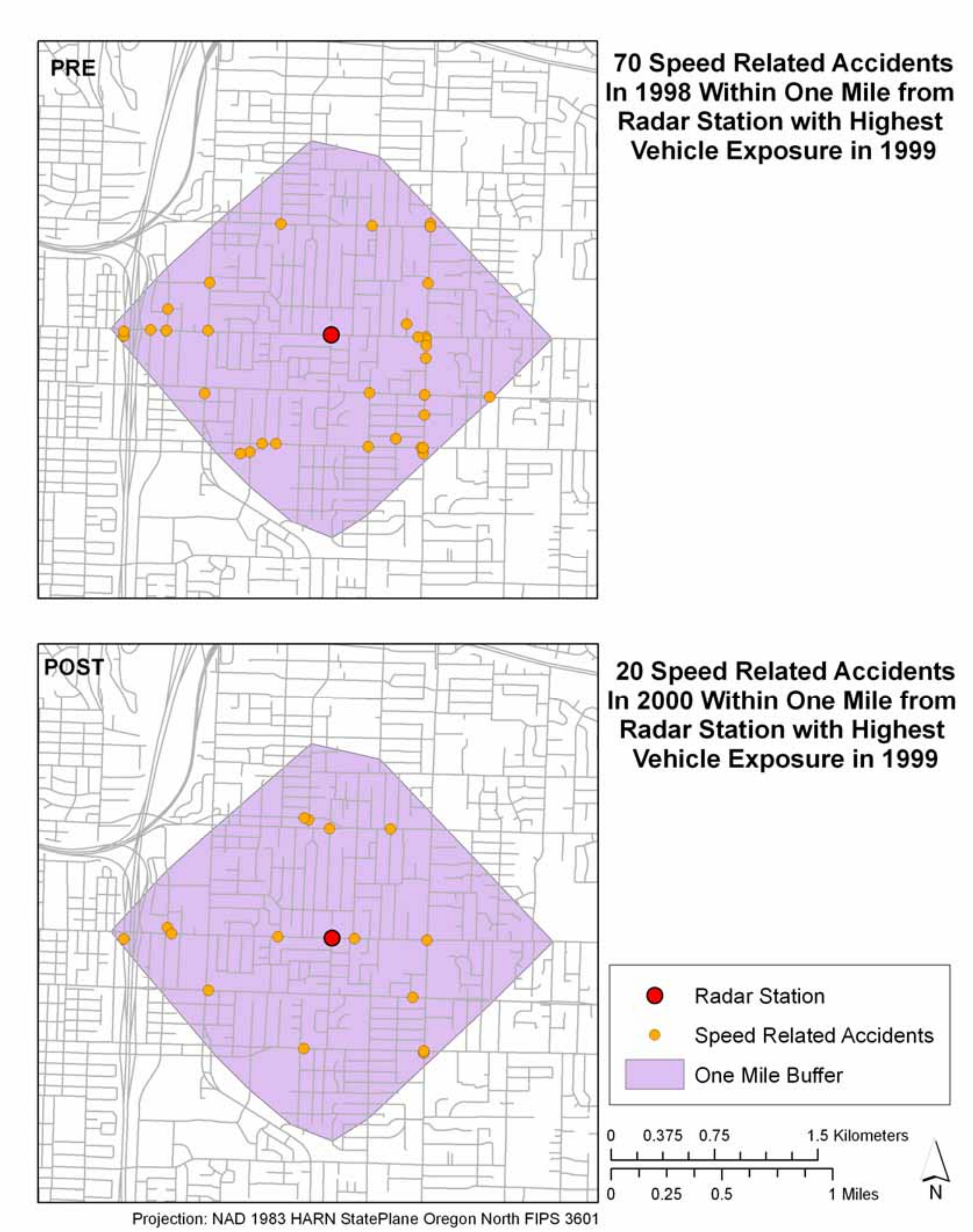
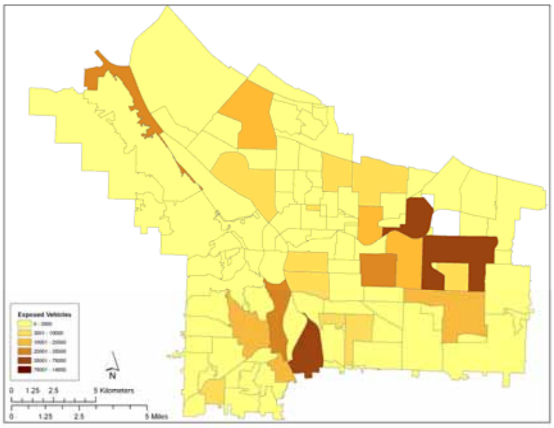
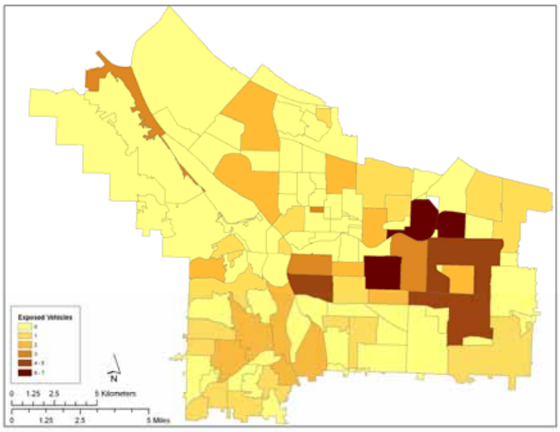


Figure 5: Buffer Analysis of Speed-Related Crashes Near Photo Radar Deployments



A



B

C

A: Number of Exposed Vehicles to Radar Stations in 2000 by Neighborhood

B: Number of Crashes Caused by Speeding in 2000 by Neighborhood

C: 3D image Combining the Number of Vehicles Exposed in Colors with the Number of Crashes Represented as the Height

Projection: NAD 1983 HARN State Plane Oregon North FIPS 3601

Figure 6: Thematic Maps of Enforcement Exposure, Speed-Related Crashes and 3D Comparison

3.2 Automated Red Light Enforcement

Another objective of the reducing driver error program is to influence crashes at intersections where drivers disregard traffic signal indications, mainly red-light running. These crashes can be addressed with automated enforcement using red light enforcement cameras. Automated enforcement systems were deployed at four intersections in Portland beginning in October 2001 and are shown in Figure 2 (actually six cameras – two intersections have cameras on two approaches, all others have cameras on only one approach). Oregon law requires that signs be placed in advance of all approaches to the intersection warning the driver that automated enforcement is in use. Inductive loops are installed downstream of the stop bar and when a vehicle enters the intersection on the red signal indication, the camera photographs the driver and vehicle license plate. As with photo radar, the citation is issued to the registered owner of the vehicle and processed by ACS.

An engineering study of the automated cameras has been conducted by PDOT engineering staff. At the time, not enough crash data were available but there was found to be a significant reduction in the number of vehicles violating the red light indication (Burchfield, 2001). The literature on the effectiveness of red-light cameras is not as conclusive as photo radar installations. Studies reviewed by Zaidel in a meta-analysis found estimates that ranged from and 11% to 45% reduction on various types of crashes (all, injury, property-damage, or fatal) (Zaidel, 2002). A review in the U.S. where automated red-light cameras are not as widely used found that there was substantial evidence of the positive effect on safety but it was not conclusive due to the methodological design flaws in the studies reviewed (McGee et al., 2003). Both reviews mention evidence that rear-end crashes may increase at these installations.

The data available for the automated red light cameras is also maintained by ACS. The data used in this analysis only contains the number of citations issued per time period. Other data, such as the time after red that vehicle enters the intersection is available but not included in these data. The same crash and spatial data were used in this section as the photo radar sections.

As performance measures of outcomes were explored, the following metrics rose to the top for further investigation:

- Crashes with error codes that indicate the driver disregarded a traffic signal. These could be measured for injuries, locations with cameras or within a buffer around the intersection. Also, these crashes could be normalized by entering volume.
- Number of citations (violations) at equipped intersections per entering volume.

Again, a simple time-series graph was created showing the trends that represent by these measures. In Figure 7, the number of crashes in which a driver violated a traffic signal are plotted over time and shown on the left axis as well as the number of persons injured in these crashes. Total crashes over the same time period are shown on the right axis. Note the cameras became operational in 2001 so there is only one year of after data shown (the 2003 data was not available at the time of this analysis). However, even with more data, the complicating factors discussed in the photo radar section are present here, perhaps more pronounced since there are so few camera deployments.

Similar to the photo radar deployment, a buffer analysis could be conducted around the intersections with cameras. The research has shown that there is some “spillover” effect at reducing crashes at surrounding intersections and this could be explored. However, since there is insufficient after data another analysis technique is presented. In Figure 8, the relationship between the crash severity and locations of existing red light cameras is shown. A severity index was calculated weighting 1) a fatality with a value of 100; 2) a severe injury with a value of 80; 3) a moderate injury with a value of 20; 4) a minor injury with a value of 1; and 5) no injury a value of 1. The severity index is a commonly used method in high-crash (black-spot) location identification and can highlight areas with problems – particularly when an agency is interested in injuries not just total crashes. The severity index for all injuries was calculated then aggregated at the neighborhood level in the map shown on the left. The locations of the six automated enforcement cameras are also shown in the figure. Overlaying the location of these six cameras with the total value of severity that occurred during the study period at the neighborhood level reveals that the city has selected to deploy its cameras in the neighborhood areas with the highest severity of related crashes. This is perhaps expected since an engineering analysis was conducted to select appropriate intersections for the treatments and the high severity areas are also the high volume areas. On the right of Figure 8, the total severity over the study period of time is divided by the total number of related crashes. This measure combines severity and the frequency in one thematic map. The result is not significantly different from the previous map but demonstrates the ease of which GIS based measures can be explored.

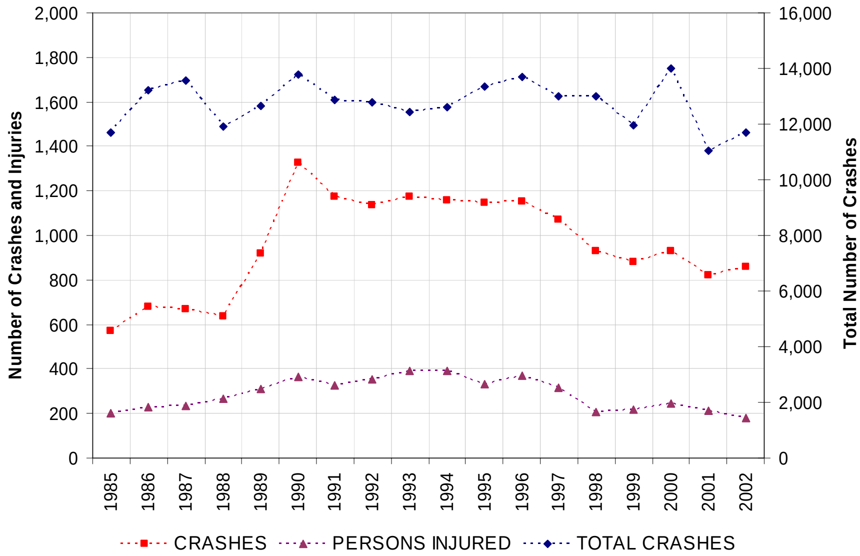


Figure 7: Crashes Where Driver Disregarded Traffic Signal by Year (1985-2002)

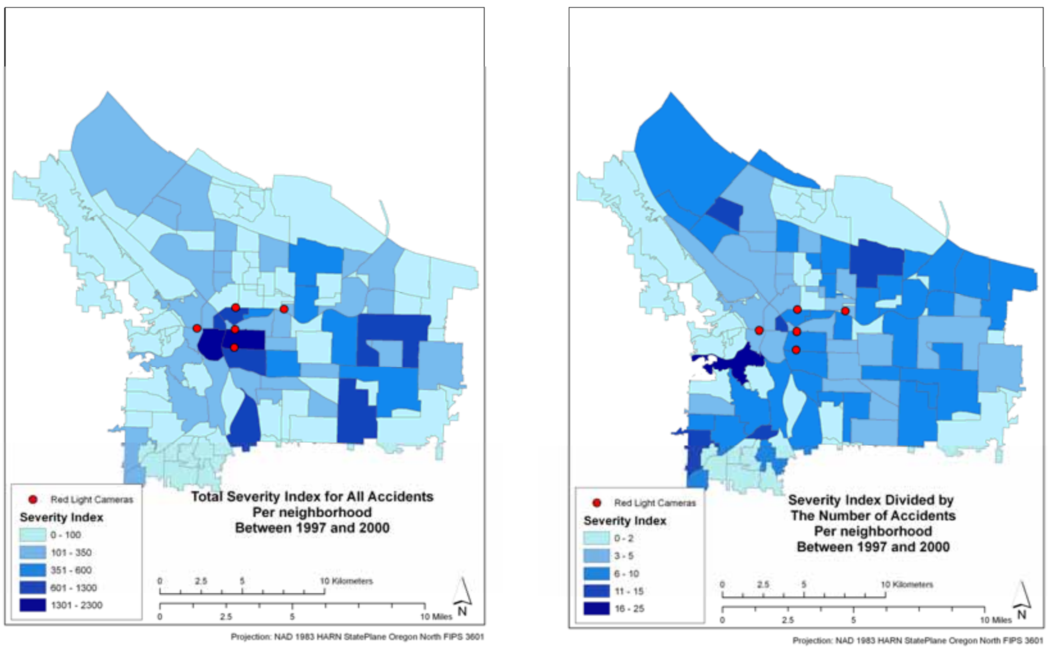


Figure 8: Thematic Map of Crash Severity Where Driver's Disregarded Traffic Signal (1997-2000)

4 CONCLUSIONS

As the public continues to demand more services from government with fewer resources, performance measures will be increasingly important. The public and decision-makers want to know the results of their investment and agencies wish to be stewards of the public trust. Performance measures bring an objective measure of success or failure in these areas. Performance measurement of safety improvements can be challenging as shown in this paper. While simple measures are desired for communication with the public decision-makers, these may not be robust or fine enough to capture the change in traffic safety. Many of the traffic safety improvements with a strong educational or enforcement component are especially hard to measure.

This paper has described the preliminary work towards developing performance measures for the CSTSP program that balance the many needs and requirements for measurements. By using available data and GIS tools for a spatial analysis, transportation planners and engineers can better understand the impact of certain investments in transportation safety. These detailed measures can easily be aggregated to less spatial detail for communication with the public and decision makers. By developing an accurate set of performance measures for this program, it is hoped that the resource allocation and strategies can be guided to optimally impact traffic safety in Portland.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the City of Portland for their ongoing support in the development of performance measures for the CSTSP. In particular Rob Burchfield, Mark Lear, Greg Raisman, and Dakota Inyoswan of the City of Portland have been instrumental in making this work possible. This work was supported by the City of Portland and Portland State University Department of Civil and Environmental Engineering. The authors also thank Vincent Parke of ACS who made the photo radar data available for analysis.

REFERENCES

Burchfield, R. (2001). Red Light Running Camera Program Evaluation – Year One. Internal Document. Portland Office of Transportation, Portland Oregon.

Chen, G., Meckle W. and Wilson, J. (2002) Speed and safety effect of photo radar enforcement on a highway corridor in British Columbia **Accident Analysis & Prevention**, Volume 34, Issue 2, March 2002, 129-138

Hughes, W. and Eccles K. (2003) Impact of Red Light Camera Enforcement on Crash Experience. Synthesis of Highway Practice. NCHRP Synthesis 310, Washington, D.C. National Research Council.

Meyer, M.D. (2002). Measuring System Performance: The Key to Establishing Operations as a Core Agency Mission. **Transportation Research Record**, No. 1817. Washington, D.C. National Research Council, 155-162.

National Highway Traffic Safety Administration. (2003). Fatality Analysis and Reporting System. Washington, D.C.

National Cooperative Highway Research Program (NCHRP) (2000). A Guidebook for Performance-Based Transportation Planning. NCHRP Report 446. Transportation Research Board., Washington, D.C. National Research Council.

Oregon Department of Transportation. (2004). Annual Performance Measures 2004. Salem, OR.

Pickrell, S. and Neumann, L.A. (2001). Use of Performance Measures in Transportation Decision Making. ***Proceedings of a Conference on System Management and Operations***, Transportation Research Board, Columbia, MD, October 2001

Transportation Research Board (TRB). (1998). Special Report 254: Managing Speed Review of Current Practice for Setting and Enforcing Speed Limits. National Research Council, National Academy Press, Washington, D.C.

Zaidel, D.M. (2002). The Impact of Enforcement on Accidents. Project Escape Deliverable 3, Contract No RO-98-Rs.3047. Technical Research Centre of Finland (VTT).