AN APPLICATION OF SPATIAL CRASH ANALYSES AND ROAD SAFETY INVESTIGATIONS TO INCREASE OLDER DRIVER SAFETY

Deanna A. Peabody
Graduate Student, College of Engineering, Department of Civil and Environmental Engineering, University of Massachusetts Amherst,
Amherst MA, USA, e-mail: dpeabody@student.umass.edu

Michael A. Knodler Jr.
Associate Professor, College of Engineering, Department of Civil and Environmental Engineering, University of Massachusetts Amherst,
Amherst MA, USA, e-mail: mknodler@ecs.umass.edu.

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ABSTRACT

An issue facing the transportation profession is the ability to provide social equity with regards to safety and mobility given the aging population. Given the dominance of the automobile within the transportation system, the ability to provide feasible alternatives is daunting. This fact, when coupled with the well-documented challenges of older drivers, underscores the need for improved safety features and system-wide safety approaches with a focus on the older driver. This paper describes an application of spatially-based crash analyses and road safety investigations that were employed in Massachusetts with a focus on the older driver. Specifically, the paper outlines an approach for identifying high crash locations for older drivers and presents the results of older driver focused road safety investigations for selected locations. The research approach targets intersections, identifying locations where older drivers are overrepresented in crashes. The road safety investigations resulted in recommended countermeasures aimed at mitigating the older driver crash problem at the identified locations. Although the resulting countermeasures, which were based upon established literature such as the Older Driver Highway Design Handbook, included a full spectrum of recommendations, a specific emphasis was placed on short-term and low cost measures that could be readily employed. Techniques to identify relationships between high crash location identification methods and the recommended countermeasures for the identified locations are considered. Ultimately the application of these techniques may provide transportation professionals with a means to associate specific older driver focused countermeasures with the results of particular methods of high crash location identification.

Keywords: older driver, network screening, safety modeling, road safety investigation.

INTRODUCTION

A critical challenge facing the transportation profession is related to the concept of social equity and its association with the ability of people to travel. The continued maintenance of a safe and efficient transportation system has far reaching implications including increased economic vitality and an improved general standard of living. The private automobile dominates the current transportation system, due in part to its convenience, reliability, and relative affordability. The ubiquity of the automobile in modern society presents a myriad of challenges for those who are unable to safely operate a motor vehicle, making it difficult for them to get to work and limited access to healthcare and educational facilities. Even simple tasks like grocery shopping can prove challenging. When viable alternatives are not readily available senior citizens, who are faced with diminishing driving capabilities, are forced to make a choice between ceasing to drive and risking the safety of themselves and those around them. The aging population is increasingly forced to make this choice. The U.S. Census Bureau expects that the U.S. population will grow from 310 million to 439 million people between 2010 and 2050, an increase of 42 percent (Vincent and Velkoff 2010). The population is not only growing, but is expected to become significantly older. Estimates indicate that by 2025, 25 percent of the population (65 million people) will be 65 years or older, and by 2050 88.5 million people will be 65 years or older. As a result, the number of individuals impacted by the mobility-safety paradox is expected to increase significantly (TRB 2005). These trends will be seen in every state, including Massachusetts. In 2000, the number of Massachusetts residents 65 years of age or older was 860,162 or 13.5 percent of the population. According to projection data from the Census Bureau this number is expected to increase to 1,463,110, by 2030, bringing the percentage of older residents to 20.9 percent of the population. This represents a 70.1 percent increase in the older population in just 30 years, while the general Massachusetts population is projected to increase by only 10 percent in the same time frame (U.S. Census Bureau 2005).

In addition to the emerging population trends, people are driving later in life. Nationally, the proportion of drivers over the age of 65 is increasing. Between 1993 and 2003 the number of drivers age 70 or older increased by 27 percent to 19.8 million. By 2030, drivers age 65 or older will account for 20 percent of all licensed drivers compared to 13 percent in 2004 (NHTSA 2004). At the same time, older citizens are becoming increasingly reliant on the use of private automobiles. Approximately 90 percent of all trips made by those over the age of 65 are by automobile; for those aged 85 and older, 80 percent of trips are made by automobile (Rosenbloom 2003).

The associated impacts of these statistics are serious given their relationship to both safety and the well-being of the public. Although it might improve overall road safety, if seniors are forced to surrender their licenses, the resulting loss of mobility, freedom, and possible negative health outcomes are possible consequences. Yet, the overall roadway network may be compromised as crash rates may increase if older drivers attempt to extend their stay on the roadway. In 2008, 183,000 older individuals were injured in traffic crashes, accounting for 8 percent of all the people injured in traffic crashes during the year. These older individuals made up 15 percent of all traffic fatalities and 14 percent of all vehicle occupant fatalities (NHSTA 2008). Although the fatality rate for all age groups has declined over the last 10 years, with drivers 65 years of age or older in particular seeing a marked decrease, the fact that the older population generally drives less frequently, for shorter distances, and almost exclusively in favorable conditions must be considered (NHSTA 2008). Looking at fatalities per mile traveled, older drivers have a greater fatality rate than other adult drivers (FHWA 2007). These statistics are indicative of the escalation of older driver safety as an issue of national importance and the resulting responsibility of transportation professionals to ensure the continued mobility of older citizens while maintaining road safety.

There are resulting challenges associated with the notion that the dominance of the private automobile remains the preferred mode of transportation given that a driver's physical and mental capabilities, driving behaviors, and crash probabilities all inevitably deteriorate with age. Furthermore, it is equally critical that the safety of other motorists is not jeopardized as a result of providing ineffective countermeasures to keep seniors on the road longer. Although there exist many plausible options for addressing existing challenges regarding older drivers including increasingly practical alternative transportation programs, increased driver education and training, improved licensing policies, and increased law enforcement, there are certainly relatively simple and cost effective measures which can be implemented in the realm of highway design and traffic operations to aid in this effort. These measures include modifying and enhancing the roadway, its surrounding environment, and the corresponding traffic control devices in order to better accommodate older drivers. Moreover, these countermeasures may provide a greater degree of community support and encouragement.

RESEARCH OBJECTIVES

It is commonly understood among transportation professionals that older drivers are a high-risk driving population and that there is a need for comprehensive understanding of older driver crash trends and characteristics. In this research, older drivers 65 years of age or older involved in Massachusetts crashes from 2007 to 2008 were thoroughly reviewed and analyzed to establish an integrative understanding of identifiable characteristics in older drivers involved in crashes in the Commonwealth. The research objective was to utilize a combination of existing high crash location (HCL) identification methodologies and analytical spatial techniques to identify locations where older drivers are overrepresented in crashes. The specific aim was to provide methodologies to identify those intersections where older drivers experience the greatest difficulty and to show how different methods of analyzing the same data set can produce different, yet equally important results. The second research objective was to combine spatially-based crash analyses with road safety investigations (RSI's), focusing exclusively on the older driver. More specifically, the aim was to use the varied approaches for identifying HCL's of older drivers by subsequently conducting older-driver themed RSI's. The RSI's resulted in recommended countermeasures aimed at mitigating the older driver crash problem at each location. Although the results, which are based upon established literature such as the Older Driver Highway Design Handbook, include a full spectrum of recommendations, a specific emphasis was placed on short-term and low cost measures that could be readily employed. This clearly identifies the specific circumstances where transportation professionals have the ability to modify and/or enhance the geometric design of a roadway, its surrounding environment, and the corresponding traffic control devices to accommodate the needs of the older population.

The final research stage was to discover relationships between the method(s) used to identify the HCL and countermeasures proposed for the specified location. Such relationships may be able to provide transportation professionals with a list of targeted countermeasures to consider when using a specified method of HCL identification.

CRASH DATA ANALYSIS

To develop a general understanding of common crash attributes for older driver crashes, it was necessary to review and analyze historical crash data. This analysis allowed for comparison of older driver crashes to those involving other age groups. Crash data and other relevant data were obtained from various agencies through the UMass Safety Data Warehouse. The UMass Safety Data Warehouse, housed within the University of Massachusetts Traffic Safety Research Program (UMassSAFE), is a tool to conveniently store and access safety-related data. Data available from the Warehouse include traditional datasets, such as crash and citation data, as well as less traditional highway safety information, such as health care data and commercial vehicle safety data. This data originates from sources such as the Registry of Motor Vehicles, the Massachusetts State Police, and Massachusetts Division of Health Care Finance, amongst others. The use of assorted, diverse data allows for truly comprehensive analyses of highway safety problem areas. Figure 1 presents a schematic of the data sets available in the UMass Safety Data Warehouse.

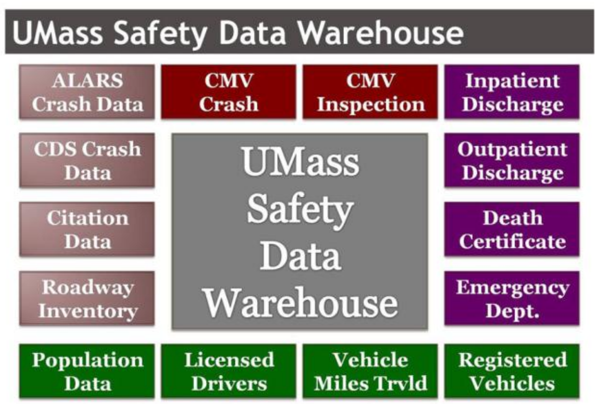

Figure 1 UMass safety data warehouse schematic

This research project utilized 2007 and 2008 (most recent "closed" years) Massachusetts reported crash data involving an older driver (age 65+) or a driver within a designated control group (age 35-55). Reporting thresholds in Massachusetts must occur on a Public Way and either result in property damage of $1,000 or greater to any vehicle/property, a non-fatal personal injury, or a fatality. Various fields of the crash report form were analyzed, quantified, and integrated to generate a unique combination of Massachusetts older driver crash statistics. ESRI's Arc Map was chosen to spatially analyze the geo-located older driver crashes as the software allows a user to view, edit, create, and analyze geospatial data in a single application.

Figure 2 represents the locations of all crashes involving older drivers in Massachusetts in 2007 and 2008. As might be expected, the greatest concentration of these crashes is in the most densely populated areas of the state. In the Boston Metropolitan area, along with the surrounding suburbs, there is a large concentration of crashes involving older drivers. In Western and Central

Massachusetts the crashes are clustered around the population centers and most travelled transportation corridors. There is also a high concentration of crashes on Cape Cod as older drivers make up a large portion of the driving population. This map represents the foundation for the following location based analysis which will identify specific locations that experience an overrepresentation of older drivers involved in crashes.

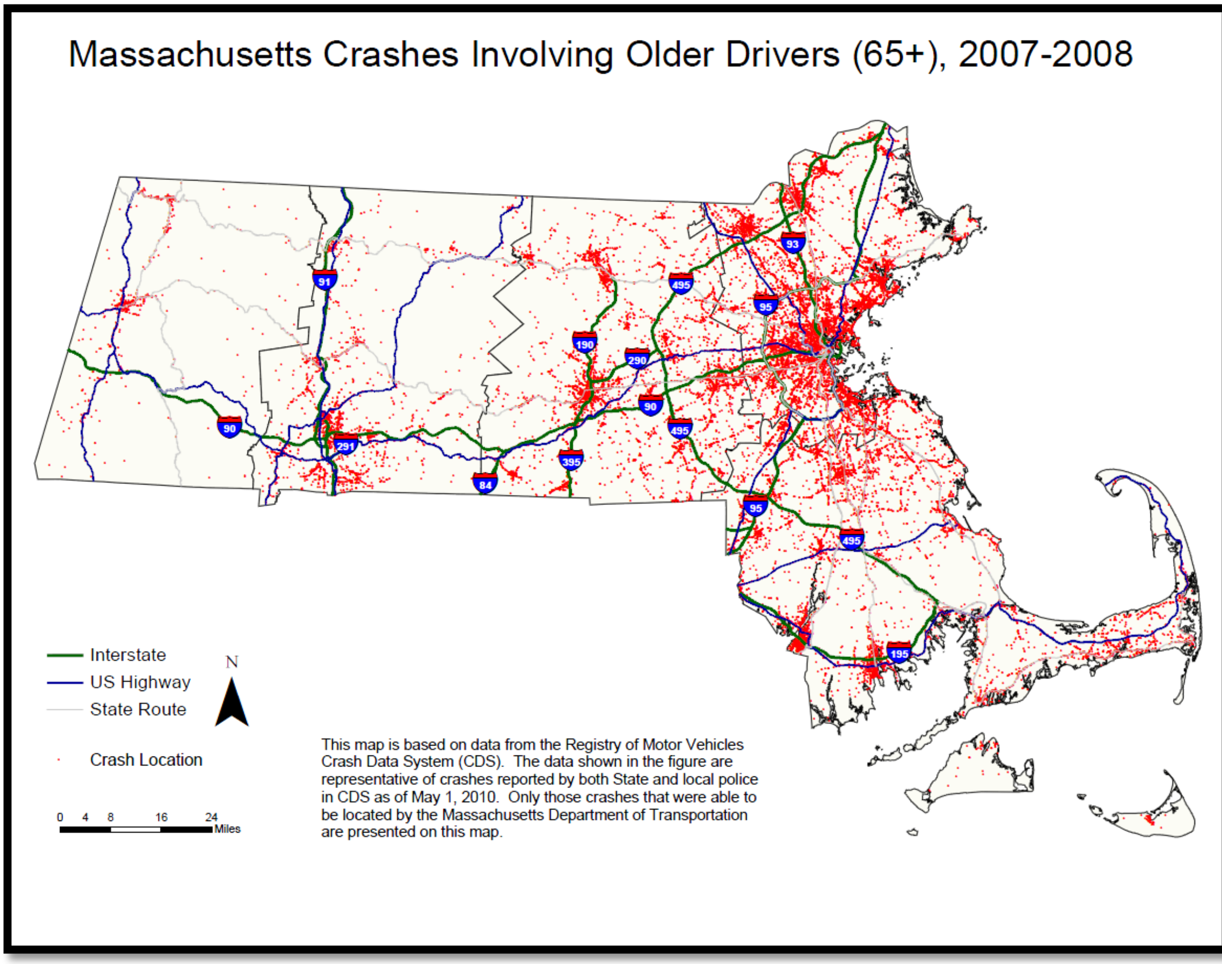

Figure 2 Massachusetts crashes involving older drivers

With increasing media coverage of crashes involving older drivers, it may appear that older drivers have only recently become a challenge; the data, however, suggests that this is not necessarily the case. In the Commonwealth, data from the early 2000's indicate that there have been approximately 20,000 crashes involving older drivers per year. Figure 3 details the total number of crashes involving older drivers and the crash rate for older and other adult drivers (per 100 licensed drivers) since 2004. While both statistics increased from 2004 to 2005, in general, both numbers have decreased since 2005. During the same period the total number of crashes and the crash rate for the remaining adult population followed a similar trend. Decreases in recent years have been attributed to increases in fuel prices and the resulting decrease in vehicle miles traveled.

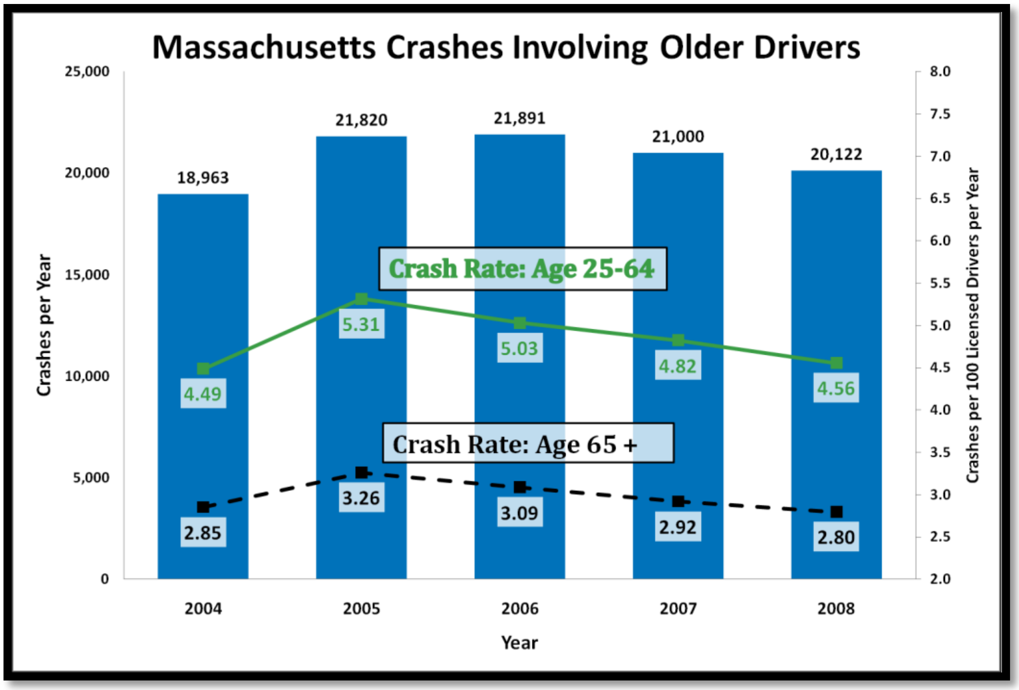

Figure 3 Older driver crash trends in Massachusetts

The older population experiences a disproportionately high number of fatalities due to traffic crashes. In Massachusetts in 2008, there were 74 traffic fatalities involving older drivers. This number translates into 8.5 fatalities per 100,000 people. Examining individual age groups, we find rates of 5.1, 6.9, and 16.8 deaths per 100,000 population for individuals under the age of 65, ages 65 - 84, and 85 years of age or older, respectively (FARS 2008). This trend is largely due to the fact that relatively minor injuries can lead to potentially life threatening injuries in seniors.

Given the diminished physical and cognitive abilities often associated with older drivers, this population tends to have difficulties navigating intersections, a trend reflected in the crash data. In the 2007-2008 Massachusetts dataset, a greater percentage of crashes involving older drivers occurred at intersections (53 percent) as compared to the control group (48 percent). Studies have indicated that this trend is, at least in part, due to older drivers' difficulty in safely executing the left turn maneuver.

To further analyze the crashes involving older drivers the manner of collision field was examined. Different manners of collision are indicative of driving behaviors and abilities. In Massachusetts from 2007 to 2008, older drivers were involved in a higher proportion of angle crashes, 37 percent as compared to 28 percent for the control age group. This type of crash is often associated with a driver's inability to appropriately judge gaps and respond to the actions of other drivers. Older drivers were involved in a significantly lower proportion of rear-end crashes, 30 percent of crashes compared to 40 percent for the control group. This type of crash is often associated with speeding, following too closely, and driver inattention.

Driving at dusk and after dark presents a special set of challenges to older drivers. However, crash data from suggests that most crashes involving older drivers do not occur at these times of day. Over 50 percent of crashes involving older drivers occur between the hours of 10 AM and 3

PM. This is different than the control group for whom a high percentage of crashes occur during the AM and PM peak hours. The distribution of the older driver crashes between 10 AM and 3 PM may occur because older drivers feel most comfortable driving at this time of day. Studies have shown that the older driver population tends to self-regulate their driving, avoiding times of perceived danger such as night, dusk, and during inclement weather.

While there are a number of actions aassociated with driver error that may result in a crash, sometimes the crash occurs even when the driver has taken no improper actions. Analyzing Massachusetts crashes from 2007 to 2008, where the contributing driver factor was noted, there are a number of trends that highlight differences between driving behaviors for drivers of different ages. For the control age group, the percentage of drivers that were noted as taking "no improper action" was 34.9 percent. This percentage declined for drivers 65 years of age or older to 29.1 percent. More specifically, a greater proportion of older drivers took some action that contributed to a crash. Of these contributing factors many were similar across age groups. However, older drivers were noted as failing to yield right of way more frequently (8.8 percent versus 4.1percent) than younger drivers. Additionally, older drivers were reported as showing a disregard for traffic signs, signals, and roadway markings with greater frequency than other adult drivers (2.3 percent compared to 1.3 percent). By comparison older drivers were less likely to be following too closely, exceeding the authorized speed limit, driving too fast for conditions, or operating the vehicle in erratic, reckless, careless, negligent or aggregative manner.

IDENTIFYING OLDER DRIVER HIGH CRASH LOCATIONS

Transportation professionals generally agree that intersections are particularly difficult for older drivers to maneuver. This research attempts to identify older driver HCL's at intersections through various frequency, rate, and severity methods. The application of these methods required pinpointed locations where older drivers are overrepresented in crashes. This was done with the combination of past crash data in conjunction with the roadway inventory file for Massachusetts which was made available by the Massachusetts Department of Transportation. Computerized crash analysis systems in which crash data, roadway inventory data, and traffic operations data can be merged are used in many countries to identify problem locations and assess the effectiveness of implemented countermeasures. By integrating these systems with a GIS platform, which offers spatial referencing and visualization capabilities, a more effective crash analysis program can be realized. Moreover, querying can be easily performed and enhanced by graphical representation.

Crash data, which was queried from the UMass Safety Data Warehouse, includes information that was recorded at the crash scene. The information was queried using a direct access portal using SQL programming and included any/all elements of the crash report that were likely to be considered in any aspect of this research. In this case, the unique identifier is at the person level (i.e., the crash number followed by an additional number which indicates the specific driver of interest). As such, this paper refers to the number of drivers involved in crashes at an intersection. To separate the drivers involved in a crash at an intersection, the "roadway intersection type" field on the crash report form was used. Drivers involved in a crash occurring at a four-way intersection, t-intersection, y-intersection, on ramp, off ramp, traffic circle, five-point intersection or more, driveway, or at a railway grade crossing were included in the analysis for HCL's at intersections, while drivers involved in a crash "not at junction" were included in a separate analysis not included within this paper. The constructed data sets include traditional fields from the crash report, including, but not limited to time of day, day of week, town, county, the manner of collision, injury status, age, sex, and the driver contributing code as well as the corresponding x and y coordinates for each driver of interest. Although recent efforts to enhance crash data quality in Massachusetts have been initiated, data quality issues remain the most significant limitation in research involving previous crash data. Accurate crash reporting is critical, especially with regards to crash location, because transportation professionals use the data to improve traffic safety. Imprecise or missing crash location information in Massachusetts crash data is a noted area of concern. Because the location information in the reports is sometimes vague, about 15 percent of crashes cannot be successfully geo-located; making the exact location of these crashes unknown. As such, only those drivers involved in geolocated crashes with assigned x and y coordinates were used in the research.

Although this basic location information is included within the crash data, a linkage data set was required to join the crash data to the Roadway Inventory File, which contains very specific location information such as the average daily traffic (ADT) and the segment length,. The linkage file provided a matched pair recording of crash number and road segment ID, making it possible to join the data sets using Microsoft Access. Since the unique identifier in the Roadway Inventory File is a roadway inventory ID which is more precise than the roadway segment ID, one value for each parameter used much be chosen to represent the entire segment. The roadway segment length was obtained by summing the lengths of each roadway inventory which together comprise a roadway segment. The roadway segment ADT, being less concrete of a parameter than the segment length, was selected as the maximum ADT value between each inventory on the segment. The result is the specific data of interest, i.e. the CDS crash data and the corresponding roadway segment ID the crash occurred on for each driver allowing for very specific roadway characteristic information to be utilized. Since the ADT is critical in performing rate calculations, it was then possible to apply the desired HCL methods to the data. It should be noted that the Massachusetts data for the average daily traffic used in this research is regarded as poor quality and may not be reliable or accurate in many instances.

There were a total of 19,576 older drivers involved in a crash at an intersection in 2007 and 2008 with successful geolocation that linked successfully to a specific roadway segment ID, and had an ADT value.

The sites are identified in this paper using the roadway segment ID they have been assigned by the Massachusetts' Office of Geographic Information. Each roadway segment ID corresponds to a different site. Next, matching roadway segment ID's were grouped to identify the number of sites where the 19,576 older drivers were involved in crashes. Those roadway segment ID's which appeared within the data set which showed up less than 5 times, were deleted as this indicates that less than 5 drivers were involved in a crash at this site. Following this step, 386 older driver crash sites were identified.

It should be noted that it is possible that additional drivers were involved in crashes at each of these 386 locations as driver records could have been associated with another roadway segment ID which is also part of the same intersection. It is common for segments to begin and end at an intersection, thus making four different roadway segment ID's plausible for a driver in a crash at a four-way intersection. As such, it is possible that more drivers were involved in crashes at the intersection than what is included in the numbers within this analysis. Similarly, drivers could have been involved in crashes at each intersection site which were incorrectly marked by the responding officer as occurring "not at intersection" and would not have been included in this analysis. Nonetheless, a minimum of five drivers were associated with each of the 338 identified roadway segment ID's and as a result each of these locations was deemed as an initial threshold in the identification of older driver HCLs.

Additional data reduction was manually performed to remove interstate locations and traffic circles as these locations were deemed outside the scope of this project. Similarly, identified sites where the segment length was greater than 0.25 miles were screened to ensure that the drivers were involved in crashes at only one intersection or at two or more intersections all within 0.25 miles of one another. The research team decided that sites with a group of intersections could be represented as one location as the distance between the intersections may be a contributing factor in the crash. Since nearly all of the sites had segment lengths less than 0.25 miles, this only resulted in the removal of a handful of sites. Following the addition of this criterion, 338 older driver HCL candidate sites were identified.

A ratio was calculated for each site to determine how many drivers in the control age group were involved in a crash at a particular location for every one older driver involved in a crash at the location. The ratio for each could then be compared to the statewide ratio. The statewide ratio was found to be 19,576: 75,671 or 1: 3.87. This statewide ratio was then compared to each of the 338 sites to ensure that these locations had an overrepresentation of older drivers involved in crashes. Those intersection locations with a ratio of 1: < 3.87 were identified as intersections in which older drivers were over-involved in crashes while intersections with a ratio of 1: >3.87 were identified as high crash locations for all road users. Given that the locations were initially identified based on the number of older drivers involved in a crash at each site, the majority (91.1%) of the 338 intersections were identified as sites with an over-involvement of older drivers in crashes.

Next, the HCL methods were applied to each location. Locations were ranked according to the results of each method, with rank number 1 being the "most dangerous location for older drivers". Separate locations were permitted to occupy the same rank for a given method. A summary table was then produced showing the four "worst" results from each method in conjunction each sites ranking for each method. It should be noted that in the case of ties between sites for the top four rankings, all sites were included in the summary table. An overview of the network screening methods employed is as follows:

- The frequency method was based solely on the number of older drivers who were involved in a crash at a particular site.
- The spot rate method accounts for the traffic volume as well as the frequency of drivers in crashes at a particular intersection. It is computed by dividing the number of drivers involved in crashes in a specified amount of time by the traffic volume in the specified amount of time. A multiplier of 1,000,000 was used for ideal resolution. The result is the number of drivers involved in crashes at the intersection per million vehicles entering the intersection. The time period is 730 days or 2 years and the ADT is the sum of identified

ADT values for both intersection roadways. The “worst” locations correspond to locations which have a low average daily traffic (Bham and Manepalli 2009).

- Next, crash severity was accounted for using the equivalent property-damage-only method. The EPDO index method gives weight based on crash severity so that those resulting in a fatality are given more attention than those resulting in property damage alone. The EPDO index was computed for each site by multiplying the drivers involved in fatal crashes by 9.5, those involved in an injury crash by 3.5, and those involved in a proper damage crash by 1. Subsequently each site was ranked based on the result with the highest EPDO index value ranking the “worst” or number 1.
- The severity index was then computed by dividing the EPDO index for each site by frequency at that site. The severity index normalized the severity, bringing sites with severe crashes to a higher ranking (Bham and Manepalli 2009).
- Next, an EPDO rate was calculated to account for traffic volume in conjunction with severity. This was done by dividing the EPDO index by the ADT multiplied by 730 days (the duration of the study). A multiplier of 100,000,000 was used for better resolution (Bham and Manepalli 2009).
- The ‘average of methods’ method averages the rankings of each method performed to give a new high ranking to those with high rankings for all performed methods.

Table 1 presents the results from the process described above. Sites highlighted in Table 1 are sites for which a RSI was performed. Worth noting, is the degree in variability of ranking for segments across each analysis method.

Table 1 Older Driver HCL Summary Table

Road Segment	City/Town	Street Name	Frequency Ranking	Spot Rate Ranking	EPDO Index Ranking	Severity Index Ranking	EPDO Rate Ranking	Average of Methods Ranking
***424843**	**Weymouth**	**Washington Street (Route 53) & Pleasant Street**	1	22	4	26	41	22
424934	Weymouth	Main Street (Route 18) & Middle Street & West Street	2	96	10	24	129	91
***375467**	**Taunton**	**Route 138 & East Britannia Street**	3	27	1	7	12	4
425174	Weymouth	Pleasant Street & Union Street & Columbian Street	3	39	17	27	76	57
***74907**	**Brockton**	**Perkins Street & Lawrence Street**	7	1	20	18	1	3
***229781**	**Marshfield**	**Webster Street & Snow Road**	9	2	32	25	2	10
438516	Worcester	June Street & Hadwen Road & Brownell Street	8	3	34	33	7	16
296842	Palmer	River Street & Church Street	9	4	28	19	3	8
111764	Dedham	Washington Street & Elm Street	4	45	2	8	26	16
***348139**	**Somerset**	**Route 6 & Lees River Avenue**	6	79	3	4	52	46
240175	Melrose	Lebanon Street & Malvern Street	9	46	14	1	19	19
***135731**	**Fall River**	**Hanover Street & New Boston Road**	8	28	10	2	11	6
135636	Fall River	President Avenue (Route 6) & Robeson Street	9	201	17	3	121	129
***307749**	**Plainville**	**Washington Street (Route 1) & Everett Skinner Road**	9	204	17	3	123	132
394139	Ware	Pleasant Street & North Street	8	6	17	10	4	2
***97032**	**Chicopee**	**Arcade Street & McKinstry Avenue**	6	14	5	9	5	1
Aggregated Classes for Rankings of Each Method			***9***	***267***	***35***	***33***	***308***	***257***

As perhaps expected, different results are yielded as the "most dangerous locations" depending on which existing, and highly utilized, methods are being performed on the same data set. There are, however, major correlations between methods which are worth noting. Correlations indicate a ranking of 1, 2, 3, 4, or 5 being entered into more than one column for the same roadway segment. For example, the results yielded using the frequency method often correlated with the EPDO index method. This is most likely the case because the EPDO index method is not normalized and therefore those locations with a high number of crashes are likely to have a high EPDO index. Therefore, it is possible for the ranking for the EPDO method to be high for two different reasons: a high frequency of crashes or locations with a relatively high number of crashes which are more severe or contain fatal crashes. This correlation does not seem to be present with the severity index method as this method divides the EPDO index by the total number of crashes at the specified location, normalizing the data as a result. As a result, the severity index method generally brings those locations with injuries or fatal crashes to a higher ranking.

Furthermore, the results yielded from the spot rate method are generally those with the smallest ADT values, since those with a low frequency of crashes have been removed from the data set. Therefore, if this is not the case, perhaps those segments are of particular interest. The results of the spot rate method often correlate with the EPDO rate method as the ADT is utilized. Additionally, the frequency of crashes is also a factor in increasing the ranking for both.

The 'average of methods' method is a method aimed at averaging the ranking results of each method for all of the locations of interest. This method brings those with relatively low rankings in all the methods to the top.

The final method or methods chosen for a basis on what locations should be focused upon for remediation are ultimately up to the transportation professional performing the study. The aim of this part of the study is to show a range of methods and the possible outcome of results. Furthermore, this study shows the importance of the ability to link crash data and road inventory data in performing spatial analyses.

ROAD SAFETY INVESTIGATIONS

Eight sites were selected as for RSI's. The RSI's consisted of identifying shortcomings in the roadway design, layout, and consistency of standards and providing recommendations for enhancing and improving the intersections and roadway segments to better accommodate older drivers. This process was similar to the process of a Road Safety Audit as defined by FHWA, although it included members of the research team rather than a truly multidisciplinary team. The intent of this decision was to identify common issues and selected countermeasures for each selected site, to determine the extent to which commonalties were found across similarly screened locations. Following the RSI's, the results were evaluated in a team setting and a written assessment was compiled. The field observations primarily consisted of identifying safety issues by reviewing the roadway characteristics, geometry, sight distance, signage, and traffic control devices and comparing them to the recommendations presented in the *Older Driver Highway Design Handbook*. Engineering recommendations to improve the operation and/or design of the site was included in the documentation. Three examples are presented below.

Example 1: Perkins @ Lawrence

The intersection of Perkins Street and Lawrence Street in Brockton, Massachusetts has an estimated total ADT of 1,200 vehicles per day. In 2007 and 2008, there were 7 older drivers and 10 control group drivers involved in crashes at this intersection. All 7 older drivers involved in crashes were involved in 2 vehicle angle crashes. The driver contributing code on the crash report form indicates that 3 drivers failed to yield right of way. It should also be noted that 4 drivers were involved in property damage only crashes while 3 drivers were involved in non-fatal injury crashes. This intersection was chosen as a location in which a road safety investigation is conducted as it ranked 1st out of 267 for the spot rate method, 1st out of 308 for the EPDO rate method, and 3rd out of 257 for the 'average of methods' method.

This four-way intersection has stop signs on the minor roadways (Perkins Street & Commercial Yard). The roads appear narrow and there are no shoulders. Furthermore, the pavement markings which do exist are barely noticeable. The stop lines on the pavement seem to be set back too far creating possible sightline restrictions, especially on the corners with buildings in close proximity to the roadway. Sight distance issues may also be present when approaching Lawrence Street from Perkins Street as you reach the top of a hill and descend down the hill on Perkins Street as you approach the stop sign. There are no crosswalks at this location and no indication of a bus stop (although Google maps indicate that the Brockton Area Transit Authority stops at this intersection). Higher speeds along mainline may make it difficult for drivers to safely pull out onto Lawrence Street.

The *Older Driver Highway Design Handbook* recommends a minimum receiving lane width of 12 feet be accompanied by a 4 foot shoulder for left turning vehicles. This location may better accommodate older drivers if this was implemented. Furthermore, this location may better accommodate older drivers if better signage was used. The use of a supplemental warning sign panel mounted below the STOP sign reading "CROSS TRAFFIC DOES NOT STOP" is recommended for two-way stop-controlled intersection sites selected on the basis of crash experience. STOP AHEAD warning signs may also be beneficial, especially on Perkins Street as motorists go down the hill to Lawrence Street. Signage indicating that there is a bus stop at this location would also be beneficial. To increase sight distance, the STOP signs and STOP bars could be moved closer to Lawrence Street. Perhaps a flashing red signal could be installed on the minor roadways with a flashing yellow on the major. The pavement markings, including the STOP bars, the centerlines and edge lines should be repainted. Additionally, crosswalks should be installed. Further investigations would be required to determine whether the vertical curve on Perkins Street meets the recommendations presented in the *Older Driver Highway Design Handbook*. Further investigation would also be required to determine whether the size and letter height of the roadway signs as well as the lighting at this intersection are sufficient.

Example 2: Route 6 @ Lees River Avenue

The intersection of Route 6 and Lees River Avenue in Somerset, Massachusetts has an estimated ADT of 19,700 vehicles per day. In 2007 and 2008, there were 8 older drivers and 20 control group drivers involved in crashes at this intersection. Of the 8 older drivers involved in crashes at this intersection, 6 older drivers were involved in 2 vehicle crashes and 2 older drivers were involved in 3 vehicle crashes. Furthermore, 7 older drivers involved in crashes at this intersection were involved in angle crashes and 1 older driver was involved in a rear-end crash. The driver contributing code on the crash report form indicates that 4 drivers failed to yield right of way and 1 driver disregarded traffic signals, signs, or markings. It should also be noted that 1 driver was involved in a property damage only crash and 7 drivers were involved in non-fatal injury crashes. This intersection was chosen as a location in which a road safety investigation is conducted as it ranked 3rd out of 35 for the EPDO Index method and 4th out of 33 for the severity index method.

This four-way signalized intersection is large in nature as Route 6 is a four lane roadway and Lees River Avenue is a two lane roadway. There are no dedicated turn lanes. Route 6 is a high volume and high speed roadway. Additionally, there are driveways, in particular the 711 entrance, in very close proximity to this intersection adding to the difficultly in safely maneuvering through it. As such, it appears that a protected left turn phase in conjunction with dedicated left turn lanes would be beneficial on Route 6 as this is a large intersection with a long left turn maneuver. The addition of left turn lanes, without reducing the number of through lanes on Route 6 would be ideal. The *Older Driver Highway Design Manual* recommends positive offset of opposite left-turn lanes to allow for unrestricted sight distance as older drivers do not position themselves within the intersection before initiating a left turn. Right-of-way restrictions may be an issue at this location. As such, the addition of signage indicating to motorists that they must yield to through traffic when taking a left turn could be implemented overhead as a low cost alternative. Pavement markings which scribe a path through the turn may also be beneficial at this location. Additionally, solar glare in conjunction with the far distance between the vehicles approaching the intersection and the traffic signals which must be viewed to safety execute through the intersection create a difficult situation for motorists, especially when heading south on Lees River Avenue. There are poor blockers on the traffic signals. The *Older Driver Highway Design Handbook* recommends the consistent use of a backplate with traffic signals wherever practical. Furthermore, this intersection is currently skewed. Ideally, the intersecting roadways should meet at a 90-degree angle to better accommodate older drivers. This would also reduce the curb radius thus slowing down vehicles taking a right turn onto Lees River Avenue. However, given the infrastructure in close proximity to this intersection and probable right of way restrictions, making this change may not be feasible. Given that Route 6 is a major roadway with relatively high speeds, no right turn on red is a strategy which could better accommodate older drivers. Prohibited RTOR movements at skewed intersections are recommended in the *Older Driver Highway Design Handbook* to better accommodate older drivers. If this is not feasible the posting of signs with the legend “TURNING TRAFFIC MUST YIELD TO PEDESTRIANS” should be implemented.

Figure 4 Route 6 and Lees River Avenue RSI photos

The Older Driver Highway Design Handbook recommends that an all-red clearance interval be consistently implemented with the length determined according to the Institute of Transportation Engineers (1992) expressions to accommodate age differences in perception-reaction time (PRT) and that for all over-the-road signals that the Commission Internationale de I'Eclairage (CIE) 1980 standard for vertical intensity distribution (percent of peak) for a 300 mm (12in) signal be adhered to in the United States to accommodate the increased optical density or reduced ocular transmittance of the older driver's eye, and to improve availability of signal information under divided attention conditions during an intersection approach. Further investigation would be required to see whether this location meets these recommendations.

Example 3: Route 138 @ East Britannia Street

The intersection of Route 138 and East Britannia Street in Taunton, Massachusetts has an estimated ADT of 13,309 vehicles per day. In 2007 and 2008, there were 11 older drivers and 10 control group drivers involved in crashes at this intersection. All 11 older drivers involved in crashes at this intersection were involved in 2 vehicle crashes. Furthermore, 8 drivers were involved in angle crashes, 2 drivers were involved in rear-end crashes, and one driver was involved in a sideswipe same direction crash. The driver contributing code on the crash report form indicates that 6 drivers disregarded signals, signs, and markings, one driver was distracted, and one driver failed to yield right of way. It should also be noted that 2 drivers were involved in property damage only crashes while 9 drivers were involved in non-fatal injury crashes. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked 1st out of 35 for the EPDO index method, 3rd out of 9 for the frequency method, and 4th out of 257 for the 'average of methods' method.

This is a four-way signalized intersection. A protected left turn with dedicated left turn lanes would be the optimal solution, however, the left turn movement volume did not seem too high and therefore this may cause an unacceptable reduction in capacity. Similarly, it seems as though there is not enough space for the addition of dedicated left turn lanes, keeping the same number of through lanes, due to probable right of way restrictions. If this solution was feasible, however, the opposite left-turn lanes should be implemented with a positive offset for unrestricted sigh distance. If this solution is not feasible, the additon of "LEFT TURN YIELD ON GREEN" signs should be implemented overhead for all approaches. These same measures should also be considered on the minor roadway (E. Britannia Street) as this minor roadway is a high volume roadway which a large percentage of turning vehicles. This intersection is currently skewed. Ideally, the intersecting roadways should meet at a 90-degree angle to better accommodate older drivers. However, given the infrastructure in close proximity to this intersection and the probable right of way restrictions, making this change may not be feasible. Given that Route 138 is a major roadway with relatively high speeds, no right turn on red is a strategy which could better accommodate older drivers. This is currently implemented when approaching the intersection from the west and heading east on E. Britannia Drive, however, this sign, located on the opposite side of the roadway on the right side is set far back and is obstructed by the street sign and the sign for the cemetery. The sign location could be moved to be more visible. Similarly, the addition of this sign could be implemented when approaching the intersection from the opposite direction. Prohibited RTOR movements at skewed intersections such as this intersection are recommended in the *Older Driver Highway Design Handbook* to better accommodate older drivers. If this is not feasible for some reason the posting of signs with the legend "TURNING TRAFFIC MUST YIELD TO PEDESTRIANS" should be implemented. This location is a busy area with a lot going on and a lot for the driver to look at. The next intersection when traveling on Route 138 is in close proximity in which the driver is required to merge and then make a fast decision as to which lane to be in. There are also driveways in close proximity as well as a building on the northwest corner which may be causing sightline restrictions (which is why the prohibited RTOR movement sign should be more noticeable). Additionally, solar glare may be an issue at this location. The *Older Driver Highway Design Handbook* recommends the consistent use of a backplate with traffic signals wherever practical. Signal backplates improve the visibility of the signal indications.

The Older Driver Highway Design Handbook recommends that an all-red clearance interval be consistently implemented with the length determined according to the Institute of Transportation Engineers (1992) expressions to accommodate age differences in perception-reaction time (PRT) and that for all over-the-road signals that the Commission Internationale de I'Eclairage (CIE) 1980 standard for vertical intensity distribution (percent of peak) for a 300 mm (12in) signal be adhered to in the United States to accommodate the increased optical density or reduced ocular transmittance of the older driver's eye, and to improve availability of signal information under divided attention conditions during an intersection approach. Further investigation would be required to see whether this location meets these recommendations.

Figure 5. Route 138 and East Britannia Street in Taunton

The final research stage was to develop relationships between the method(s) used to identify a HCL and the recommended countermeasures proposed for the location. The identification of connections between methods and recommended countermeasures can provide transportation professionals with a suggested list of countermeasures to consider depending upon which method was utilized in identifying the specified location.

Table 2 Correlations between identification methods and resulting countermeasures proposed

Frequency & EPDO Index Methods		Spot Rate & EPDO Rate Methods	
Correlations	***Countermeasures***	***Correlations***	***Countermeasures***
➢ Four-way signalized	➢ Dedicated left turn lanes	➢ Two-way stop controlled on minor roadway	➢ Widen roadways and shoulders (12 ft. lanes w/ 4 ft. shoulders recommended
➢ Skewed	➢ Protected left turn indications	➢ Narrow roads	➢ Replacement of stop bars or stop signs
➢ Large	➢ "Left Turn Yield on Green" signs on overhead signal bars	➢ Low volume	➢ "Stop Ahead" warning signs
➢ High volume	➢ Pavement markings which scribe a path through the intersection for left turn maneuvers	➢ Faded pavement markings	➢ "Cross traffic does not stop" sign in conjunction with stop signs
➢ High speed	➢ Fix geometry so that roadways meet at 90 degrees	➢ Sightline restrictions	➢ Fixed lighting installations
➢ Long left turn maneuvers	➢ Repave roadways/fill pot holes	➢ Buildings close to intersection	➢ Removal of bushes and/or other objects which may be obstructing motorists' view
➢ No protected left turn indications or dedicated left turn lanes	➢ Repaint pavement markings	➢ High speed on major roadway	➢ Flashing yellow beacon on major roadway and/or flashing red beacon on minor roadway
➢ No "Left Turn Yield on Green" indication signs overhead	➢ Prohibited RTOR movements w/ appropriate signage		
➢ No signal backplates	➢ Signal backplates		
➢ Driveways and/or intersections in close proximity	➢ Fixed lighting installations		
➢ Possible sightline restrictions	➢ All-red clearance interval per the ITE expressions		
➢ Possible glare issues	➢ Check standards for the vertical intensity distribution		

The severity index method brings those HCL's with injury or fatal crashes or a significant to attention; however, no significant correlations could be made between this method and the findings from the RSI's.

The 'average of methods' method can have varying results based upon which methods you use to analyze the data and which you decide to average. The findings and countermeasures vary greatly for this method. This method is good to get a mixture of results.

CONCLUSIONS

This research highlights sufficient and comprehensive methods of identifying high crash locations with an overrepresentation of older driver crashes and specific locations where older driver crashes are most frequent, successfully combining spatially-based crash analyses with established HCL methods. Subsequently, a roadway safety investigation was employed to assess the effectiveness of the older driver HCL method in developing engineering countermeasures specifically catered towards reducing crashes involving older drivers. Furthermore, relationships between the method(s) used to identify the high crash location and the recommended countermeasures proposed for the specified location were documented. This can provide transportation professionals with a list of countermeasures to consider depending upon which method was utilized in identifying the specified location.

This research aids in gaining a better understanding of engineering countermeasures specifically catered towards reducing crashes involving older drivers. Thus, this research will aid in the extensive work towards increasing seniors driving time and thus improving their quality of life. Although other countermeasures, such as licensing restriction and re-education, will continue to garner appropriate consideration, there is an opportunity to make engineering related improvements that aid the mobility and safety of older drivers. Worth noting, is that many of the countermeasures suggested within the RSIs were low cost / short timeframe measures and their use will likely benefit all drivers (not just older drivers).

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